Chapter 2
Characteristics of Arid and Desert Ecosystems

An ecosystem is simply defined as organisms and their environment. The term "ecosystem" implies an integral link between organisms and their non-living environment with interactions that mean they cannot live outside the specific environment. For this reason, any study of a natural environment must necessarily focus on organisms that live in the same place.

A unit consisting of environmental factors interacting with living organisms, in which the flow of energy leads to nutrient structure, distribution of organisms and nutrient cycle, is called an ecological system or ecosystem. In other words, ecosystem refers to an environment which is livable and where effective factors such as atmosphere, water, minerals, soil, plants, animals and micro-organisms act together in such a way as to provide for the survival of the system. In such systems, man is also involved. From the viewpoint of plant ecology, it can be said that living organisms and their abiotic environment in nature are woven into each other by countless interactions. A part of living space that is somewhat distinct from the surrounding space and appears as a separate unit is called an ecosystem.

Arid and desert ecosystems include areas where annual rainfall is <250 mm. Precipitation is irregular and random and in some years, rain may fail. Most of the Earth's deserts are located in the temperate zone and latitudes of 20° to 40°. In Table 2.1, some of the characteristics of both arid and humid ecosystems are compared.

2.1 Arid and Desert Areas Climate

Arid areas and deserts are a part of the biosphere in which abiotic environmental factors are dominant. The most important abiotic factors affecting these ecosystems are climatic factors, of which humidity and temperature are two major limiting factors. Low annual rainfall with irregular distribution throughout the year and severe daily, monthly and annual temperature changes, as well as high

M. Jafari et al., *Reclamation of Arid Lands*, Environmental Science and Engineering,
https://doi.org/10.1007/978-3-319-54828-9_2

Table 2.1 Characteristics of arid and wet ecosystems

Environment properties	Humid area	Arid region
Vegetation	Dense forests cover the entire surface of the soil	Only a portion of the soil is covered with vegetation and a large part is bare
Rocky or salt layer	Not always seen, except where there are strong winds	Often stones appear, especially around the arid and semi-arid regions
Water and materials circulation	Emission of elements from the initial layer of soil	Accumulation of elements in the initial layer of soil
Environment reaction	Often acidic	Often alkaline
Clay minerals formation	Kaolinite, illite and so	Often not formed or montmorillonite and layered clays
Soil organic matter	Often rich in humus, with humic acid molecules and often acidic	Often poor except in the steppes
Percentage of cations in the soil colloid	H, Al and Fe (4%) and Na, K, Mg, and Ca (73%)	Na 30%, K 15%, Mg 20%, Ca 30% and free of H, Al and Fe

evapotranspiration potential, are among the important features of these areas. Local and seasonal winds increase the degree of aridity of these areas, so that as the severity of wind increases, evapotranspiration becomes faster. The climate characteristics of arid areas and deserts can be briefly stated as follows:

- Intense solar radiation
- Severe changes in seasonal and annual precipitation
- Lack of relative humidity
- Severe changes in spatial and temporal rainfall
- Deep penetration of water into alluvial deposits
- Severe changes in the amount of surface water and groundwater storage.

In some arid regions or deserts of the world, rainfall does not occur even once a year, and there are deserts and territories whose rainfall is <100 mm per year. In these regions, scattered small vegetation is observed. Desert regions and their margins in Iran are among them. Then there are areas whose annual precipitation is 100–200 mm. These include a large part of Iran in the east, south, and centre.

According to the atlas of arid zones prepared at the 1977 United Nations Conference on desertification, a large part of the Eastern and Southern Iran is considered arid, in that in 50–75% of the years severe drought occurs. Most of the arid and semi-arid areas of the world are located in the middle latitudes, affected by high-pressure systems. In terms of geomorphology, in these areas the mountainous slopes are devoid of suitable vegetation, and in the lowlands, alluvial sediments are accumulated. The natural drainage network in these areas is usually young. Stream bed erosion is severe and rivers are wide. Streams are initially small and shallow, and in the downstream areas are observed in a V or U cross-sectional shape. In large streams, a sinusoidal and branch mode occurs. The floor and suspended sediment load of these rivers is very high during flooding. In most of these watersheds, the streams end in vast plains, marshes and local lakes, water is evaporated and a lot of salt is left.

2.1.1 Precipitation

Precipitation in arid areas is a convective type. Topography affects the formation of precipitation; in the margin of the mountains, orographic precipitation may occur. Therefore, in general, surface features cause cloudburst spatial variations in the arid and desert regions.

The amount of precipitation for each cloudburst is usually around a few tens of millimeters, and the maximum is usually 70–80 mm, in rare cases reaching 100 mm. In the lowlands with no surface features, the rain may not reach the ground due to evaporation.

Studies in the arid areas of Australia, America and Africa have shown that the profile of average rainfall intensity in the arid and semi-arid regions is asymmetrical, usually with a low continuation and maximum intensity in the first part of the cloudburst. Studies carried out in Saudi Arabia show that the occurrence of maximum rainfall in a cloudburst varies but it usually occurs in the first half of the precipitation.

Usually, the statistical properties of the cloudbursts of convective precipitation are independent of the region; therefore, the issues related to this condition could be generalized to the other arid and semi-arid parts of the world. According to statistical analysis of low continuous precipitations in these areas, about 50% of the precipitation has a rainfall intensity of more than 20 mm per h and about 20–30% has an intensity of more than 40 mm per h. In fact, these characteristics are independent of high continuous rainfall in particular areas.

In arid and semi-arid areas, the problems caused by variations in the annual precipitation are greater than that of limited amount of annual rainfall. In warm areas, the standard deviation of annual precipitation is about 10–20% in 19 out of 20 years, and annual precipitation is about 75–125% of the average long-term rainfall. In drier areas, the minimum annual precipitation is much higher and the distribution of annual precipitation becomes more skewed with increasing dryness. For example, if the average annual precipitation is about 200–300 mm, the rainfall varies from 40 to 200% of average in 19 out of 20 years. However, in drier areas with an average annual precipitation of about 100 mm, the variation is about 30 to 35% of the average annual precipitation.

In very dry areas, for example, the Thar Desert in northwest India, the average annual rainfall is 130 mm; however, within two days of a single year, 860 mm rainfall has occurred. In an area of northern Chile with no rainfall during four consecutive years, only 15 mm of rainfall occurred in the fifth year; therefore, the average rainfall was calculated as 3 mm per year; however, in the same area, a rainfall of 64 mm was measured in a cloudburst (Aubert 1962).

In addition to temporal precipitation variations, spatial variations in regional precipitation are observed in arid and semi-arid regions due to the nature of rainfall. For example, it is observed that in arid areas, one rain gauge station shows some amount of cloudburst, while in a nearby station, rainfall is zero. In some cases, for distances of up to 150 km between stations, there is continuity in the rain curves.

In arid and desert areas, seasonal or monthly precipitation variation is observed more than annual variations.

2.1.2 Temperature

The highest temperatures in the world occur in hot and dry climates. A clear sky causes the maximum radiation to reach the earth's surface during the day but the earth is out of it at night. This makes a significant difference in temperature day and night. In summer, temperature in the desert regions reaches 30–40 °C. If the vegetation is sparse, the soil surface receives too much heat during the day and its temperature reaches up to 93 °C. Heat is received and lost quickly in deserts. During the night, almost 90% of the heat received during the day is lost; in humid areas this figure is 50% (Aubert 1962).

The range of annual temperature fluctuations in hot deserts is less tangible than in other areas; however, its value is more than in humid areas. The average daily temperature fluctuation range in the warmest months of the year is 27–35 °C, and maximum daily temperature is 37–42 °C. The average temperature in the coldest month is 10 °C and frost occurs occasionally. Temperature in warm and semi-arid climate is usually similar to arid regions.

2.1.3 Evapotranspiration

Evaporation is the natural conversion to vapor of moisture from the land and water resources like wells, canals, ponds, rivers, lakes and wetlands; plants also emit some moisture to space, and this is called transpiration. Evapotranspiration means that a portion of the total amount of precipitation is emitted from the environment; the higher the evapotranspiration rate, the higher the relative drought intensity. In arid and desert areas, despite low rainfall, the evaporation and transpiration rate is too high, so that evaporation in Tehran is about 1250 mm, i.e., more than 5 times the amount of annual precipitation, and in the Lut Desert, it is about 5000 mm, which is 100 times the amount of annual precipitation. In some parts of Africa, annual evaporation is reported to be around 6000–7800 mm (Aubert 1962).

2.1.4 Wind

One characteristic of arid regions is frequent and intense winds, partly due to convection during the day. The sparse vegetation in these areas cannot inhibit wind speed. These winds are thus associated with sand storms. A lot of sand and dust is transmitted across great distances and then falls in neighboring areas. The heavier sand particles cause soil surface erosion during the movement. Wind affects plant growth physiologically and mechanically. Sand particles carried by the wind may cause damage to plant tissues. Germinated seeds may be buried under sand completely and the roots may be removed from the soil and exposed to wind. Meanwhile, winds cause major damage, breaking the stalks of cereals and scattering the seeds.

The physiological effect of wind is to increase the amount of evapotranspiration and the evaporation of water from the earth's surface. Even if soil moisture is high, dry winds may result in closure of the leaf stomata, affecting the rate of photosynthesis, resulting in reduced crop yields.

Arid regions are usually affected by winds originating in seas or deserts. In summer, the temperature of desert areas increases enormously. The hot air rises and as a result, the surrounding air flows to these areas. If the airflow passes over the sea, clouds become pregnant. Winds like these that blow from the southwest in the desert in summer are called monsoon.

In winter, the reverse is the case; desert areas are colder than the tropical areas around them, so the wind flow is outwards from the desert. These winds are cool and dry at the beginning of the growing season; however, they become relatively warm and drier with the approach of spring. In the Near East, these winds are called khamsin, and in humid tropical areas of West Africa and north of the Equator, they are called harmattan. The number of days that these dry and warm winds blow in the spring may be very small, but their effect on crop yields is high. The temperature at night varies between 25 and 46 °C and relative humidity is between 5 and 10%. If cereals are in the flowering stage, khamsin winds cause damage to the spikes and no grain will be produced. However, if the khamsin winds occur in the later growth stages, the seeds are wrinkled, leading to a premature crop.

Hot and dry winds may also have some beneficial effects. The main reason for non-occurrence of wheat stripe rust (*puccinia glumarum*) in the Near East is the sensitivity of this pathogen to the high temperatures of hot winds. In the years that khamsin winds do not blow, rust disease may cause huge damage to the crop.

The beneficial effects of moderate winds on photosynthesis derive from the replacement of the carbon dioxide absorbed by the leaf's surface. In mild weather, the efficiency of photosynthesis is 2%, but it is 4% in turbulent weather. It is also observed that the efficiency of photosynthesis is increased even when the plant is wilting from lack of water and the stomata are closed.

The beneficial effect of the wind on the layers of lower leaves of the plant is more evident. Severe winds cause the lower leaves of the plant to have higher photosynthetic efficiency for the amount of light they receive.

2.1.5 Surface Runoff

Surface floodwaters in arid regions are extremely important to water supply. Normally surface waters have a slight soluble material. The floodwaters of arid and desert areas are usually of short duration and principally without base flow since rivers originate from flood and temporary types. If river flows continue, the river is fed by groundwater of inadequate quality.

The maximum flood in high-intensity rainfall is short and only takes a few minutes. Sometimes, due to basin characteristics, several flood hydrographs are observed that have happened one after another, and this confirms the point of the rainfall in different areas of the basin.

Due to water penetration in the alluvial bed, the flood peak usually reduces to a current downstream and in fact this nourishes the local aquifers in arid and semi-arid areas. The amount of flood penetration into the ground depends on factors such as the depth of the water table, surface permeability, water temperature, the extent of flood plain, the moisture content of the unsaturated zone and the nature of sediments.

Watercourses or rivers in arid and desert areas show many changes over time, so that primary watercourses are usually shallow and narrow. The form of the watercourse varies according to the rock type. In the main path of the basin, the cross-section is a V form in hard substrate and a wide U form in frail substrate. The main watercourses are usually observed to be sinusoidal and meandering; the width of branches and watercourses usually increases when the gradient is shallow.

2.1.6 Microclimatology

Microclimatology is recognition of those environmental factors that affect plant and soil. This science operating zone is limited between high altitude extent which affects plant growth to the depth of air penetration in the soil.

The microclimate above the soil surface and below the vegetation (eco-climate) is affected by plant type and may change depending on the water and air surrounding the plant. Even a small shrub also changes the soil surface climate, because it reduces air flow and casts a shadow. The more a plant grows, the smaller the difference between minimum and maximum temperatures. The range of soil surface temperatures may vary from those that are recorded in weather stations: the eco-climate may be wetter and cooler than the air above the plant. These conditions are suitable for the development of some diseases. Shrubs in desert regions also create suitable growing conditions for other species under their shelter by creating a microclimate at the soil surface. Henteh (2003), studying the Saveh pastures of Zarand, showed that the *Atriplex canescens* caused an increase in the density of annual and perennial species such as the annual grasses *Stipa barbata* and *Artemisia sieberi*, due to their relatively large canopy and the relatively favorable

Table 2.2 Reflection coefficient of light on different soil surfaces

Surface	Reflection coefficient in terms of input radiation percentage
Wet sand	9
Dry sand	18
Grass–green plants	15–30
Forest	15–18

conditions of moisture created in their surroundings. Distance from *Atriplex* reduces the effects of the microclimate and hence the density of these species.

Soil climate is very different with air above it. Only a part of the light is absorbed into the soil surface and the rest is reflected, depending on the soil surface characteristics. The percentage of light reflected by the Earth's surface is called the reflection coefficient (albedo). The coefficient depends on various factors including vegetation type, soil type and percentage of soil moisture. The reflection coefficient of different surfaces is given in Table 2.2.

Among the characteristics of desert plants that are effective in retaining moisture, white-gray color can be noted for its high light reflection coefficient. According to Thornthwaite (1948), the most important characteristic of these plants is moisture retention. Moist soil absorbs more solar radiation than dry soil. Most received energy is used to evaporate the soil moisture, because water is a good conductor of heat. The rest of the solar energy is spent on heating deeper layers of soil. If soil moisture is at field capacity level, 85–80% of solar radiation energy is consumed by evapotranspiration.

In dry areas where soil moisture is low and vegetation is sparse, the amount of actual evapotranspiration is low and solar energy is spent heating the soil surface and the air above it. The drier the soil is, the lower the ability of the plant to use the soil moisture, reducing actual evapotranspiration. The temperature at the soil's surface layer is higher than in the surrounding air, but daily fluctuations reduce in lower depths of the soil. Fluctuations in daily temperature do not occur at a depth of 50 cm. The temperature is relatively constant throughout the year at a depth of 1–3 m below the surface. Soil temperature is very effective for the growth of plants and micro-organisms. Warm (20–30 °C) and moist soils are desirable for crop production in arid regions.

Air exchange always occurs between soil and atmosphere. Air is removed from the soil by the infiltration of water and fresh air imparted to the soil dries ir.

2.2 Soils of Arid and Desert Areas

The two basic groups of soils are: pedocal, observed in arid and semi-arid areas, and characterized by the existence of calcium carbonate; and pedalfer, observed in humid areas and characterized by aluminum and iron silicate compounds.

In arid soils, the lower layers have more clay than the upper layers. It seems that the conditions for the formation of clay in lower layers are more suitable than in upper layers due to higher moisture content. Despite the low clay formation of arid regions, many soils are rich in clay. In the semi-arid regions, precipitation is higher in the margins of deserts and moisture can penetrate to greater depths and remain there for a longer period, causing better vegetation to exist in these areas. Especially in the colder parts of temperate semi-arid lands, soils have a dark color and the amount of organic matter is also higher. These soils have a large amount of soluble materials and calcium at lower depths.

2.2.1 Pedogenesis Factors

Pedogenesis factors are those that cause soil formation in humid areas. These factors include climate, vegetation (living organisms), topography, parent rock, time and human factors (note that studies have started to distinguish humans from living organism factors and consider them an independent factor in soil formation and evolution). Recall that the factors in soil formation in arid areas are mainly the same factors as in humid areas but with different degrees of effectiveness. Thus, composite soils have the characteristics of dry areas. In dry areas, the intensity of physical weathering processes is very high, but in wet areas, chemical weathering processes are more effective and act over short periods. in arid regions are erosion and re-sedimentation, which are accompanied by leaching and re-settling. Other processes such as clay formation, organic matter production, redox and others are of less importance.

The main factors affecting soil formation, particularly in arid and desert areas, are discussed below.

2.2.1.1 Parent rock

The amount of minerals in the soils of arid and desert regions depends mainly on the type of the parent rock. Kaolinite and partly Montmorillonite form the majority of the clay minerals in the Sierozem soils of Central Asia. Parent rock effect on soil properties is more evident in young soils that have not yet developed. Because most of the rocks alternate to similar compounds though with different ratios caused by degradation and chemical variation, the role of parent rock is reduced in developed soils due to different processes of soil formation.

2.2.1.2 Weather

Although parent rock affects soil properties, the role of climate is more significant for those soil properties that are important in agriculture. Therefore, it is observed that soils developed in different areas but under similar climatic conditions have similar characteristics and these characteristics only change under the influence of local conditions such as parent rock type, slope, runoff and drainage conditions. Two important climatic factors in soil formation are rainfall and temperature. The roles of wind and humans should not be ignored.

2.2.1.3 Precipitation

Water is required to perform all the processes of chemical weathering of parent rock such as hydrolysis, hydration, dissolution, leaching, extraction of materials, oxidation and carbonation. Alternate wetting and drying of rocks occurs frequently in arid regions and some interactions which are effective in the physical weathering of rocks is done at every stage.

Deficiency of precipitation and high speed of evaporation in arid regions limit the rate of water infiltration into the ground and the soil remains dry for long periods. Soluble materials are carried down along with the water and soil particles are detached from their original location and transmitted to a depth that water penetrates. This depth depends on soil gender, and the amount and intensity of rainfall. Only rarely is the whole soil profile observed to be washed out. As a result, a relatively low layer of soluble salts and calcium carbonate accumulates and a hard layer called the carbonate stratum is caused by carbonate sediments: this is characteristic of most soils in arid regions. Silica is also effective for the stability and the sticking together of soil layers. In the calcium layer of the soil, carbonates may be observed in the form of hard and soft grains. Sometimes excessive erosion reveals the calcium layer, called calcareous stratum in this case. This calcium layer covers a large segment of desert and semi-desert soils.

2.2.1.4 Temperature

The high daytime temperature and rapid cooling of air at night that are features of arid regions cause alternate expansion and contraction of parent rocks, cracking and separation into their components. High temperature intensifies short-term chemical weathering processes so that for every 10 °C of increase, the speed of chemical reactions is approximately doubled.

2.2.1.5 Wind

Wind causes the intensification of drought and increase in erosion. Where vegetation is sporadic, the power of erosion increases. In semi-arid and arid areas, strong winds cause the abrasion of rocks by carrying sand particles. These winds carry sand and gravel and finally leave them elsewhere. Desert winds are the main factor in the formation of the very flat lands sometimes carpeted with the rubbles which

Fig. 2.1 Landscape of a region with desert pavement (photograph by Ali Tavili 2016)

geologists call desert pavement. Desert pavements are areas where fine particles have been removed and stones with a diameter of 5.2 cm remain (Fig. 2.1). Desert pavement occurs only in places where the soil is a mixture of fine and coarse sand. Wind is also the main cause of the formation of the large inferiorities or hollows that occur in the desert. If the groundwater level is high, most of these hollows are converted to oases.

2.2.1.6 Biological factors

Vegetation cover is less important in the formation of desert soils than in semi-arid areas. The soils of arid regions are low in organic materials due to the sparse cover and negligible vegetation, so that the amount of organic matter is far $<1\%$ in some desert soils. High temperatures that are appropriate for oxidation processes cause the formation of minor quantities of humic acids. The ratio is usually low and this is possibly due to the activity of stabilizer blue-green algae present on soil surface. It is observed that nitrogen stabilizer bacteria are active in relatively arid soils. When the soil is low in calcium and contains sodium, humus particles are dispersed and the soil takes on the black color that is characteristic of such land. Creatures such as earthworms that are specific to humid areas are not always seen in desert soils but there are other creatures that dig up the ground to resist the sunshine and take refuge in the soil, affecting soil characteristics.

2.2.1.7 Topography

Accidents of terrain affect soil formation through runoff, erosion, sedimentation and drainage. Surface runoff on the slopes may be collected in the hollows and may create a small relatively moist region with soil that has the character of pluvious regions. There is a close relationship between factors affecting soil formation, especially climate, topography and vegetation. In hyper-arid regions, the lack of vegetation causes the fine particles of soil to be eroded by water and wind. These materials can only re-precipitate in blocked basins. In places with less drought, the ecological environment of hollows and cold hillsides can create denser vegetation and hold eroded soil particles. With increased precipitation and arid conditions, many regions that have balanced topography are covered by soft particles of soil.

The most important processes affecting soil formation in arid environments are climate, groundwater and dissolved solutes.

2.2.1.8 Climate

The most obvious climatic feature in the arid regions is scattered and irregular rains causing moisture deficiency in the soil. Soil-forming factors in these areas are active only for part of the year, unlike humid areas, and they are almost non-existent at other times.

The main cause of the destruction and breaking of rocks in arid regions is daily and seasonal variations of temperature and to an extent, moisture. Daily variations of temperature of up to 70 °C are observed in some deserts. If there is no erosion, due to lack of moisture, the development of different parts of soil and sub-rock weathering are inhibited. Although gradually, as a result of developments such as leaching, solutes of soil metal alkalines are washed away, it should be noted that this leaching is minimal. Also, because precipitation in arid environments mainly takes the form of storms and torrential rain, and considering the low depth of the soil, calcium, sodium and magnesium are not leached and are not often transferred vertically, but mainly diagonally.

2.2.1.9 Groundwater

This factor has an adverse impact on the evolution of soils in arid regions. Kovda (1967) believes that groundwater plays a major role in the speed of soil development. If soil is waterlogged, organic matter increases, iron and manganese divalent oxides increase, re-oxidation of these compounds occurs gradually and therefore dissolved solutes eventually remain in the soil.

The presence of groundwater to depths of one or a few meters also creates the same conditions in the soil. In this situation, the soil below groundwater level or in its capillary margin form a regenerative environment and they will contain bivalent iron and manganese.

Groundwater always contains solutes and leaves white- or gray-colored deposits of chloride salts, sodium sulfate, calcium and magnesium on the soil surface after evaporation. If strongly alkaline sediment caused by sodium carbonate is present, the surface of the soil becomes black due to the dissolution of organic matter.

Red spots seen in soils are due to trivalent iron compounds previously oxidized from bivalent iron compounds. Soil with bivalent iron is greenish-blue or sludge-colored, for example, soils in paddy fields with redox state.

2.2.1.10 Solutes

The soils of arid and desert regions are rich in dissolved solutes of different origins. In some soils such as limestone, gypsum and salt rock, the parent rock contains solutes that are mainly observed as calcareous, gypsum and salt marls. In some other soils, dissolved solutes are separated from the parent rock but due to low humidity, they are not leached and are left in the soil. Wind can also transmit solutes from the surface of seas and oceans, depositing them at the coast. The capillary rise of groundwater can make saline soil (secondary salinity).

Accumulation of soluble salts in the soil has a major impact on the physical and chemical properties of clay and humus. Sodium salts often cause the release and dispersion of clay and humus particles, forming a dense impenetrable layer in the lower sections of soil that prevents the passage of water and air to the plant root. Soil solutes also have a great impact on the growth and activity of soil organisms or micro-organisms. They also increase the osmotic pressure of the soil solution and as a result reduce the power of water uptake by plants. Sometimes solutes are toxic to plants.

2.2.2 Soil Properties

In general, the amount of rainfall, available water in the soil and groundwater in arid regions are unable to compensate for the shortage of water caused by surface water runoff and evapotranspiration. If there is water in warm regions, pedoclimate increases the speed and intensity of soil-forming processes. The water that penetrates to the soils of these areas and causes leaching is usually hot and is on average 15 °C warmer than penetrating waters in temperate regions. As a result, the ionization of water is increased, solubility of silica is higher, salt dissolution is faster, penetration of carbon dioxide in the soil is less and the viscosity of water is less. The main characteristics of soils in arid regions can be summarized as follows:

1. Precipitation is very limited in arid areas, occurring only over a few months. The soil surface often has a crust and thus only a small amount of rain penetrates he soil, evaporating immediately. The lower parts (subsoil) are called the dead horizon because the soil is almost dry.
2. A carbonate-rich stratum is observed under the leached surface horizon in calcareous soils or the soils caused by parent materials containing carbonate.
3. The lack of organic matter and low carbon-to-nitrogen ratio are characteristic of soil in arid areas. Among the reasons for the shortage of organic matter in these areas are sparse vegetation, an oxidizing environment, the lack of humic acid formation and a significant amount of nitrogen compared to carbon that is obtained from the destructive effects of bacteria on organic material. It is notable that bacterial activity in the formation of humus is greater in arid than in humid areas. Due to the presence of abundant oxygen in the soils of arid areas, conditions are more suitable for bacterial and oxidative activity, the nitrogen of organic matter is decomposed further and the C/N ratio is reduced. It is noteworthy that the appropriate amount of C/N for the exploitation of the soil is 10–12.
4. In similar conditions, the clay content available in the soils of arid regions is less than in the soils of humid regions. The formation of clay in the soils of arid areas is often possible on the B horizon, because the rainfall in these areas rarely causes moisture in soil, while the creation of B horizons in humid areas is due to the leaching of clay from the upper horizon and its deposition on this horizon.
5. B horizons in the soils of arid areas are not as thick as other soils, usually not exceeding 20 cm, since a long time is needed for their formation.
6. Despite the gradual formation of clay in the soils of arid regions, a major part of the soils in these regions are rich in clay. There are two reasons for this: first, some rocks such as sedimentary rocks containing clay particles are degraded due to weathering and clay particles are added to the soil; and second, the alluvial and lacustrine sediments created by sedimentation of fine particles of clay minerals in stagnant water along with other materials, contain clay which would be added to the soil.
7. The soils of arid areas are usually alkaline and rarely have pH <7. If alkalinity in soil is due to the presence of calcium carbonate, the soil becomes calcareous and pH in these soils is often <8.4. A pH of 8.5 or higher indicates the presence of sodium carbonate which is a strong alkali. This combination is achieved from the hydrolysis of clays containing high levels of sodium and combined with air CO_2. In addition to restricting plant growth, soil alkalinity reduces soil permeability and destroys the appropriate soil structure. Adding lime to the soil is not recommended in Iran's arid regions, because this practice has caused some injuries and due to the high levels of calcium and alkalinity of soils in these areas, the solubility of some plant nutrients, especially phosphorus and iron, is reduced, causing chlorosis. If lime is added to the soil, the clays take one ion instead of two: and the resulting Na_2CO_3 is an extremely dangerous

combination that prevents plant growth and causes further degradation of soil. If gypsum is added to the soil, it is separated into Ca^{2+} and SO_4^{2-} and comprises Na_2SO_4 which is neutral in solution form and is emitted from the environment.

It is obvious that much of the soil in arid regions, especially in real deserts, is azonal soil carried by strong winds on the soil surface. Shortage of moisture will limit the development and evolution of the soil.

2.2.3 Types of Soils

In the traditional American classification, arid and semi-arid soils belong to the class of zonal soils and the sub-class of light-colored arid soils. The major groups of these soils are: real desert soils; gray desert soils; red desert soils; sierozem soils; red sierozem soils; reddish-brown soils; and brown soils.

The following large groups are also recognized in the intra-zonal and azonal classes: regosol soils; lithosol soils; alluvial soils; saline soils; and alkaline soils.

2.2.3.1 Zonal Soils

The characteristics of these soils, also called normal soils, depend on the impact of weather and vegetation during soil formation and also on their location in desert, semi-arid and sub-humid areas, with each one having exclusive characteristics. Zonal soils in arid and desert areas are categorized as follows

Real desert soils have a C(A) profile and are usually seen in regions with <75 mm precipitation. The A horizon is rarely observed in these soils, often having been eroded and eliminated by wind and rain.

Gray desert soils have an AC or A(B)C profile and are observed in areas with annual precipitation of 75–150 mm. The brown or gray A horizon is 0–10 cm thick and its organic matter does not exceed 0.6%. Lime accumulation is observed on the C horizon, mainly up to 35 cm deep.

Red desert soils have an A(B)C or ABC profile and are formed in warmer climates than gray desert soils. The color of the A horizon is red in these soils and its organic matter is very low. The B horizon is almost a cambic horizon and is observed in brown or brick colors coupled with limestone sediments.

Sierozem soils are gray soils with an ABC profile that are formed in areas with annual precipitation of 200–300 mm. The thickness of the A horizon is 10–15 cm and its organic matter is about 1%. The B horizon is cubic in structure and there is an accumulation horizon of calcium carbonate at a depth of 30–40 cm from the surface, called the Ca horizon. Deposits of calcium sulfate or gypsum or C horizons are observed in sierozem at a depth of 80–90 cm and in the C horizon.

Generally, there are sufficient solutes in the soils of arid regions, such as $CaCO_3$ (low/insoluble), $CaSO_4$ (less soluble), NaCl (solution) and Na_2SO_4 (solution).

Red sierozem soils have an ABC profile and characteristics similar to sierozem but with more red color. In most cases, their soils are old or paleosolic, formed during a warmer age.

Reddish-brown soils have an ABC profile and are seen in areas with annual precipitation of about 300 mm. These soils may be wet at a depth of 1–3 m for several months of the year. The A horizon of the soils has 1–2% organic matter is about 20 cm thick. The amount of clay in the B horizon B is greater than in the A horizon. Accumulations of calcium carbonate or Ca occur at a depth of 40–50 cm and chalky sediments or Cs in the C horizon.

Brown soils have an ABC profile and a little lime is leached from the A horizon. Organic matter content is 2–3% and the thickness is 15–25 cm. The B horizon is brown or close to brown. The structure of this horizon is well developed, block-shaped or prismatic. Argillic horizon indicating clay transmission is observed in these soils. The accumulation horizons of calcium carbonate and gypsum exist at depths of 60 cm and 150–300 cm, respectively. This type of soil is observed in areas with an annual precipitation of 400–500 mm.

2.2.3.2 Azonal Soils

These soils are similar to their parent materials and have not evolved as well, as they are relatively young. The following soil categories from this group are observed in arid and desert areas:

Lithosols have an (A)C profile. The A horizon, which has not evolved very well, is shallow, contains pebbles and is located on parent rock or rubble (FAO 1964). About 21% of the world's soil is formed from them but only 5.2% is arable land. These soils are too shallow and rocky for agricultural use but may have agricultural potential. They are used for viticulture in the north of Africa and as rangeland in the south of Africa.

Regosols have an (A)C profile and the A horizon is not well developed. The difference between these soils and lithosols is that they are made of soft, unhardened material which is mainly inorganic but not heavy. These soils are deep, unlike lithosols, and their characteristics are uniform from the surface to a depth of 150 cm or more. Most of these soils are composed of sand (Fig. 2.2).

Sandy soils have been created by diminishing sedimentary rocks in arid regions. Due to the lack of dense vegetation, drought and lack of clay particles, these soils are easily eroded by winds to create mobile sand dunes. Sandy soils are without doubt one of the best soils for desert plants and the most suitable place to grow them is the gentle slopes of the dunes. Due to their high permeability, sandy soils quickly absorb water and the water does not flow on the land surface even after heavy rains. The water may remain between sand layers for a long time at a depth of 20–30 cm in these soils, creating a humid layer. Historically it was believed that if

(a) (b)

Fig. 2.2 Regosols profile (regosol alluvial (**a**) and regosol marine (**b**)). *Source* http://www.ucalgary.ca

sandy soils are irrigated, the most fertile desert oases are created. Even after long irrigation with saline water, soil does not lose its fertility.

In an alternative classification, azonal soils in arid regions are called raw material soils, with the following notable types:

Reg: an old soil located under the surface of desert pavement. In fact, this soil is maintained by the pavement. Reg is created in wetter geological periods than pavement.
Erg: from raw soil types found in the form of dunes with different shapes and dimensions not showing the effects and symptoms of soil formation (specified horizon is not observed).
Pseudo sand dunes: similar to erg, but there are clay or silt-like particles.

Alluvial soils are formed on new alluvial deposits and their evolution is very slight. For this reason, the color change from the A to the B horizon is scarcely tangible or there is no color change. Soil properties are similar to the parent rock in many cases and soil is usually stratified. The soil texture depends on the amount and the rate of materials deposition, so the soil texture is fine near coarse streams and rivers and in the external margin of floodplains. In general, the alluvial soil profile is heterogeneous in texture and has very specific horizons indicating alternating sedimentation layers and different alluvial stages. Various minerals in these soils have many similarities with sediment and parent rock. The intermittent floods add new minerals to the soil surface causing soil fertility, and these soils are buried by other deposits before they have time to develop, thus a new soil has formed on them. The profile of these soils is mainly AC and rarely A(B)C. Alluvial soils exist in all areas including humid, very humid, semi-arid and arid regions, and they are not specific of arid regions.

Alluvial soils have great fertility and are rich in required minerals for plants. The new nutrients have been brought in each flood which are not evolved.

2.2.3.3 Intra-Zonal Soils

A topical agent such as parent rock or geological era has a great impact on their formation. Saline and alkaline soils belong to this group.

Saline soils: Most soils in arid regions contain a lot of soluble salts that have been brought from different resources. These resources include:

- Parent rock weathering and salt production so that these salts are not washed by the rain.
- Salts may be transported by winds from the sea or saline soils in other regions.
- Salts are raised from groundwater by capillary force (in this case, the higher the groundwater level, the higher the raised salt content). If the groundwater level reaches 2–2.5 m from ground level, the situation becomes critical, because there is not enough precipitation in arid regions for salts to leach and because salts accumulate on the soil surface due to evaporation being too high.

The soils of arid regions usually have a pH above 7 and are strongly alkaline. Alkalinity in calcareous soils is often due to the saturation of the clay particles by calcium and their pH is <5.8. But in soils with clay particles saturated by sodium, some sodium hydroxide is formed due to hydrolysis, then is combined with CO_2 to create sodium carbonate (Na_2CO_3). In this case, the soil pH is higher than 8.5. Many of the saline soils in the world are of sedimentary origin. If excess salts can be removed, soil fertility will be increased, but without this action they cannot be used.

2.2.3.4 The Types of Saline and Alkaline Soils

There are three types of soil in this group (see Table 2.3): saline soils (high concentration of soluble salts); sodic soils, called alkaline soils (high amount of exchangeable sodium); and saline-sodic soils (high concentration of soluble salts and high content of exchangeable sodium).

Table 2.3 Properties of different saline soils

Soil	EC (dS m^{-1})	pH	ESP %	SAR
Saline	>4	<8.5	<15	<13
Saline-sodic	>4	<8.5	>15	>13
Sodic	<4	>8.5	>15	>13

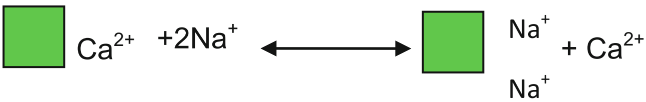
Saline soils (*solonchaks*)

Salt concentration is remarkably effective for crop growth. The amount of soluble salts is more than 0.1%. The index of salinity determination is the electrical conductivity of soil saturation extract at 25 °C. Where the electrical conductivity of soil saturation extract is 4 dS m^{-1} or more soil is called saline; and the exchangeable sodium percentage is <15. Of course, the quantities used to differentiate saline and sodic soils are not constant and depend on the type of plant.

Sodium is not absorbed in large amounts in these soils. There are other salts in the soil including cations of calcium, magnesium, potassium and anions of chloride, sulfate, bicarbonate, carbonate, borate and nitrate. The soil particles are almost saturated with Ca^{2+} and Mg^{2+}. A white layer of salts can be seen in these soils on the ground and soil pH is usually <8.5. For this reason, the concentration of soluble salts is higher than the exchangeable sodium in these soils, therefore, saline soils are follicular compared with sodic soils, and show good structure and sustainability against water. On the negative side they have high osmotic potential, causing difficulties for plant water absorption.

Sodic soils (*solonetz, alkaline*)

The total concentration of salts is not high (<4 dS m^{-1}) in the soil, but the exchangeable sodium percentage (ESP) is at a level harmful to plants. If the ratio of soluble Na^{+} to soluble Ca^{2+} and Mg^{2+} exceeds 2, sodium will be able to replace calcium and magnesium and thus, sodium ions are attracted to clay particles.



In this case, the absorbed sodium is not easily washed off by water, unless sufficient calcium is added to the soil. When the calcium in the particles' surface is completely replaced by sodium, excess sodium is combined with CO_2, and the resulting Na_2SO_4 increases pH to 5.8–10. Sodium carbonate causes the dispersal of soil organic matter which is later solved in the soil solution. The water raised by capillary force from the earth leaves some of this material on the soil surface, and because of its dark color it is called "black alkali". As a result of the placement of calcium and magnesium in the soil exchange collection, clay particles are dispersed and the soil structure disintegrates. As a result of this action, soil permeability is reduced. The dispersed particles of soil, penetrated in depth in the course of rain or irrigation, have left the soil, so that eventually the surface texture of the soil becomes coarser. Clay particles are gradually accumulated in lower layers of soil, constituting an impenetrable stratum. A certain structure will arise due to the intermittent soil wetting and drying that appears in prismatic, pillar and sheet forms during drying. Replacement of calcium by sodium in the soil exchange collection is a reversible process, but the deposition of a layer of clay particles is irreversible and may prevent the restoration of these lands.

Alkaline soils are ductile and sticky when they are wet and they form large hunks if soil has been desiccated after tillage. Consequently, it is difficult to prepare land for seeding. In addition, due to lack of sufficient aeration, permeability is low and crust formation on the soil surface causes difficulty for plant growth.

Saline-sodic soils

These soils occurred due to the combined processes of soil salinization and alkalinity. The high amount of soluble salts (more than 4 dS m^{-1}) and exchangeable sodium (more than 15%) arise from the properties of these soils. The soil pH is usually <8.5. The high concentration of salt has a follicular effect and this prevents the dispersal of clay particles due to sodium absorption. So until the soil contains a large amount of soluble salt, it has a proper structure and its permeability will be very high. If soluble salts are leached and the amount of calcium is insufficient, sodium clays are hydrolyzed and sodium hydroxide is released. This substance causes the dispersal of clay particles and thus saline and alkaline soils have been converted to sodic soils that have less favorable properties. If the soil contains gypsum, water dissolves calcium and this calcium is replaced by sodium which is washed out from the soil, preventing the destruction of soil structure.

Alkaline elements in soils take the form of exchange and synthetic. The ions are in exchangeable form while there are both exchangeable and synthetic forms in saline-sodic soils. In saline soils, there are more synthetic ions and fewer exchangeable ions.

There is a balance between exchangeable and synthetic ions in saline and sodic soils which controls pH to below 8.5. In saline and sodic soils, due to irrigation, synthetic ions are quickly dissolved and reduced and the sodium of exchangeable ions is released, which would destroy the soil structure. Gypsum needs to be added with irrigation to replace Na with Ca and to evict Na from the environment in neutral form.

Takyr soils

These are very dry and barren soils which are found in the deserts of Asia including Iran. Takyr soils form when the soil salinity begins to decrease. The texture of these soils is clayey and there are no plants. The soil surface is polyhedral during drought; after rain, due to the low soil permeability the soil surface becomes a temporary impassable swamp. These soils are covered with a dense layer of clay 3–5 cm thick and the rate of solutes under this stratum is about 1.5%. Groundwater is usually located at depths of over 10 m. Restricting factors of these soils include high drought, unfavorable physical conditions, alkaline pH about 10, high solutes, lack of organic matter and humus and the lack of biological activity. Takyr soils can be rehabilitated for cultivation. 300–700 tons of sand per hectare are added to them in the former Soviet Union, some gypsum is brought to the surface soil from lower layers by deep tillage and then 5000–10,000 m^3 of water per hectare are added to decrease soil salinity up to the desired range.

2.2.4 Factors Affecting Saline Soil Formation

2.2.4.1 Climate

Saline soils occur mainly in warm and arid regions. High drought, high temperature and high evaporation speed are among the requirements that increase evaporation and disturb salt balance. In extremely arid deserts such as the Arabian and Chilean deserts, soil salinity may reach 75%, with a 50 cm thick salt layer covering the soil surface. Soil may also be saline in deserts with cold winters. Some salts have low solubility in cold temperature, which is important for soil salinization.

2.2.4.2 Relief

Hot weather alone is not enough for soil salinization. If the groundwater level is low and evaporation from the soil surface is equal to the precipitation, salts will not accumulate on the ground. When an arid zone is located in a deep hollow surrounded by mountain ranges, the groundwater flow will wash out salts and carry them to the arid area. Because these waters are under great pressure, the artesian rising of water redeploys salts to the soil surface. This aggregation is usually performed in secondary hollows and causes salt pans known as sabkhas or shotts.

2.2.4.3 Irrigation and Drainage

Irrigation water always contains different concentrations of various salts. Water loss due to evaporation causes the inevitable increase of salt in the root zone. The plant absorbs only a very small amount of salt. For example, a product equivalent to 4 tons of cotton per hectare absorbs only about 10 kg of sodium.

Accumulation speed in the root zone depends on factors such as the quality and quantity of irrigation water, irrigation method and sufficient drainage.

A sandy layer covering heavy soils effectively prevents evaporation and contributes to preserving humidity. If sprinkler irrigation and proper management have been applied (chemical fertilizers and manure, etc.), these soils can be very fruitful. On the other hand, in many desert regions, such as parts of southern Iraq, a white stratum of salt accumulation is found on the soil surface, which is an obstacle to cultivation. Prolonged irrigation and lack of drainage make for permanently unusable soil.

Evaporation of surface water, groundwater, seas and lakes is the most important factor in the deposition of solutes and the formation of gypsum and lime. The following points are significant:

Critical concentration of groundwater: This is the concentration needed to reach the soil surface through capillary action if soil is to be salinized. The concentration varies depending on the type of salt. If the groundwater solute is mainly chloride and sulphate, the critical concentration is 2–3 g l^{-1} but if the solute is sodium, the critical concentration is reduced to 0.7–1 g l^{-1}.

If groundwater salinity does not exceed these figures, good soil is often formed enabling cultivation of crops such as cotton, sugar beet and sugar cane, but if the salt concentration exceeds these limits, salinization and alkalinization begin and soil fertility decreases rapidly.

Critical depth of groundwater: This is the depth at which water can rise to the soil surface under the influence of capillary action. If the solute concentration is higher in the groundwater, the critical depth will be also higher. Generally, critical depth in the soils of arid regions in Iran with a concentration of 10–15 g per l is 2–2.5 m from the soil surface. Critical depth is also a function of evaporation intensity and is calculated from the following equation suggested by Kovda (1967):

$$y = 170 + 8t \pm 15 \tag{2.1}$$

In this formula, y is the critical depth in centimeters and t is the mean temperature in degrees centigrade. There are two variable components in the above equation, so it can be used in local conditions by changing these variables. In arid regions that are irrigated, the concentration of soluble salts in the soil should be <5 g per l.

2.2.5 Agricultural Aspects of Soil Characteristics

Most soils in arid and desert areas have a relatively large amount of nutrients due to the absence of nutrient leaching by rain. Of course, these elements may not be appropriately balanced. In these soils, potassium is high, phosphorus is low and there is a shortage of micronutrients. These soils are low in organic matter and nitrogen due to the sparseness of vegetation. Sierozem soils can be used for sheep grazing without irrigation. Of course, these soils have good physical features and if irrigated, they produce well. Soils with calcareous crust on or near the surface are inferior in terms of agriculture. Brown soils that have less dryness can be used for rain-fed cultivation but the yield is low. One common feature of arid soils is their lack of stability, and human intervention has led to erosion.

Soil salinity is one of the major limiting factors in arid and desert areas, and is discussed in detail in the next section.

2.2.6 Soil Salinity

A soil is called saline if the concentration of soluble salts results in reduced performance, provided that there are no other factors inhibiting growth.

The problem of salinity in soil and irrigation water is not unique to Iran—it is faced by most countries in arid regions—but one of the important issues is the utilization of soil and water resources in Iran.

Various specialist studies have shown that there are about 25 million hectares of saline and alkaline areas in Iran constituting almost 15% of the country's area, 30% of its plains and plateaus and more than 50% of the irrigable and agricultural lands. Salinity in soil and irrigation water should be considered a serious problem in Iran.

A large part of Iran is located around 30′ of latitude north, and this leads to drought and the formation of saline soils, but there are also other factors:

1. The existence of gypsum, salty and marl structure in most parts of Iran.
2. The lack of drainage due to the heavy texture or lowland situation of soils as well as saline shallow saltwater aquifers.
3. Salinity of irrigation water particularly where qanats, springs and wells need to be used.
4. Farmers' involvement in soil salinization and the raising of groundwater levels, leading to incorrect irrigation systems.

Iran's saline soils often contain a large amount of lime; however alkaline soils have rarely been found in Iran. So, the amount of lime have to be paid attention in terms of irrigation and agriculture capability, not to rely on a method which is common for determining the capability of land irrigation in Iran with regard to the fact that the American one is not satisfactory for classification of Saline soil and water in Iran.

Saline soils contain high amounts of soluble salts which cause changes in their physical, chemical and morphological properties, making them often an unsuitable environment for plant growth. In order to recognize saline and alkaline soils and fully understand their evolution we need to study not only their physical, chemical and morphological characteristics but also their relationship with the environment and the climate. This section considers issues relating to the relationship between salinity and geographical location, chemical composition of salts, causes of saline soil emergence, conversion of salts, and their effects on the physical and chemical properties of soils.

2.2.6.1 Salinity and Geographical Location

Soil or pedosphere is an active transmission zone between the lithosphere and the atmosphere where the conversion of substance to energy occurs. This effect is more limited in arid regions than in humid and semi-humid regions.

The solutes are the most important factor affecting the development of soils in arid regions. Transmission and leaching do not occur completely in these regions, because the little water that penetrates into the soil through rainfall cannot transfer solutes too deep into the soil. Therefore, they remain in the soil profile and their concentration increases due to high evaporation. If their concentration exceeds certain limits, it will be saline.

A look at the distribution of saline soils and arid regions of the world shows that these soils are widespread mostly around the 30′ circuit (North Africa, Iraq, Iran, central parts of Asia, Arizona, Texas and Australia). One reason is that there are a series of atmospheric vertical currents in this circuit, the origin of which is the Equator and 60′ circuit. These currents rise from the Equator and 60′ circuit and, traversing an arc, descend in the 30′ circuit. During the descent they absorb a large amount of air moisture, causing cloud scattering and regional drought in places where conditions are not appropriate for the formation of a microclimate. As there is sufficient rainfall in humid areas, the salts in the soil profile are leached from the soil and transferred to the sea or other locations by surface and underground waters, so in practice there are no saline or alkaline soils in humid regions except for sea coasts and other places where morphological and geological conditions are favorable for the formation of saline soils.

2.2.6.2 The Origin and Causes of Soil Salinization

The causes of salinity are either intrinsic (genetic) or adventitious.

Primary salinity. The salts in the soil are derived directly from decomposition and destruction of rocks. Soils based on marine deposits or salty formations, such as those of formations of the third age, have intrinsic causes. Such soils are observed in southern Iran, especially in the region of Baluchistan and Dashtiari. The main origin of these soils is saline marl and limestone in the surrounding mountains. The salinity of these soils, especially those in very arid regions, is not observed as well in their profiles, because the low humidity turns the crystals to powder.

Secondary salinity. One or more secondary factors can cause solutes in the soil, so it can be said that soil salinity is not related to the main rock and does not initially affect the evolution of these soils. If these soils can be reclaimed and the salinity agent eliminated, they will continue along their primary evolutionary path. For example, if the brown soil of arid regions is converted to saline and the salinity is destroyed, it will evolve again to brown soil.

The most important adventitious factors for the salinity of soils include: the mixing of saline and fresh water in groundwater aquifers; irrigation with saline water; solute transport by wind; biological agents; and human influences.

Saline groundwater aquifers. One of the major causes of salinity in the soils of arid regions is the presence of shallow saline groundwater aquifers which usually contain a large amount of salts, the concentration of which increases continuously as a result of evaporation. The amount of salts depend on the type of formations that it passes through.

Evaporation intensity from the aquifers depends on their depth and the ambient temperature. According to Kovda (1967), the shallower the aquifers, the greater the amount of evaporation in certain soil types.

Which decreases suddenly from a specific depth known as the critical depth. Aquifers are created in lowlands by the impermeable dense layer in the lower levels of soil. The movement of water from upstream basins to downstream regions gradually raises the water table and even temporarily produces a swamp. Shallow saline aquifers have a major impact on soil salinization Asghar (1961) claims that one hectare of arable land in Pakistan is salinized every 30 min due to rising saline groundwater. According to Kovda (1967), the critical value should not exceed 2–3 g of chloride or sulfate per liter in underground irrigation and one gram per liter in bicarbonate irrigation, because the chemical composition of soil and groundwater will be balanced over time.

If solute concentrations in the groundwater exceed a certain level, salinization and loss of soil properties will quickly occur. If soils exposed to the risk of saline groundwater aquifers are to be used, groundwater levels need to be controlled. To establish the depth, soil should be exposed experimentally to evaporation, and the evaporation intensity plotted on a graph to find the critical groundwater depth. If the amount of salts in the groundwater does not exceed 1–2 g per l, the critical depth can range between 1 and 1.5 m.

Irrigation with saline water. If scientific principles are not observed in irrigation, the good properties of the soil may be lost. Some solutes will be added to soil with every irrigation if additional water is not added to wash out soil salts.

If the rainfall is zero at the time of irrigation and exchange between irrigation water and sedimentary soil is not performed, the increase of salts in soil can be determined from Eq. (2.2) proposed by Richards (1954).

$$\frac{D_{\mathrm{iw}}}{D_{\mathrm{s}}} = \frac{\mathrm{ds}}{\mathrm{d_{iw}}} * \frac{\mathrm{sp}}{100} * \frac{\Delta C\mathrm{s}}{\Delta C_{\mathrm{iw}}} \tag{2.2}$$

where

D_{iw} irrigation depth (cm)
D_s depth of soil that is moist with water (cm)
ds bulk density of soil to a depth DS (g cm^{-3})
$\mathrm{d_{iw}}$ specific weight of irrigation water (g cm^{-3})
sp saturation moisture percentage
$\Delta \mathrm{c}_s$ increase of salts in the soil saturation extract
Ciw concentration of salts in irrigation water (g l^{-1})

If solute concentration is replaced by electrical conductivity in Eq. (2.2), we would have:

$$\frac{D_{iw}}{D_s} = \frac{\mathrm{d}s}{\mathrm{d}_{iw}} * \frac{\mathrm{sp}}{100} * \frac{\Delta \mathrm{EC}_s}{\Delta \mathrm{EC}_{iw}} \tag{2.3}$$

If we assume that to irrigate the soil to a depth of 30 cm, we use water with electrical conductivity of 1 dS m^{-1}, we use 54 cm of water and if the density of soil saturation moisture percentage are taken to be 1.5 g cm^{-3} and 40 respectively, (and density of irrigation water is 1 g cm^{-3}) the increase of soil solutes is as follows:

$$\frac{D_{iw}}{D_s} = \frac{\mathrm{d}s}{\mathrm{d}_{iw}} * \frac{\mathrm{sp}}{100} * \frac{\Delta \mathrm{EC}_s}{\Delta \mathrm{EC}_{iw}} = \frac{54}{30} = \frac{1.5}{1} * \frac{40}{100} * \frac{\Delta \mathrm{EC}}{1} \tag{2.4}$$

$$\Delta \mathrm{EC} = \frac{54 * 1 * 100 * 1}{30 * 1.5 * 40} = 3\,\mathrm{ds/m} \tag{2.5}$$

Therefore, as a result of soil irrigation with 54 cm of water, the electrical conductivity of the saturation extract increases by 3 dS m^{-1}.

Understanding the chemical composition of salts in irrigation water, especially the ratio of sodium ions to calcium and magnesium cations as well as the rate of carbonates and bicarbonates, is important for the reclamation of saline land. According to Chapman and Harding, the solute concentration of irrigation water should not exceed 1500–2000 ppm; and according to Richard et al., electrical conductivity of irrigation water should not be more than 2.25 dS m^{-1} (2250 μ℧). Water with a high concentration of salts can be used when as much as solutes are added to the soil by irrigation water, provided they are flushed away by drainage at every irrigation.

Solute transfer by wind. This phenomenon is called pulverisation (Vysotskii 1905). A certain amount of salts is always transferred to inshore regions by rainfall as a result of the wind blowing from the sea. The further from the sea these regions are, the lower the solute transportation. According to Schoeller (1945), the amount of rainwater chlorides reduces with distance from the beach. Another problem in desert margin areas is the movement of fine limon particles from the deserts by wind, causing salinization. This phenomenon has been observed around Sabzevar especially in south and southwest parts. According to those mentioned about sand fixation, salinity levels should also be considered.

2.2.6.3 Chemical Composition of Solutes in Saline Soils

Saline soils generally contain a lot of minerals that are gradually released from the rocks and enter the soil solution or surface and underground water by physical and chemical processes such as hydrolysis, dehydration, oxidation and reduction, dissolution and carbonization.

The most important anions of saline soils are chloride, sulphate, carbonate, bicarbonate (sometimes with nitrate); the most important cations are calcium,

Table 2.4 Chemical composition of Earth's solid crust

Element	Percentage	Element	Percentage
Oxygen[a]	49.13	Potassium[a]	2.35
Silica	26	Hydrogen[a]	1
Aluminum	7.45	Titanium	0.61
Iron	4.2	Carbon[a]	0.35
Calcium[a]	3.25	Chlorine[a]	0.25
Sodium[a]	2.4	Phosphorus	0.12
Magnesium[a]	2.35	Sulphur[a]	0.1
		Manganese	0.1

Elements marked with 'a' play an essential role in the formation of soluble salts causing soil salinization.

magnesium, sodium and potassium. In addition, they may contain a small amount of boron, iodine, copper and zinc.

Not only are the concentrations of carbonate, chloride and sulfate anions in the Earth's crust (shown in Table 2.4 as carbon, chlorine and sulfur) that are involved the solute composition of saline soils less than the concentration of calcium, magnesium and sodium cations, but they are almost minimal in comparison with other compounds of Earth's solid crust. The concentration increases in saline soils to a level higher than their average value. Magma formation and volcanic activity continue in certain geological periods, causing an accumulation of chlorides, sulphates and borates in the soil, the oceans and the sediments of sea.

Elements marked with an asterisk in Table 2.4 play an essential role in the formation of soluble salts causing soil salinization. Other elements that are not listed in the table and are present in the Earth's solid crust constitute only 0.39%. The solutes of saline soils are divided into three categories in terms of their relative solubility: (1) salts with low solubility such as calcium and magnesium carbonates; (2) salts with medium solubility such as calcium sulfate; and (3) salts with high solubility such as sodium and potassium carbonates, sodium, potassium and magnesium sulfates, chloride and sodium, potassium, calcium and magnesium nitrates.

The amount and proportion of each of these salts in saline soils vary according to the soil type and the conditions for its formation. The presence of these salts in the soil not only changes in its physical and chemical properties, but it also causes a disturbance in plant growth if they exceed a certain level.

Apart from the degree of solubility, the solutes of saline soils can be divided, in terms of constituent anions into carbonates, sulfates, chlorides, nitrates and borates.

Carbonates

There is a large amount of carbonate in the soil and groundwater of arid and semi-arid regions. The effect of carbonates on the soil properties depends on the type, amount and degree of their solubility.

- Calcium carbonate ($CaCO_3$)

The solubility of calcium carbonate is very low in pure water (0.0131 g per l), but if there is enough carbonic acid in water, its solubility increases rapidly and reaches about one gram per liter. Calcium carbonate is composed of a strong alkaline and a weak acid. So the solution is considered a strong alkaline (pH of 10–10.2), but if there is carbon dioxide in water, pH is reduced to about 7.5–8.5.

The presence of calcium carbonate in the soil does not harm most crops due to the low solubility, but plants that need acidic pH for growth, such as tea, cannot grow in calcareous soils. There is a lot of calcium bicarbonate in groundwater and most rivers, while calcium carbonate is highest in lakes and seas, constituting a relatively important part of their deposits (7–15%). On land where the groundwater level is near the soil surface, some of these waters have reached to the upper levels due to capillary force and have deposited carbonate minerals.

The amount of calcium carbonate may reach 20–80% in steppe soils and soils in arid regions. Calcium carbonate in saline soils especially in saline-alkaline and alkaline soils may appear as crust, mycelium and concretion. The color of these deposits is white with a slight tendency to yellowness, and they are easily detectable in the soil profile. There is a large amount of lime in saline soils in arid regions, especially those with gypsum-calcareous marls and Third-Age formations, such as in most of Iran (for example Baluchistan).

- Magnesium carbonate ($MgCO_3$)

The solubility of magnesium carbonate is more than that of calcium carbonate and if there is carbon dioxide in water, its solubility will rapidly increase. This salt consists of a strong alkaline and a weak acid, so the solution is strongly alkaline (pH = 10) and disturbs plant growth. The amount of magnesium carbonate together with calcium carbonate creates dolomite {$CaMg(CO_3)_2$} which is observed in the soils of arid regions.

- Sodium carbonate (Na_2CO_3)

There is often some sodium carbonate (alkaline) in saline and saline-alkaline soils as well as in the groundwater of arid regions. This substance is crystallized in the soil with different amounts of water and eventuated as $10H_2O$, Na_2CO_3 and Na_2CO_3, H_2O. Sodium carbonate is a strong alkali with pH up to 12 and is poisonous to most plants. This substance causes the dispersion of colloidal particles of the soil and loss of structure stability in the soil.

The higher the microbial activity and organic matter in the soil, the faster is the transformation of sodium carbonate to sodium bicarbonate. If the groundwater contains sodium carbonate and bicarbonate, their concentration is increased due to evaporation and they are crystallized as Na_2CO_3–$NaHCO_3$, $2H_2O$. Most waters (rivers, springs, groundwater, etc.) where the amount of soluble salts is 0.5–3 g per l contain some sodium carbonate and bicarbonate.

The soils irrigated by these waters are gradually alkalized and their permeability decreases. In most arid and semi-arid soils, sodium carbonate is transformed to sodium carbonate and sodium sulfate, because chalk is usually available in these soils; where there is not enough chalk, sodium carbonate and bicarbonate are free. Hilgard (1907) suggested that a small amount of Na_2CO_3 is gradually created due to the effects of chlorine and sodium sulfate on calcium carbonate. The present researchers believe that part of the sodium carbonate in the soils is created as a result of the reaction between carbonic anhydride or calcium carbonate and exchangeable sodium in the soil.

Some plants produce alkaline carbonate and bicarbonate due to the mineralization of organic matter in their organs. For example, sunflower contains high amount of potassium carbonate (K_2CO_3) or anabasis, *Seidlitzia* and *Haloxylon* contain a relatively large amount of alkaline carbonates. If their residues are poured onto the ground, they increase the alkaline carbonates in the soil. The solubility of sodium carbonate is very high in water. The solubility depends strongly on environmental conditions, especially temperature. Its solubility is low at 0 °C or less, but it will increase at 30 °C. The solubility of Calcium Chloride is approximately 350 g per l at 30 degrees centigrade. This amount reaches about 500 g per l at higher temperatures that it is higher than the solubility of sodium chloride.

The variations in the solubility of sodium carbonate are highly significant in terms of temperature in the chemistry of saline and alkaline soils. Some sodium carbonate is deposited in the soil at normal atmospheric temperatures (over 15 °C) due to its reduced solubility, while the solubility of sodium chloride does not change and it flows to groundwater through drainage.

- Potassium carbonate (K_2CO_3)

Potassium carbonate has high solubility and severe alkalinity and causes toxicity in plants, if the value is high.

Sulfates

- Calcium sulfate

Calcium sulfate is present in large quantities in the soils of arid and semi-arid regions. The chalk ($CaSO_4$, $2H_2O$) loses its crystal water and eventuates as $CaSo_4$, $1/2H_2o$. The proportion of gypsum reaches 50–90% in some areas (50% for Dargaz in Iran).

The presence of gypsum is due to evaporation from shallow groundwater or geological origin (soils of Dargaz). Gypsum may appear in the form of crystalline, hard granules or prism particles in the soil. It sometimes constitutes a hard layer that prevents water penetration and plant roots in the soil. The solubility of gypsum is not high in water (1.9 g per l), therefore it does not harm the plant. Gypsum is usually used as a corrective material for alkaline soils.

- Magnesium sulfate ($MgSO_4 \cdot 7H_2O$)

Magnesium sulfate is one of the main components of salts in saline soils. It is also found in the groundwater and is toxic to plants due to its high solubility (262 g per l).

Magnesium sulfate is always mixed with other solutes.

- Sodium sulfate (Na_2SO_4)

Sodium sulfate is a major component of saline soils, saline groundwater and saline lakes. Its toxicity is two to three times lower than that of magnesium sulfate.

If the temperature is high, its solubility will be greater. A certain amount of sodium sulfate reaches the soil surface in summer along with other soluble salts (e.g., magnesium sulfate, sodium chloride and magnesium chloride) and is deposited on the soil surface in cold seasons due to its reduced solubility.

Crystalline sodium sulfate (Na_2SO_4, $10H_2O$, called miralilite) loses its water of crystallization and becomes a white powder called thenardite. Sodium sulfate usually co-crystallizesn with calcium sulfate, forming $Na_2Ca(SO_4)_2$ (glauberite). Sodium sulfate is usually observed as thenardite in arid areas.

- Potassium sulfate (K_2SO_4)

Potassium sulfate is less visible in saline soils and has properties similar to sodium sulfate: it is less toxic to plants.

Chlorides (*Cl*)

Chlorides, along with sulfates, are the most important compounds of saline soils. These solutes generate a large amount of toxicity to plants due to their high solubility, and as the soil and water salinity increases, the amount of chlorides will increase. The most important chlorides include the following types.

- Calcium chloride ($CaCl_2$)

Sodium chloride is rarely observed in the soils, because it eventuates as calcium sulfate and carbonate and deposits due to the reaction with sodium sulfate and carbonate, unless water salinity is very high (500–400 mg) in soil. Calcium chloride is toxic to plants, but its toxicity is less than that of sodium chloride.

$$CaCl_2 + Na_2SO_4 \rightarrow CaSO_4 + 2NaCl$$
$$CaCl_2 + Na_2CO_3 \rightarrow CaCO_3 + 2NaCl$$
$$\text{Magnesium chloride } (MgCl_2)$$

Magnesium chloride is found in saline soils, groundwater and lakes to a greater extent than calcium chloride. Its solubility is high (353 g per l) and it is one of the most toxic salts for plants. It is moisture absorptive like $CaCl_2$ and for this reason, the horizons of soil surface remain almost humid after rainfall.

- Sodium chloride (NaCl)

Generally NaCl, MgSO and Na_2SO_4 are the main components of solutes in saline soils. The solubility of sodium chloride is high (264 g per l). For this reason, it is severely toxicto plants, because even soils containing about 0.1% NaCl constitute an extremely inappropriate environment for plants. The amount of NaCl in saline soils may reach 2–5% and must be modified by leaching. If there is $CaSo_4$ in these soils, leaching and amendment are easier, but if calcium sulfate is not available in the soil, the leaching and amendment will be difficult, because the sodium in the soil solution has been exchangeable and it causes soil alkalization:

$$2NaCl + CaSO_4 \rightarrow CaCl_2 + Na_2SO_4$$

- Potassium chloride (KCl)

The properties of potassium chloride are similar to those of sodium chloride. If its amount in the soil is low, it is commonly referred to as fertilizer, but if it is high, it will be toxic to plants, like sodium chloride. It should be noted that the amount of potassium chloride is high in saline soils.

Nitrates

The amount of nitrates does not exceed 0.05 or 5% in the soil. Potassium and sodium nitrate are mined in Chile, Peru and India, because the amount of nitrate reaches as much as 50%. Although nitrates are important nutrients for the plants, if their concentration exceeds certain limits, they will be toxic to plants. Nitrates are very soluble in water and a large amount of them are dissolved and destroyed due to leaching, when they have been restored in the anaerobic environment and converted to ammonia and even nitrogen.

Borates

The amount of borate is usually not high, but some borate has often been observed in saline soils due to its high solubility. Boron is one of the toxic substances and causes disturbance in plant growth.

2.2.6.4 Modification of Solutes in Soil

Quantitative and qualitative changes to solutes in the soil may occur due to the following factors:

(a) type of soil solutes
(b) amount of soil moisture and rainfall
(c) type of soil texture
(d) topography
(e) effects of temperature

(f) solute interactions
(g) biological factors.

Type of soil solutes. Movement of solutes depends on their type. The mobility of chloride in the soil is usually more than that of sulfates, which in turn is higher than carbonates. Solutes with greater solubility have greater mobility. To study the quality of solute transport in soil, Yaalon (1965) poured chloride and sulfate salts onto dry soils and placed them under leaching conditions. After leaching he measured the amount of chloride and sulfate at different depths (Fig. 2.3).

Comparison of the changing moisture content against the changes of salts in the soil shows that the depth of the water corresponds to that of the chloride, that is, chlorine moves as far as the water penetration. Sulfate ions, however, do not penetrate to the same depth as water. Yaalon's (1965) transfer coefficient of ions in the soil is defined as:

$$R = \frac{x}{y} \tag{2.6}$$

where R is the transfer or migration coefficient of ion in soil, x is the distance traveled by ions in the soil and y is the distance traveled by water. R is equal to 1 for chlorides and is smaller than 1 for sulfates and carbonates. The variations of this coefficient are: carbonates < sulfates < chlorides.

To calculate the distance where ions have maximum concentrations, Yaalon (1965) proposed the equation

$$D = \frac{P \cdot R}{W}$$

where D is the depth with the maximum concentration of salts, P is the amount of water that has penetrated into the soil, W is the moisture-holding capacity of the soil and R is the migration coefficient of ion.

Amount of rainfall and moisture. As rainfall and leaching increase, solutes penetrate to a greater depth of the soil, but the depth of different solutes varies, with carbonates located at shallower depth than sulfates and chlorides. Figure 2.4 shows the changes in the amount of carbonates, gypsum and chlorides at different depths of medium-texture soil against the amount of rainfall.

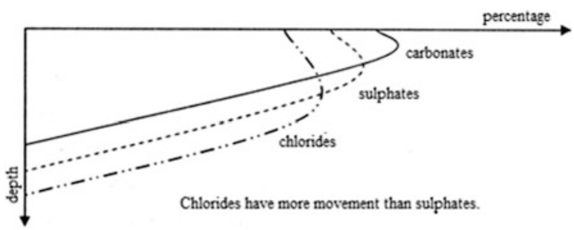


Fig. 2.3 Variations in soil solutes at different depths after leaching. *Source* Bybordi (1981)

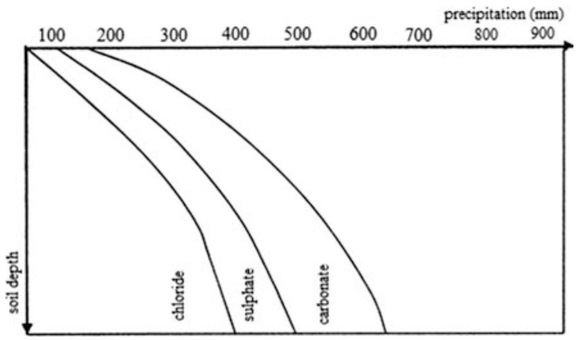


Fig. 2.4 Changes in depth of solute deposition with amount of precipitation

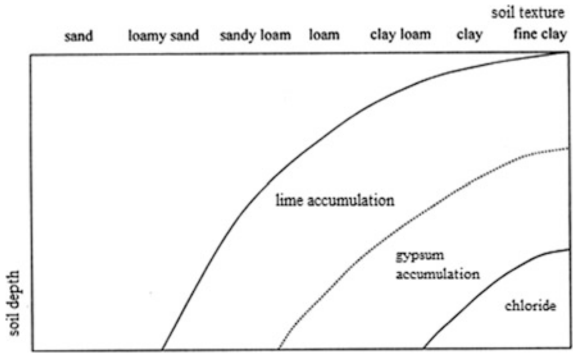


Fig. 2.5 Changes of the solute accumulation in different soils

Soil texture. The type of soil texture has a great impact on leaching. Where soil texture is lighter, solute leaching is stronger and faster. Fine-textured soils have higher water-holding capacity and lower porosity and for this reason, the solute leaching is slower than in sandy textures where porosity is higher. Figure 2.5 shows variations in the depths of solutes in soils with different textures with precipitation of about 350 mm.

Topography. The topography has a significant effective on the amount of solute leaching. There is a large discharge on steep slopes, so these areas are more arid, the depth of water penetration is low and solute leaching is limited, while greater leaching usually occurs in lowlands due to water accumulation.

Temperature. Temperature affects not only the interaction of salts and the intensity of their combination, but also liquidation. The rate of chemical composition reaction increases approximately 2.5 times for every 10 °C increase in temperature.

Understanding changes in salts caused by seasonal temperature variation is very important since as a rule, the saline land should be amended when oil solutes have sufficient solubility. Solubility changes in some salts with temperature changes are given in Table 2.5, which shows that solubility of all solutes listed except sodium chloride increases with rising ambient temperature.

Table 2.5 Changes of salt solubility in 100 g solution with temperature increase

Solute type	Temperature (°C)					
	0	10	20	30	40	50
Na_2CO_3	6.5	10.9	17.9	28.4	32.4	32.1
$NaHCO_3$	6.5	7.5	8.7	10	11.3	12.7
Na_2SO_4	4.3	8.3	16.1	29	32.6	31.8
NaCl	26.3	26.3	26.4	26.5	26.7	26.9
$MgSO_4$	18	22	25.2	28	30.8	33.4
$MgCl_2$	38.8	39.8	41	48.6	8.51	54.5
$CaCl_2$	37.3	39.4	42.7	50.7	4.53	56

Table 2.6 Changes in the solubility of calcium sulfate in calcium chloride at 25 °C (grams per 100 g of water)

$CaCl_2$	$CaSO_4$
0	0
17.2	0.787
20	0.823
24.4	0.820
29.3	0.614
35.8	0.709

Table 2.7 Changes in the solubility of calcium sulfate in calcium chloride at 25 °C (grams per 100 g of water)

$CaCl_2$	$CaSO_4$
0	0.204
5.2	0.103
9.9	0.086
18.9	0.077
40.8	0.035

Solute interactions. Since salts in the soil solution are composed of different anions and cations, the solubility of each of them in soil solution varies according to solubility in water, because each salt in the soil solution affects the solubility of the other salts. Some salts increase and others decrease the solubility of other salts. Tables 2.6 and 2.7 show changes in the solubility of calcium sulfate in sodium chloride and calcium chloride salts.

The effect of salts on each others' solubility is shown by the curves of Fig. 2.6.

Biological factors. Biological factors play a part in redox of organic and inorganic substances. These factors convert organic material to mineral material and transform mineral material. Micro-organisms have a major role in the formation of carbonates as well as in the conversion of carbonates to bicarbonates. In the anaerobic environment, the oxygen required for the oxidation of organic matter is derived from the reduction of compounds such as sulfates. If we assume that the organic material is composed of cellulose, the reduction sodium sulfate is as follows:

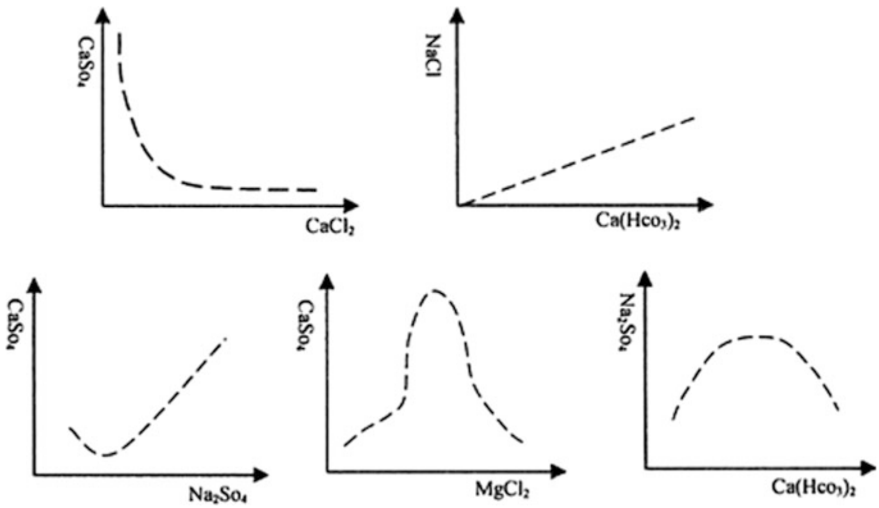


Fig. 2.6 Interactions of solutes on each others' solubility

$$3Na_2SO_4 + C_6H_{10}O_5 \rightarrow 3Na_2S + 5CO_2 + 5H_2O$$

The above reaction results in the formation of sodium sulfide and carbonic acid. By recombining sodium sulfide with carbonic acid or calcium carbonate, sodium carbonate is obtained in accordance with the following reactions:

$$Na_2S + H_2CO_3 \rightarrow H_2S + Na_2CO_3$$

or

$$Na_2S + CaCO_3 \rightarrow CaS + Na_2CO_3$$

It will be seen that the reduced sodium sulfate is converted to sodium carbonate. This phenomenon has been observed in swamps and coastal lands such as parts of northern Iran around Lake Rezaieh and also in acidic coastal areas of the Netherlands where it is known as acid sulfate or Cat Clay.

2.2.6.5 The Effect of Solutes on Physical and Chemical Properties of Soil

The effect of solutes on the physical and chemical properties of saline soils, which depends on their type and amount, is significant not only in terms of morphology and better identification of these soils, but also for the relationship between plants and soil and their appropriate utilization.

- *Chemical properties*

Increasing the electrical conductivity and osmotic pressure of soil solution.

Salts are conductors of electricity, so as the concentration of salts in soil increases, so does its electrical conductivity, so that there is a linear relationship between salinity and electrical conductivity. The electrical conductivity of the saturation extract rather than the salt itself can therefore be indirectly used to measure soil salinity instead. This method is now popular in all soil laboratories.

To convert the electrical conductivity of the saturated extract to the soil salt percentage, scientists at the US Salinity Laboratory obtained the following empirical relationship:

$$\mathrm{Psw} = 0.064\mathrm{ECe} \tag{2.7}$$

$$\mathrm{Pss} = \frac{\mathrm{Psw} - \mathrm{Pw}}{100} \tag{2.8}$$

where, ECe is the electrical conductivity of soil saturation extract in terms of decisiemens per meter, Psw is the percentage of salts in the soil saturation extract and Pss is the percentage of salts in dry soil.

Equation (2.7) is for American soils and similar equations can be obtained for any other region. Different salts are not constant in their electrical conductivity. For example, the electrical conductivity of chlorides is higher than that of sulfates. Thus, their electrical conductivity will vary depending on the type of soil solute. Generally each millimhos of electrical conductivity at 25 °C is equivalent to 10–12 meq per l (meq l^{-1}) of soluble salts in the soil saturation extract. The following equation, obtained for saline soils around Eshtehard in the Karaj area, is probably a guideline for the measurement of solutes in soils of this area:

$$\mathrm{Psw} = 0.071\mathrm{ECe} \tag{2.9}$$

The increase of solutes in soil not only increases electrical conductivity, but also raises the osmotic pressure of soil solution. Rising osmotic pressure of soil solution prevents water uptake by plants, disturbing their growth.

There are various methods for measurement of osmotic pressure. One of them measures the freezing point reduction of the solution, because when solution concentration is high, its freezing point will be lower than that of pure water (see Eq. (2.10)).

$$\mathrm{OP} = 12.86\Delta T \tag{2.10}$$

OP is the osmotic pressure of the solution in terms of the atmosphere and T is the reduction of freezing point in the solution in terms of centigrade degree.

US experts have proposed the following equation for measurement of osmotic pressure of soil saturation extract from the EC:

$$\mathrm{OP} = 0.36\mathrm{ECe} \tag{2.11}$$

where OP is the osmotic pressure of the solution in terms of the atmosphere and ECe is the electrical conductivity of soil saturation extract in decisiemense per meter at 25 °C.

- Soil pH

The pH of saline soils is a function of factors such as the type and composition of exchangeable cations, the type and composition of soluble salts, the presence or absence of gypsum and alkaline carbonates and soil alkalinity. In general, the important factors in raising pH of saline soil are exchangeable sodium and alkaline carbonates.

There have been many studies of the relationship between pH and various soil factors such as humidity, salinity, presence or absence of alkaline carbonates and exchangeable sodium. The results have shown that there is a significant correlation between pH and the above factors. Servant (1975) achieved the following relationship between pH and exchangeable sodium of saline and alkaline soils in the south of France:

$$\mathrm{pH} = 0.7 \log \frac{\mathrm{Na}}{\mathrm{Ca} + \mathrm{Mg}} + 0.67 \tag{2.12}$$

The above correlation cannot be considered definitive, because the correlation between pH and exchangeable sodium is obtained by Chang and Dregne (1955) is 0.84.

Minart and Pascaud (1973), investigating soils without organic matter in the Abdullah plains of Algeria, concluded that not only does the amount of exchangeable sodium, but also the amounts of solute and clay, affect the pH of saline and alkaline soils. They provided a half-logarithmic relationship between these parameters as the following equation:

$$y = a_0 - a_1x_1 + a_2x_2 + a_3x_1x_2 + a_4x_3 \tag{2.13}$$

where y is ESP or exchangeable sodium percentage, X_1 is pH, X_2 is logarithm of the electrical conductivity of saturation extract and X_3 is the percentage of clay in the soil. The coefficients include:

$$a_0 = 52.9 \quad a_1 = 6.68 \quad a_2 = -88.85 \quad a_3 = 12.75$$
$$a_4 = -0.12$$

As can be seen, the function of this relationship is a $_y$ or exchangeable sodium percentage, and pH and other parameters of this equation are variables, so in this way, Exchangeable Sodium Percentage can be calculated using the rate of pH, Clay percentage and saturated paste Electrical Conductivity instead of using difficult laboratory methods for measuring ESP. These laboratory methods are somehow full of problem for saline and sodic soils. The equation can be changed as follows to make pH or X_1 a function and other factors variable:

$$x_1 = \frac{a_0 - y + a_2x_2 + a_3x_1x_2 + a_4x_3}{a_1} \quad (2.14)$$

However, Fireman et al.'s (1954) statistical study of pH of saline soil (pH of saturation paste) obtained the following results:

1. If the soil pH of saturation paste is 8.5 or more, it is a sign that exchangeable sodium will be about 15% or more and there are also alkaline carbonates in the soil.
2. If the soil pH of saturation paste is <8.5, exchangeable sodium will be <15%.
3. If soil pH of saturation paste is <7.5, there are usually no alkaline carbonates in the soil and exchangeable hydrogen is observed in the soils with pH about 7.
4. The electrical conductivity of saturation extract is not usually high in soils with pH of more than 9.

The conclusion from this test is that increasing exchangeable sodium will increase soil pH and as a result, the soil will evolve to intensely alkaline soil.

- Exchangeable cations

Cation exchange plays a major role in the chemistry of saline and alkaline soil, especially in alkaline soils. Sodium and calcium cations are of prime importance in this phenomenon, because these cations influence, respectively, the destruction or improvement of soil structure. If the exchangeable sodium, calcium and magnesium cations are known, not only can the degree of alkalinization be predicted during irrigation with saline water.

Many factors are involved in the absorption of cations, the most important of which are their capacity, diameter, and concentration in the soil solution. Cations of high capacity and low diameter are absorbed by the soil with greater force. Where there is a high concentration of cations in the soil solution, they can be absorbed further into the soil surface in accordance with the law of gravitation.

In general, cations can be arranged in terms of their power absorption by colloids as follows:

$$Ca^{++} > Sr^{++} > Mg^{++} > K^{+} > Na^{+} > Li^{+}$$

The adsorption of soil cations can be interpreted and justified by different laws, such as those of Coulomb or Gappon (1933). Coulomb's law gives the adsorption force of two ions in a solution as the following equation:

$$F = K\frac{l_a \cdot l_c}{d^2} \quad (2.15)$$

where l_a and l_C are respectively the load of anions and cations, d is the distance between them and K is a constant coefficient. Equation (2.15) can be written about cations adsorption by soil colloids as follows:

$$F = K\frac{l_s \cdot l_c}{(rs + rc)^2} \quad (2.16)$$

L_s and l_C respectively are electrically charged colloidal particles and cations, and rs and rc are the radius of colloidal particles and cations. As the load of colloidal particles and cations increases and their diameter accordingly reduces, they absorb each other with more force.

Since the radius of cations such as lithium and sodium is smaller than the radius of calcium, it might be thought that these cations are absorbed with greater force by the soil, but as Fig. 2.7 shows, these cations are water absorbing, so that the diameter of lithium and sodium cations increases and will be greater than the diameter of calcium cations by the amount of water absorbed by them. For this reason, they are actually absorbed with less force by the soil. Therefore, the effective radius of cations (cationic radius adding water shell thickness) should be included in the above equation in place of radius of cations, so it can be used for cationic adsorption in the soil.

Among other more general equations in the investigation of saline and alkaline soils, is Gappen's Gappon (1933), which indicates the reaction of soluble and exchangeable sodium and calcium as follows:

$$\frac{Na_e}{Ca_e} = K\frac{Na}{\sqrt{Ca}} \quad (2.17)$$

where Na_e and Ca_e are exchangeable sodium and calcium in meq per 100 g soil and Na and Ca are soluble sodium and calcium in millioxyvalents per liter, respectively. K is the exchangeable coefficient which varies from 0.01 to 0.25 according to soil type, but it is consistent for a specific soil type and is equal to $(\text{meq/l})^{-1/2}$.

Bower (1954) changed Eq. (2.17) to exchangeable and soluble magnesium as follows:

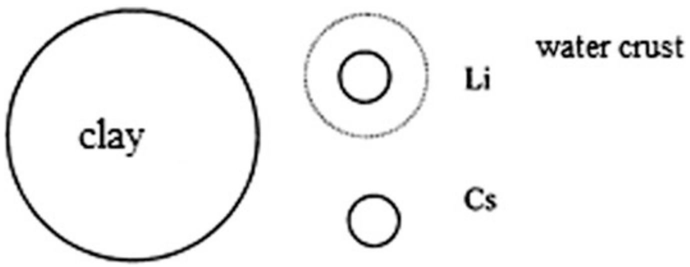


Fig. 2.7 Water retention and non-water retention cations by clay particles

$$\frac{Na_e}{Ca_e + Mg_e} = K\frac{Na}{\sqrt{\frac{Ca+Mg}{2}}} \tag{2.18}$$

Since the amount of exchangeable potassium in saline soils is minimal compared to the exchangeable sodium, calcium and magnesium, it is conceivable that the exchange capacity in saline and alkaline soils is equal to the sum of exchangeable calcium, magnesium and sodium or:

$$T - Na_e = Ca_e + Mg_e \text{ and } T \approx Ca_e + Mg_e + Na_e$$

If instead of $Ca_e + Mg_e$, its equivalent from the above equation is placed in Eq. (2.17), the final equation will read as follows:

$$\frac{Na_e}{T - Na_e} = K\frac{Na}{\sqrt{\frac{Ca+Mg}{2}}} \tag{2.19}$$

The above equation is today one of the best known equations in the chemical analysis of water and saline and alkaline soil. The equation $\frac{Nae}{T-Na_e}$ is known as the exchangeable sodium ratio and $\frac{Na_e}{T-Na_e} = E.S.P$ and $\frac{Na}{\sqrt{\frac{Ca+Mg}{2}}}$ are the sodium absorption ratio.

It should be noted that Eq. (2.18) is true when exchangeable cations and soil solution are in equilibrium; the balance will be disturbed in the case of a change in the concentration of soluble cations. Equation (2.18) shows a direct relationship between the exchangeable sodium ratio and SAR. In the Soil Salinity Laboratory in California Bower et al. (1954) obtained the following equation between the exchangeable sodium percentage (ESP) and SAR of soil saturation extract:

$$\frac{Na}{T} = \frac{100(0.0475SAR - 0.0126)}{1 + (0.0475SAR - 0.0126)} \tag{2.20}$$

This equation can also be used to predict the alkalinity of saline waters in soils after irrigation.

- Dissolution of organic and inorganic materials in the soil

Saline soils contain large amounts of soluble salts. These salts can be effective in the dissolution of organic and inorganic matter in soils, particularly sesquiterpene oxides. In studies on this subject by different specialists such as Antipov-Karataev (1960), it has been shown that alkaline solutions, especially sodium solutes, generally have a major impact on the dissolution of organic and inorganic soil substances. For example, according to Tyurin and Antipov-Karataev (1960), humic acid solubility is different in alkaline solutions as (Fig. 2.8).

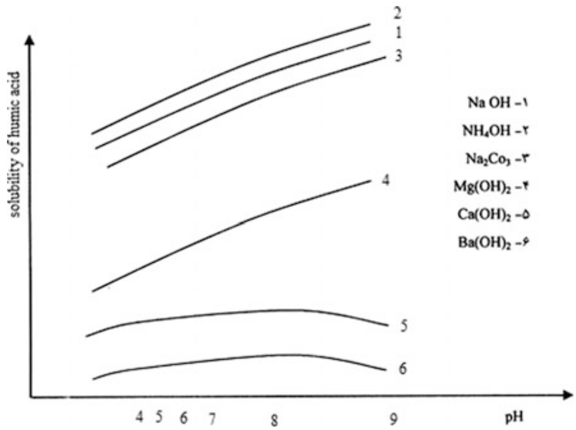


Fig. 2.8 Solubility variations of humic acid in different solutions

Solutes of sodium have a greater effect on humic acid solubility than solutes of calcium and magnesium. It is even thought that humic acid solubility in calcium and magnesium solutes has actually decreased. So that the effect of increasing calcium hydrate, where pH is higher than 9, is that calcium homate coagulates and deposits.

According to Fig. 2.9, the role of magnesium is an intermediate between sodium, calcium and barium, because it is does not affect humic acid dissolution as much as sodium, but its effects are higher than those of calcium and barium. The effect of sodium on the dissolution of organic matter has been observed particularly in alkaline soils. Materials derived from this dissolution are brought to the soil surface due to capillary force and they form fatty black splotches.

Sesquiterpene oxides are dissolved under the effect of alkaline solutes of soil; this is important for the role of sodium salts in the dissolution of aluminum and silica hydroxide which is more observed in degraded alkaline soils.

The impact of sodium salts on the dissolution of these compounds can be observed in Figs. 2.9 and 2.10 (Tyurin and Antipov-Karataev 1960). Sesquiterpene oxides are dissolved in increasing amounts of soda solution. Especially when the

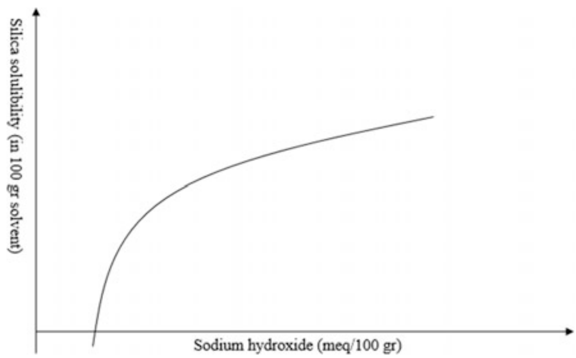


Fig. 2.9 Changes to silica solubility in soda solution

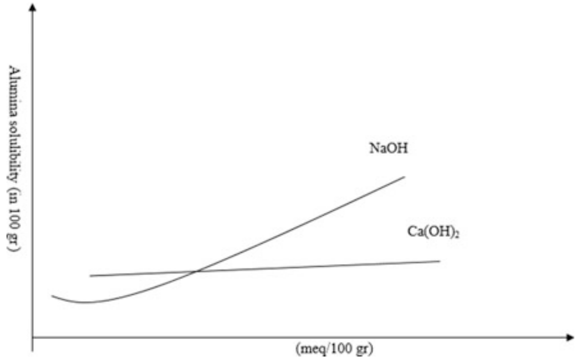


Fig. 2.10 Changes to aluminum oxide solubility in calcium and sodium hydroxide

environmental pH is higher than 8.8, the solubility of aluminum oxide is greatly increased, while calcium ions have no significant impact on its dissolution.

Physical properties

- Colloidal dispersion

The dispersion of colloidal particles in the soil is affected by various factors, including exchangeable sodium. The main reason for this is the impact that cations have on the electrokenetic potential of colloidal particles, or zeta potential. Jenny (1941) showed that when the clay particles are saturated with sodium ions, the zeta potential is greater than when they are saturated by calcium and magnesium. The results of Jenny's experiment (1941) are shown in Table 2.8.

Table 2.8 shows that the zeta potential of the samples that have been saturated with sodium and lithium is more significant than that of the others.

The practical result of the increased zeta potential by sodium cations is Brownian motion and diffusion of colloidal particles as a result of which the soil structure loses stability. The released particles move down from the surface to lower parts,

Table 2.8 Changes of zeta potential by cation type

Cation	Zeta potential (mv)
Li	58.8
Na	57.6
K	56.4
NH_4	56
Rb	54
Cs	51.2
H	48.4
Mg	53.9
Ca	52.6
Sr	51.8
Ba	50.8

causing an accumulation horizon or illuvial. This phenomenon is one of the characteristics of alkaline and solonetz soils.

- The increase of inflation, adhesion and resistance of clay particles

The increase in exchangeable sodium not only causes the release of soil colloids, but it also increases the inflation, adhesion and resistance of clay particles. Demidov's (2007) experiment shows the effect of exchangeable sodium ions on soil inflation (Tables 2.9 and 2.10).

Working in soils with sodium (as a main part of the exchangeable cations) is very difficult, because they are not only very sticky when moistened, but also very rigid and densely multi-faceted after desiccation. Thus, their resistance increases against osmotic pressure (Table 2.11). Sodium ions can alter the mechanical properties of the soil. It is important to consider this point when working with mechanical devices in construction works, especially the laying of roads and foundations.

- Reduction in soil permeability

One of the physical properties of soil is its permeability to water and air. Exchangeable sodium causes an extreme reduction in this property, because clay particles are inflated more than usual, so porosity is reduced. The overall porosity of

Table 2.9 Changes in inflation of clay particles with increase of exchangeable sodium percentage

Exchangeable sodium percentage	0	1.7	3.8	20	21	35	62	100
Volume (5 cc in water)	6.8	6.8	8.5	9.3	22.4	33	33	34

Table 2.10 Changes in adhesion of soil particles depending on exchangeable sodium percentage

Exchangeable sodium percentage	0	17.5	21	22.5	57	100
Adhesion (g cm^{-2})	15.7	202	240	252	430	529

Table 2.11 Soil resistance and exchangeable sodium percentage

$\frac{Ca}{Na}$ ratio	$\frac{100}{0}$	$\frac{96}{4}$	$\frac{92}{8}$	$\frac{82}{18}$	$\frac{70}{30}$	$\frac{48}{52}$	$\frac{24}{76}$	$\frac{0}{100}$
Soil resistance (kg cm^{-2})	128	128	138	143	152	160	180	183

Table 2.12 Soil permeability and exchangeable sodium percentage

$\frac{Ca}{Na}$ ratio	$\frac{100}{0}$	$\frac{98}{2}$	$\frac{89}{11}$	$\frac{57}{43}$	$\frac{30}{70}$	$\frac{0}{100}$
Relative permeability	100	80	37.5	25	0.8	0

alkaline soils may reach 40–60%, but its permeability is very low due to the presence of sodium and may be reduced by up to 10^{-5}–10^{-6} cm per s. When exchangeable sodium reaches about 15–20%, soil permeability decreases rapidly (see Table 2.12).

- Physiological dryness

Soil salts have a high impact on the soil moisture regime in terms of quality and quantity, because on the one hand, they increase osmotic pressure of soil solution, and on the other hand, if they contain exchangeable sodium, it destroys physical properties and structure of the soil and prevents water and air movement.

The increase in osmotic pressure prevents water uptake by the plant, because the maximum suction force of a plantabsorbing water from the soil is usually 15 atmospheres. In other words, if the entire suction force of the plant roots is used to absorb water, it does not exceed 15 atmospheres. But if there are salts in the soil, inevitably a proportion of the root suction force is used to counteract the osmotic pressure of the soil solution, so the maximum force for absorbing water will be <15 atmospheres.

For example, if it is assumed that the electrical conductivity of the soil saturation extract is equal to 25 dS m^{-1}, the osmotic pressure of the soil solution increases by up to 9 atmospheres according to the formula $OP = 0.36ECe$. It is clear in this case that 9 atmospheres of the maximum suction force of the roots is used to counteract the osmotic pressure of the soil solution and water can be absorbed only by 6 atmospheres (15–9 = 6) from the soil by the plant in the wilting point. For this reason, while there is enough moisture in the soil, the plant cannot use it appropriately, because the soil reaches wilting point earlier and a type of synthetic or physiological dryness is created.

On the other hand, if the soil contains exchangeable sodium, the permeability and capillary speed of water will be reduced due to the dispersion of colloidal particles. The moisture surrounding the plant's roots is absorbed by water in these soils, but cannot reach lower segments in time. As a result, the soil around the roots dries out quickly, resulting in a wilting or dying plant, even though the average moisture of the soil may be sufficient.

2.2.6.6 Moderating Factors of Salt Effects on Soil

Soil texture. Sandy soils have a lower moisture-retaining coefficient and exchange capacity, but greater permeability. Clayey soils have a higher moisture-retaining coefficient and exchange capacity, but lower permeability. Texture is therefore important in the salinization and alkalization of soil. As the water content in the soil increases (whichever of moisture-retention coefficient or saturation point is the greater), the concentration of salts is reduced by an equal amount. For example, if we assume that the percentage of salts in dry soil is equal in clayey and sandy soils, the salt concentration in the saturation extract of sandy soil will be greater than in clayey soil due to its saturation percentage, so the electrical conductivity of saturation in sandy soils is higher than in clayey soils. Thus saline sandy soils are theoretically more harmful than saline clayey and limon soils. As the increased concentration of salts in sandy soils cannot inhibit plant growth, it is better to increase irrigation time in these soils. Sandy soils can also be modified earlier and their salts can be leached.

Soil alkalization that occurs as a result of the reduction in permeability caused by exchangeable sodium absorption differs between clayey or sandy soils, because sandy soils have a reduced exchange capacity and greater permeability. For this reason, a given amount of exchangeable sodium does not have the same effect on sandy and clayey soils. For example, the permeability of a sandy soil with 50% exchangeable sodium may be as high as the permeability of a clayey soil with 15–20% exchangeable sodium. Generally, sandy soils become saline earlier and become alkaline later. In contrast, clayey soils beoame saline later and alkaline earlier.

Colloidal particle area and mineralogical property of clay. Clay can quite effectively modify the physical properties of saline and alkaline soils in terms of the reaction with exchangeable sodium. Barshad and Kelly (1961) found that there is usually more than 30% montmorillonite clay in saline soils, but at the same time, they may also contain about 5–30% of mineral colloids such as colloidal calcium carbonate, colloidal feldspar and so on. There is not usually a large amount of montmorillonite in alkaline soils and solonetz, however they contain a lot of amorphous mineral colloids.

In soil containing 25–40% exchangeable sodium, permeability is higher than the value that such soils must have. Studies have found that these soils contain high levels (40–50 meq l^{-1}) of soluble silicates such as potassium which reduce the phenomenon of inflation and dispersion of clay particles by sodium ions.

Organic matter not only maintains soil structure, but also increases density and thus its permeability. Therefore, it can reduce the inappropriate effects of exchangeable sodium in the soil.

Some pedology and irrigation specialists have reported the importance of anions of irrigation water and soil solution in the destruction of soil properties. If sodium ions are present with anions such as carbonate, bicarbonate and silica, they can be replaced completely with exchangeable calcium. The reason is that in combination with the above anions, calcium anions become insoluble, their activity is diminished and they are deposited in the soil. The effect of sodium ions increases, making the soil more alkaline, but sodium chloride and sulfate do not alkalize soil so deeply because the reaction is irreversible.

2.2.6.7 Classification of Saline Soils

Saline soils (basically any type of soil) can be classified in two ways: first, genetically; and second, in terms of their agricultural potential and irrigation capacity.

Salts in saline soils change the soil in terms of quantity and quality, and the physical, chemical and morphological properties of the soil, advancing their evolution in a particular direction. Climatic factors also have a major impact on the evolution of these soils.

There is little difference in the definition of saline soils between typical classifications such as American, French, Russian and FAO, the differences being more about sub-classes or groups. For example, saline soils are in an independent class in the French classification, but may belong to steppe or desert soils in the Russian classification depending on the conditions.

The most important diagnostic horizons of saline soils are salic, argillic and nitric. In the salic horizon, the various salts consisting of the anions of chloride, sulfate, carbonate and bicarbonate and cations of sodium, calcium and magnesium are usually observed as a stratum or salty masses, spots and salty crystals. For a horizon to be called salic, the proportion of salts must be more than 2% or the multiplication of its thickness in cm, and the percentage of soluble salt greater than 60. Saline groundwater, environmental evapotranspiration and soil texture contribute to the formation of this hori.

The argillic horizon is not specific to saline soils, but because it is observed in some saline soils with high exchangeable sodium, it can be considered one of the diagnostic horizons of saline soils. This horizon is formed by the movement of clay particles from the upper to the lower horizon, where they congregate. To move clay particles into the lower depths requires seams and cracks to be created in the soil, which does not occur unless the soil is dry for a whole year.

The main characteristics of the argillic horizon are:

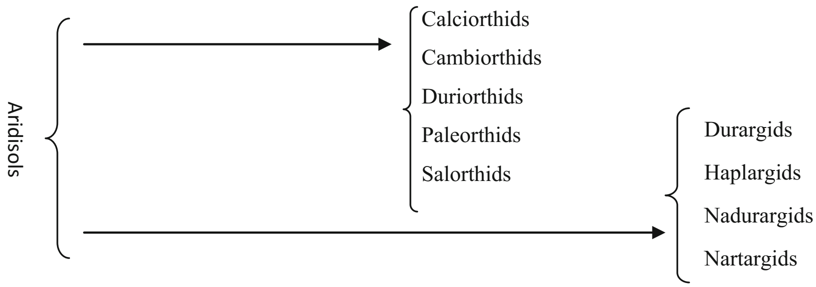
1. If the surface horizon (eluvial horizon) is not destroyed by erosion and the contour between the two horizons is clear (sometimes the two horizons overlap so the contour is not clear), the clay in the argillic horizon should be finer than in upper horizons provided that it contains the following characteristics:
   - If the percentage of clay particles in the eluvial horizon is <15, the argillic horizon should contain at least 3% more clay.
   - If the amount of clay in the eluvial horizon is more than 15% and <40%, the proportion of clay in the argillic and eluvial horizons should be greater than 1/2.
   - If the amount of clay in the eluvial horizon is more than 40%, the argillic horizon must have 8% more clay.
2. If the total thickness of the eluvial and argillic horizons is more than 150 cm, the thickness of the argillic horizon should be at least 0.1 times the total thickness of these horizons (at least 15 cm or more).
3. In compacted soils, clay particles form a bridge between the sand particles and coat the pores.
4. In this horizon, some soft clay forms a glossy coating on the structure blocks; if the blocks were broken, the coverage would be considerably better. The Argillic

horizon starts from the point where clay particles for coverage have easily covered the structure blocks of the soil.

The natric horizon is a particular kind of argillic horizon with the following additional characteristics:

- columnar or prismatic and rarely blocky structures.
- exchangeable sodium more than 15% of the exchangeable capacity.

Saline soils belong to the aridisols category in the *new American classification* of saline soils. This category contains the two subclasses of argids and orthids, depending on the presence or absence of a diagnostic argillic horizon. Each subclass is also divided into the number of large groupsas follows:



The salorthids (derived from the Russian word *solonchak*) class has no argillic diagnostic horizon. In addition to the main characteristics of the soils in arid regions as well as the orthids subclass, the morphological characteristics are as follows:

- It has a salic horizon one meter deepth in soil profile.
- It has gypsic and calcic horizons above the salic horizon.
- It has no hardpan horizon which its upper limit is located between one meter depth below the soil surface.

The natrargids class has, in addition to the general characteristics of the aridisols and argids subclasses, a natric horizon (Fig. 2.14). The naduragids class shares similar characteristics with soils of the natrargids class, with the difference that there is a hardpan below the natric diagnostic horizon and the upper limit of the hardpan is usually one meter below the soil surface. This class should be considered a special case of the natrargids class.

Each of above large classes is divided into different subgroups and categories according to other conditions such as high humidity, changes in organic materials, and others. Although saline soils may exist in other classes in the US classification, typical saline soils are essentially found among the aridisols.

The *Russian classification*, which is partly based on the work of Dokuchaiev and his disciple (1898), is based on genetic characteristics, physical and chemical properties and genetic phenomena of soil formation and in this respect is somewhat similar to the French classification. In this scheme, steppe soils include typical steppe soils (chernozem, turf chernozem and oak chernozem), typical turf soils, humid turf soils, solonetz (steppe solonetz and turf solodized solonetz), and solonchak (solonchak and steppe). Desert soils include semi-desert brown, desert brown-gray and desert turf brown, Takyr, desert solonetz (desert solonetz and desert turf solonetz), and desert solonchak.

Saline soils are in an independent class in the *French classification*. This system, initiated by Aubert (1962), is dependent on the degree of profile development and its genetic characteristics and in fact, it coincides with the crucial points of American and Russian classifications.

Aubert (1962) categorized saline soils according to their construction. Entirely saline and alkaline soils that have not been destroyed and salinized are divided into the two categories of saline and saline-alkaline soils.

Saline soils

There are a lot of salts in these soils. According to the studies and suggestion of Scofield (1942), electrical conductivity of soil saturation extract is greater than 4 dS m^{-1}. The exchangeable sodium of the soil is <15% of the exchange capacity and pH is <8.5. French and North African soil scientists believe that 4 dS m^{-1} salinity of soil saturation extract is not sufficient as the limit of salinity and it is advisable to increase up to 7 dS m^{-1}. The French approach is more accurate in countries like North Africa and Iran which are in arid climate and saline soil and where water has been used for agricultural purposes for many years. Chemical properties of soils depend on their soluble salts. High amount of salts in these soils increase osmotic pressure of soil solution and provide an unsuitable environment for growing plants due to disturbance of the ionic balance and the existence of harmful ions such as boron. For this reason, only tolerant plants can grow in these soils, therefore, plant population is a discontinuous community and the amount of organic matter and humus is extremely low in the soil (not exceeding 1–2%). Important anions in these soils are constituted of chlorides and sulfates, but sometimes a small amount of carbonates and even nitrates is also observed in them. The major cations in these soils are constituted of calcium, magnesium, sodium and sometimes potassium. The combination of exchangeable cations depends on the combination of soluble salts in these soils. Because the soluble cations of these soils are formed by the above-mentioned cations, naturally these cations constitute exchangeable cations in different ratios. Nevertheless the exchangeable sodium is <15% of exchange capacity of the soil.

The salts mentioned come up to soil surface in arid and semi-arid areas under the influence of capillary force and form a salty cortex. The thickness of the cortex may reach 5–6 cm. As the cortex is white in color, Hilgard (1907) named them white alkali. The strata have a dense and impermeable structure with different chemical composition and may be constructed of sulfate, chloride and lime strata or a mixture of mentioned compounds. The presence of high electrolytes in these soils causes coagulation of colloids and stability of their structure, thus clay and aluminosilicate particles of the soil have not been transferred to the lower classes. Physical and chemical experiments confirm the theory. Overall, their physical properties, particularly permeability, are more appropriate than similar soils. Nevertheless, some saline soils that have developed more or less into alkaline soils, are inappropriate in terms of physical properties and permeability. These soils are called solonchaks (from *sol* meaning salt and *chak* meaning soil).

Saline underground waters have a tremendous impact on the formation of solonchaks. The intensity of salinization in these soils differs according to the composition and water depth. Kovda (1967) divided solonchaks into three types. If the depth of groundwater table is low and directly involved in soil salinity, the soil is called *hydromorph*. If the depth of groundwater table is high and cannot directly affect on soil salinity, and soil is salinized often under the influence of irrigation with saline water and other factors, the saline soil is called *automorph*. If the depth of the groundwater table is not very high—between the two—soil salinity will occur due to the impact of groundwater table, irrigation with saline water and/or other factors. For this reason, these soils are called *semi-hydromorph*.

Saline soils can also be classified according to type of salt apart from their genetic and morphological classification. Classification of soluble salts or electrical conductivity of saturation extract soil was stated for the first time by the US Soil Salinity Laboratory (Table 2.13).

The Russian classification is not based on the total amount of soluble salts, but it also divides soils into different groups according to the type of anions and cations in the soil. Kovda (1967) classified saline soils as follows:

- *Sulfate solonchaks*: There is a large amount of sodium, magnesium and calcium sulfates in them.
- *Chloride solonchaks*: They contain sodium, magnesium and calcium chlorides.
- *Nitrate solonchaks*: They often contain sodium and potassium nitrates.
- *Sodic solonchaks*: Their soluble sodium is very high. It can be said that they constitute a type of saline and alkaline soil.

Sadonikov divided saline soils in terms of the rate of $\frac{CI}{SO_4}$ (see Table 2.14).

Rozanov and Ivanova classified saline soils by taking the ratio of soluble cations (Table 2.15).

It should be recognized that when the ratio of soluble sodium to soluble calcium and magnesium cations increases, the soil will develop to alkalization. Therefore,

Table 2.13 Classification of saline soils in terms of electrical conductivity of saturation extract soil

Soil type	Electrical conductivity of saturation extract in dS m^{-1}
Non-saline soil	<2
Soil with low salinity	2–4
Soil with moderate salinity	4–8
Soil with high salinity	8–16
Soil with very high salinity	>16

Table 2.14 Sadonikov's classification for saline soils

Soil type	$\frac{Cl}{So_4}$
Chloride saline soil	>5
Chloride-sulfate saline soil	1–5
Sulfate-chloride saline soil	1–0.2
Sulfate saline soil	<0.2

Table 2.15 Classification of Rozanov and Ivanova for saline soils

Soil type	$\frac{Na+K}{Ca+Mg}$
Sodic saline soils	>4
Sodic and magnesium saline soils	$\frac{Ca}{Mg} < 1$ with $1 < \frac{Na+K}{Ca+Mg} < 4$
Sodic and calcic saline soils	$\frac{Ca}{Mg} > 1$ with $1 < \frac{Na+K}{Ca+Mg} < 4$
Calcic saline soils	$\frac{Ca}{Mg} > 1$ with $\frac{Na+K}{Ca+Mg} < 1$

sodium solonchak in Kovda's classification and sodic saline soil in Rozanov's classification are usually a type of saline and alkaline soil. Soluble sodium of saline soils constitutes <50% of total cations in the soil solution. However, knowing the ionic relationship anionic combination in saline soils is very important in modifying them as well as the plant and salinity relationship, and for complete success in implementation of reform plans for saline soils, it is necessary that these relationships are studied and then reform plans are implemented by considering these relations.

Saline and alkaline soils

The electrical conductivity of the soil saturation extract is more than 4 dS m^{-1}, exchangeable sodium is more than 15% of exchange capacity and pH is <8.5, except when the amount of soil soluble sodium is very high compared to other cations. These soils consist of a combination of salinization and alkalization phenomena. Their properties are usually similar to those of saline soil. So their structure is appropriate at first, but if they are leached, salts are washed but sodium ion is hydrolyzed and it produces sodium hydroxide or with CO_2 in the soil causes the formation of sodium carbonate that leads gradually to severe alkalization of soil and then the clay particles are dispersed and transmitted down into the soil profile. Amendment of these soils is more difficult than saline soils, since their minerals solutes must be washed out of the root zone and amendments such as calcium compounds must be added to cause the coagulation of clay particles and thus to prevent their distribution in the effect of leaching. Leaching these soils should be performed gradually and frequently.

Saline and alkaline soils sometimes contain gypsum, therefore if they have been gradually leached, exchangeable sodium is replaced gradually by calcium ion and their structure is improved. These soils are in parts of Iran such as Qazvin Plain, Khuzestan, Khorasan and the south of the country.

Soils where construction has been destroyed are divided into alkaline soils and degraded solonetz or solod, depending on the degree of evolution and leaching that has occurred.

Alkaline soils

The electrical conductivity of the soil saturation extract is <4 dS m^{-1} in 25 °C, but exchangeable sodium is more than 15% of exchange capacity. Their pH usually varies between 8.5 and 10 and even up to 11. These soils are called solonetz in the Russian classification (from *sol* meaning salt and *netz* meaning low).

The important anions in these soils include chloride, sulfate, bicarbonate and carbonate, therefore the majority of soluble calcium and magnesium deposit and exit from the environment. So sodium is the most important cation in these soils. The formation of these soils is usually associated with the creation of sodium carbonate. This chemical compound is a strong alkali which is readily hydrolyzed. For this reason, pH of the most typical alkaline soils may reach 10 or even 11. So the physical properties of soils decay severely under the influence of sodium ions and their permeability is decreased, because the clay particles and colloids of the soil are dispersed and transferred to the lower layers, where they form a dense clay horizon. Some of the soil colloids have also been destroyed under the influence of micro-organisms, water, carbonic acid and other alkaline salts. This phenomenon occurs when almost all the soluble salts of soil are washed, since soluble salts can coagulate soil particles.

Soil organic matter saturated to a greater or lesser extent by sodium is dissolved and released in the soil profile. Part of it reaches the soil surface under the effect of capillary forces and is deposited there in the form of black fatty marks. Accordingly, Hilgard (1907) called these soils black alkali.

Due to the severe reaction of alkali, silica is converted in the form of alkaline silicates, especially sodium silicate, and released in the soil profile. Some iron and aluminum is also released in the soil solution. However, soil colloids which have been washed from the surface horizons have knocked up with unwashed salts within the soil profile and coagulated and then constituted an accumulation or illuvial horizon. In general the profile morphology of a solonetz is as follows.

- A: Washed or eluvial horizon that is light to dark gray color depending on the amount of humus. Its construction is laminate and sometimes cement or spongy. The thickness of this layer may vary from 5 to 25 cm depending on the type of solonetz.
- B: Cumulative or Illuvial horizon has a columnar or prismatic construction. The diameter of the columns may reach 5–10 cm and its height may reach 10–20 cm. The upper parts of the columns are more or less circular. Some columns break into smaller cube-shaped units from 10 to 20 cm in size. The color

of the columns is dark brown to black-brown and is related to the dissolution of organic matter and its transmission in this horizon. The horizons are extremely compact when they are desiccated. This is due to the cementation of mineral and organic colloids which have been accumulated in the horizon. This horizon's pH is greater than 9 and its exchangeable sodium constitutes more than 20% of exchange capacity.

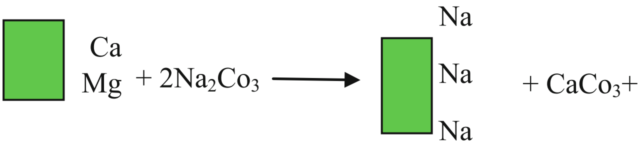
C: There is a salt aggregation layer in the above sub-class in many cases. Gypsum and sodium sulfate are usually greatest among the salts, but chlorides may also be found. The horizon color is brighter than the two previous layers due to the presence of high salts and its thickness may range from 50–70 cm to 2–3 m that gradually attaches to the original stone.

Solonetz often contains calcium carbonate in the form of small spots and parts and they are called white eyes of solonetz and may be seen in the middle or lower part of the columnar horizon. The thickness of the layer with patches of calcium carbonate may also reach one meter. Solonetz is more likely to be observed in Azerbaijan, Kerman and the vicinity of Gorgān and the Turkmen Sahra.

The main reason for the emergence of solonetz is the leaching salts of saline and alkaline soils, because it often happens that saline soils and especially saline and alkaline soils are naturally exposed to leaching and as a result, their salts are washed and lost. This phenomenon is called elimination of salts in the soil or desalinization. The reason for this varies; it is sometimes related to precipitation and increased air humidity and sometimes to fluctuation of groundwater levels. We know that groundwater is one of the main factors in the formation of saline soils. So when groundwater levels are lowered sufficiently, salts are also transferred to their lower limit due to water movement in the soil profile. Depending on the rate of leaching or descending groundwater, as well as the degree of salinity and type of solutes in the soil, removal action may be performed in the following ways.

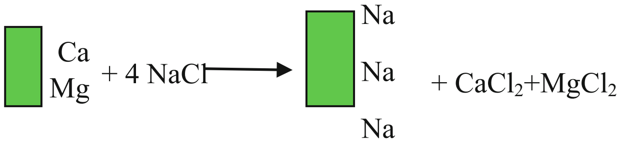
(a) *When gypsum is present in the soil*. If soils containing chalk are exposed to leaching, primarily more soluble salts of them such as sodium and magnesium compounds are leached and removed from the soil and then calcium sulfate is gradually transmitted to the lower parts, but during the leaching, calcium cations derived from partially dissolved gypsum in the soil solution are replaced with sodium and magnesium exchangeable cations, and improve soil structure accordingly. If the groundwater level has been controlled so that it does not rise again and does not cause secondary soil salinity, the soil will gradually find its own initial evolution (for example chernozem, oak and brown) and the plant community will change over time.

(b) *When there are carbonate anions and sodium carbonate in the soil*. One of the main sources of exchangeable sodium in alkaline soils is sodium carbonate, which is formed by various factors. If these soils are exposed to leaching, sodium is strongly absorbed by soil colloids. This exchange can be shown schematically as follows:



Calcium and magnesium carbonates are insoluble, especially in an alkaline environment, and deposit quickly. After the above reaction is carried out thoroughly, sodium of sodium carbonate almost entirely replaces exchangeable calcium and magnesium cations. The result obtained from this reaction is the formation of alkaline soils and solonetz.

(c) *When there is sodium chloride in the soil solution*. When sodium is present in the soil solution in the form of neutral salts such as sodium chloride, the alkalization phase of soil is more or less different from what has been stated above. The reaction occurring between sodium chloride and exchangeable calcium is shown as follows:



Because the compounds of $CaCl_2$ and $MgCl_2$ are soluble, the reaction is reversible. So sodium changes only a part of the soil exchange cation, but since calcium and magnesium chloride are constituted from completely dissolved salts, they are emitted by leaching from the soil. So again soil proceeds toward alkalization over time.

(d) *Degraded alkaline soils or solod.* These soils are the advanced stage of solonetz found in lowlands which receive a large amount of precipitation and current water from upstream areas and as a result, the soil is wet for a period of years. Some salt is washed and removed in each rainfall and thus sodium ions have been highly hydrolyzed and the soil structure destroyed, but exchangeable hydrogen occupies the place of other soil cations in surface horizon due to leaching. Due to the degradation, colloids, alkalines and oxides sesquiterpene of soil are washed and descend to lower layers and they constitute a cumulative horizon (illuvial) associated with clay particles already transferred there. The soluble part is transferred to surface and deposited as cement due to the evaporation. This phenomenon is seen especially in the case of iron and manganese oxides. In fact, these bodies have been restored in the lower part of the soil profile due to soil saturated by water and then moved up by the upward movement of water and oxidized and deposited in the surface parts.

The schematic profile of a Solod is as follows:

A_1: A grey washed humus class with 6–10 cm thickness.

A_2: A white silica class that is quite similar to A2 podzols. The thickness of this class is 10–20 cm. Its pH is often acidic and usually contains a sesquiterpene oxidant that have been turned into cement.
B: It is a cumulative layer or illuvial that is the center of clay particles and sesquiterpene oxidant accumulation and the evidence of columnar structure of solonetz have also been seen. The lower part bubbles in acid that it is as a result of the presence of calcium carbonate.
C: The solutes accumulation layer that attach with parent rock. Solod morphology is similar to podzols and therefore these soils are initially called podzols of saline soils.

Analytic classification of saline and alkaline soils

This classification is based on chemical analysis of soil and does not relate to its morphology, because as we have seen, the two variables of salinity or electrical conductivity and exchangeable sodium percentage can be called the basic variables of saline and alkaline soils. According to them, soils have been divided in terms of salinity and alkalinity. But measuring the exchangeable sodium accurately is not easy and that is why there is a direct relationship between the percentage of exchangeable sodium and the sodium adsorption ratio of the saturation extract. Instead of measuring the exchangeable sodium, sodium adsorption ratio of saturated extract can be measured which is easier and more reliable, and saline and alkaline soils can be classified in accordance with Table 2.16 using this variable and the electrical conductivity of saturated extract.

Saline soils, due to factors previously mentioned, evolve into solod soils. Desigmand identifies five evolution stages as follows:

1. Salinization stage or primary stage of saline soils formation created by solute accumulation in the soil.
2. Alkalization stage effected by sodium absorption by soil colloids.
3. Desalinization stage leading to leaching and loss of soil soluble salts.

Table 2.16 The classification of saline and alkaline soils

Electrical conductivity of saturation extract at 25 °C	Sodium absorption ratio		
	0–4	4–10	>10
0–2	–	Non-saline soil but with low alkalinity	Alkaline soils or solonetz
2–4	Soil with low salinity	Soil with low salinity and alkalinity	
>4	Saline soil or solonchak	Saline soil with low alkalinity	Saline-alkaline soils

4. The destruction of soil colloids (degradation) which is the replacement of exchangeable sodium by hydrogen and the acidification of the environment as a result of the continuous leachingin the soil.
5. The re-accumulation of salts in the soil (de-degradation), a phenomenon causing a re-accumulation of salts in the soil.

So if non-saline soil has been exposed to saline solutes, it will not only be saline, but may also advance to solod. Generally, the gradual evaluation of non-saline soil to solod is as follows: non-saline soil, solonchak-saline soil, solonetz, solod.

2.2.6.8 Plant Response to Soil Salinity

The most significant plant response to soil salinity is growth reduction. By increasing the concentration of salts in excess of the tolerance threshold, the growth rate is reduced and the size of plants is miniaturized. Tolerance threshold or plant resistance threshold is the concentration of soluble salts in the soil beyond which yield will be reduced. The threshold of resistance and growth rate reduction depends on the type of plant species.

Soil salinity affects physiological activities of plant in several ways, but signs of damage due to existence of salinity are usually found when the concentration of soluble salts is very high in the soil. Generally, salinity limits the growth and the performance of plants in three ways. The first and dominant effect is related to the total soluble salts in the soil which causes osmotic potential. By decreasing osmotic potential, the free energy of water is reduced and the plant should use more vital energy to gain a certain amount of water. Therefore a part of the energy required for growth and development is spent obtaining water and thus general growth will decrease. This effect is called the osmotic effect. The second effect is related to the existence of certain ions in the soil solution. Ions such as chloride, sodium or boron can individually and directly cause toxicity and disrupt the mechanisms of plant uptake. The soil may be not saline, but the plant is poisoned by increasing the relative concentration of one of these ions in the soil solution. If the soil is saline and the relative frequency of these ions is high, the plant will suffer from ionic toxicity in addition to damage caused by salinity. This is called the specific ionic effect or exclusive ionic effect. The third effect is actually created by the second type which caused nutritional imbalance. This means that the presence of sodium, chlorine and so on in large quantities leads to disturbance of the balance of nutrients in the soil solution and finally of the absorption and transport of essential nutrients such as calcium, potassium and magnesium from the soil to the plant.

The effect of salinity on germination. Leguminous plants (except alfalfa), corn, sugar beet, wheat, alfalfa, rye, oats and barley have from the lowest to the highest resistance respectively. In very high concentrations, barley germinates perfectly but wheat has 50% reduction in yield and Trifolium does not germinate in general. saline

Effect of salinity on plant growth. There are the following correlations between solute concentration and product loss:

1. Plant products are reduced by increasing the concentration of soluble salts in the nutrition environment of the plant.
2. The effect of salt concentration is different on the vegetative and reproductive growth of the plant. For example, when the concentration of soluble salts increases from 0 to 0.9%, the product reduction for straw (vegetative) is 25% and for barley grain (reproductive) is negligible, but it is vice versa in tomato.
3. Different plant varieties show different reactions in the face of increasing the concentration of soluble salts.
4. The toxic effects of soluble salt concentration on plant depends on the type and grade of salt toxicity.

Resistance mechanism to salt in halophytes. Plant responses to soil salinity differ widely. Some of halophytes are relatively unaffected by high soil salinity. These plants modify high salinity in the soil solution by the osmotic method and often through the absorption and accumulation of soil salts. In response to high salinity, salts accumulate in root cells, causing the establishment of water flow from the soil to the root. Special features of organs in these plants allow them to store of salts in plant cells without damage. The appearance of these characteristics may be coincidental but it is certainly hereditary and will be seen in the plant by cultivation in saline environment after 4 or 5 generations and resistant crop plants can be isolated by natural selection (Table 2.17).

Shakhov proposed two methods to create resistance: choosing the seed of productive and succulent plants; and soaking seeds in salts solution before planting. In

Table 2.17 Changes in salinity tolerance and diversity of tolerance mechanisms in some plants

Plant	Resistance level (Mmol)	Resistance mechanisms
Bean	40	Sodium excretion, transition of leaves sodium to roots
Rice	40	Sodium excretion, sodium storage in older leaves
Corn	60	Sodium excretion
Wheat	140	Partial sodium excretion, storage of sodium in leaf vacuoles
Barley	200	Controlled removal of sodium, sodium storage in leaf vacuoles
Diplachne fusca	313	Sodium storage in the vacuole and salt tubers
Atriplex canescens ssp. Canescens	350	Sodium storage in salt bags and salt tubers
Distichlis palmeri	600	Sodium storage in salt bags and salt tubers
A. canescens ssp. Linearis	700	Removal of most sodium than canescens subspecies
Salicornia bigelovi	More than 720	Succulent and absorbing too much sodium

Table 2.18 Resistance to salinity of selected plants

Scientific name	Salinity threshold (dS/m)	Line slope	Tolerance degree
Hordeum vulgare L.	6	7.1	MT
Avena sativa L.	–	–	T
Agrostis stolonifera L.	–	–	MS
Cynodon dactylon L. pers.	6.9	6.4	T
Bromus marginatus	–	–	MT
B. inermis Leyss	–	–	MT
Pennisetum ciliare (L.)	–	–	MS
Poterium sanguisorba L	–	–	MS
Phalaris arundinacea L	–	–	MT
Trifolium hybridum L	1.5	12	MS
T. alexandrium L	1.5	5.7	MS
Melilotus alba Dest	–	–	MT
Trifolium repens L	1.5	12	MS
T. resupinatum L	–	–	MS
T. pretense L	1.5	12	MS
T. fragiferum L	1.5	12	MS
Festuca elatior L	3.9	5.3	MT
Alopecurus pratensis L	1.5	9.6	MS
Eragrostis sp	2	8.4	MS
Secale cereale L	7.6	4.9	T
Dactylis glomerata L	1.5	6.2	MS
Lolium perenne L	5.6	7.6	MT
Sesbania exaltata (Raf)	2.3	7	MS
Lotus pedunculatus Cav	2.3	19	MS
Agropyron sibiricum	3.5	4	MT
A. cristatum (L)	7.5	6.9	T
A. elongatum	7.5	4.2	T
Elymus tricoides Bucki	2.7	6	MT

Note S sensitive; *MS* moderately sensitive; *T* tolerant; *MT* moderately tolerant

the former Soviet Union, a large area of land was under cotton cultivation where seeds were soaked for an hour in a brine solution and three hours in distilled water. As a result, seed germination, flowering and maturity of product were 4–6 days earlier and production increased 41%. Increasing the amount of protein increases resistance to salinity.

Table 2.18 shows the reduction threshold and line slope for some pasture species. It is difficult to apply a standard method to plants grown in different climates and conditions. Moreover, the figures were obtained from experiments where soil salinity is kept as constant as possible in the root zone from germination to maturity. The numbers cited in the table are only a general guide to estimatg the relative resistance of plants to salinity. Actual tolerance of a species will change depending on climate, soil type and agricultural operations. The quality rating of plant resistance is based on the shape.

2.3 Vegetation Cover in Arid and Desert Areas

2.3.1 Generalities

The dominant plants in arid and desert regions include bushes, short shrubs and herbaceous annuals with sparse and non-condensing vegetation. There is no evidence of vascular plants in desert hyper-arid regions. In some parts, a single vegetative form constitutes the vegetation cover of the region, while various vegetative forms are seen elsewhere. In many arid and desert regions, vegetation cover is limited to streams resulting from the floods. Generally, about 50% of vascular plants in desert areas are therophytes or annuals. Of course there are exceptions in some areas. For example, in the desert region of Southern California, annual plants constitute only 25% of all flora.

In areas where summer rains are common, the seeds of some annual plants germinate after the first rainfall. The lifetime of these plants has ended 6–8 weeks before facing drought, thus most of their life in every year is as seed and in sleep mode. This group of plants is called summer or short-lived annuals (ephemerals); they have short roots and are not resistant to drought in terms of morphology (appearance characteristics). Another group of annuals begin to grow when autumn or winter rains begin. These plants have a longer growth period, grow taller and finish their last phenological stages in the spring when the rain stops and the temperature rises. These plants are classified as winter annuals and grow bigger in subtropical climatic conditions. The characteristics of annuals and other plants of arid and desert areas include variable plant longitudinal growth from year to year depending on the amount and frequency of rainfall, and high heterogeneity in seeds. This means that some seeds germinate quickly due to rainfall, while others need time or more rain to wash the growth hurdle from the seeds' surface. This and other factors cause the preservation and maintenance of the rogue and adverse natural desert vegetation agents prevailing in these regions.

Another type of vegetation that can be seen in limited areas of the desert is succulent plants. These plants, such as cactus, have leaves or stems with abnormally thickened parenchyma that are swollen by moisture absorption during rainfall. By the onset of the dry season, they reduce their perspiration rate and use water stored in their organs until they get the opportunity to fill their organs up again with moisture. These plants have a special metabolism which means the stomata remain closed during the day. A network of surface roots enables these plants to make use of very low rainfall. Some plants even produce awns during the short rainy season to make the best use of poor and limited rains.

Because most annuals have a short lifetime before apparently disappearing and succulents exist only in limited areas of the deserts of the world, it is shrubs that dominate arid and desert areas. These plants have deep roots and use underground moisture; some have surface roots and receive moisture from the scarce and limited rain typical of these areas. The ratio of root to stem is high: sometimes six to one. The leaves are blade-shaped and very small to prevent evaporation from the surface and shoots are usually covered by wool or hair. The leaves of these plants usually fall completely or partially. These plants keep their stomata closed during the day and can reduce evapotranspiration to a minimum. The stems of these plans are usually prickly and green to photosynthesize in the absence of leaves. Generally, the sequence and frequency stages of desert vegetation are slow. This is because plant communities are often scattered and the shadows that are an important factor in the emergence and establishment of a large number of plants are only created in these regions after many years.

Ecologists have identified three types of plants according to adaptation (Fig. 2.11). In the soils of arid areas, mesophytes (adapted to wet soil conditions) and xerophytes (able to withstand dry conditions for long periods) rely on moisture from rain or permanent underground water. Plant response to soil water conditions is shown in Fig. 2.11.

Most soils of arid regions contain a limited amount of moisture, so that adequate rainfall increases the negligible moisture content at field capacity. The amount of the moisture coefficient varies according to soil texture: about 19.6% in loamy soil, higher in sandy soil and lower in clay soil. If there is natural drainage, excess moisture will be extracted from the soil and in the case of limited natural drainage, the moisture content will increase up to full saturation of soil (50%) when the water table is at ground level. Excess water can be accumulated on the surface. Hydrophytic plants can live at this moisture level until moisture content is reduced

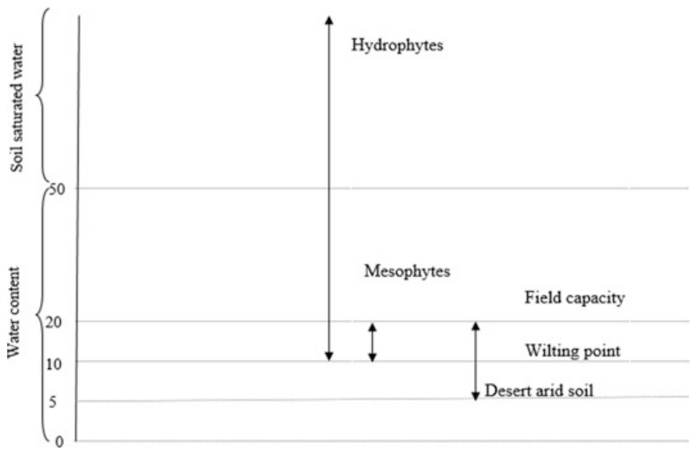


Fig. 2.11 Water, soil and plant relationship

to holding capacity. Of course life may be possible at lower levels but moisture cannot be used by a plant at wilting point (for loamy soil about 10%) and the plant will die.

Phreatophytes and xerophytes cannot tolerate the shortage of oxygen caused by the presence of free water or moisture in excess of field capacity. Where there are drainage restrictions, phreatophytes are only able to live in 10–20% moisture content and their death will be imminent at wilting point. In contrast, xerophytes do not die at this point, but they experience an interruption in growth; the plant will be able to continue living when the soil moisture level is below 5%. Xerophytes can germinate through the seeds again by soil moisturizing.

No plants are unable to live in conditions with soil moisture below 50% unless they obtain the required moisture through other means, such as the direct absorption of moisture from the atmosphere (cactus). The range of moisture conditions in which mesophyte and xerophyte plants grow is very small. As a result, minor changes in humidity in this limited range after a heavy rainfall in arid lands leads to germination of annuals.

However, plants are able to tolerate drought stress by absorbing water vapor from the atmosphere. In a humid environment, the stomata of some plants are patulous during the day, absorbing carbon dioxide in daylight. These are known as C3 plants. Plants of arid regions perform carbon adsorption at night, so their stomata are often closed during the day to reduce transpiration and release carbon absorbed too slowly for photosynthesis. These are known as C4 plants. The third group of plants adopt the carbon adsorption and process of both C3 and C4 systems. These are known as CAM plants (named the discovery of crassulation acid metabolism in the crassulaceae species) (Adams, 1978).

Since the soil plays an important role in the ecology of plants in arid regions and is sometimes regarded as the main factor, shrubs of arid areas are divided into 5 categories according to the soil conditions.

Plants tolerant to salinity or halophytes. These plants have grown on soils with sulfate-chloride salinity or with high groundwater aquifers such as solonchaks and coastal solonchaks. They have a distinctive structure and are succulent. Their cells are small and the external walls of their epidermis and cuticle are thick to prevent excessive transpiration and to resist extreme air temperatures. Their organs contain tissues with water reservoirs to withstand the high salt content in the soil and excessive transpiration, and the plant consumes the water stored as necessary. Cell sap comes from a solution of saturated sulphate and chloride salts with salts sometimes constituting up to 45% of the total dry weight of the leaves. The frequency of soluble salts in the soil water increases the osmotic pressure of cell sap and delays evaporation and transpiration. Osmotic pressure of cells in these plants increases in proportion to the concentration of alkaline solutions. That is why if the succulent and halophytic species *Salicornia herbaceae* is cultivated in nutrient solutions or in sweet soil without alkaline mineral, it loses its succulent features. If sodium or potassium chloride is added to nutrient solution or soil, the plant will again turn succulent, greener and juicier (Sabeti 1976).

Halophytes consume the insignificant amount of water available to plants in the soil, establishing a balance between absorption and transpiration. To perform absorption, the sap concentration and osmotic pressure of hair cells should be higher than the concentration of soil solution, such that sap concentration will increase in cells that are further away from hairs. The concentration of nutrient solutions is high in saline soils, thus sap concentration of plant cells should be much higher than the concentration and osmotic pressure of normal plants in order to perform absorption and to provide nutrients for the plant. Not all plants are equally sensitive to the amount of alkaline salts, and even the same plant may have different sensitivity to various salts. Generally, many plants are tolerant to soil salinity. Many species of *Chenopodiaceae* such as *Salsola, Aellenia, Suaeda, Anabasis, Atriplex, Salicornia* and *Seidlitzia* and some plants of *Gramineae* such as *Aeluropus, Calyceria* and *Sphenopus* can be called halophytes.

A large amount of carbonate salts accumulates in soil depressions in the desert which usually are without vegetation, but in the margin where carbonate concentration is decreasing gradually, various plants appear and surround the soil depression like a belt. Plant density will increase as the solute concentrations decrease (see the example in Fig. 2.12).

Plants tolerant to sand or psammophytes. Psammophyte shrubs are plants that grow on sand. Often covered by sand, they are not destroyed even when they are buried by it. If the sand on them is partially wet, many roots split from the branches. Sand affects the anatomy of the root and stem of buried plants, especially the stem When the plants have been covered by sand at the time of growth, the mechanical effects of sand particles cause fractures in the xylem vessels, creating considerable complexity for the parts of the plant.

Psammophyte plants have a special root system. Lateral roots usually develop 25–30 m along the barkhan slope. Sometimes the roots reach 20–25 m in depth to capillary water and as a result, moisture is adequate.

The soil is removed from the roots during sand movement, so that part of it will be visible on the barkhan surface. However, the roots do not wilt and are protected

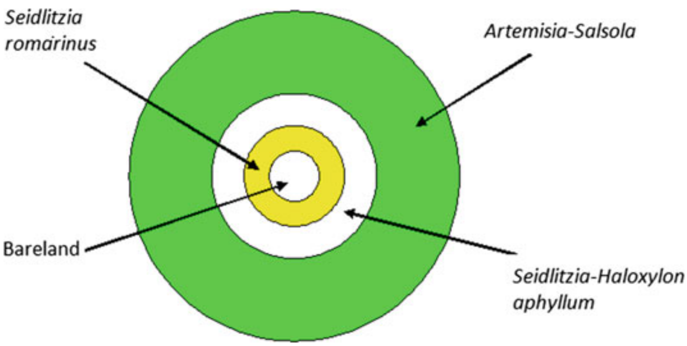


Fig. 2.12 Banding vegetation cover from the center of playa to surrounding area in the Saghand desert of Yazd

from the sun's radiation by a thick crust (e.g., *Calligonum sp.* and *Ammodendron conollgi*) or by a sheath of sand (*Aristida*). In sandy deserts the need for moisture causes bushiness. Sandy soils usually readily absorb moisture and store it in depth, so direct evaporation is low and all the water is used by plants. The plants observed on sand dunes are *Calligonum sp.*, *Smirnovia torkestana*, *Populus euphratica*, *Aristida* spp., *Cyperus conglomeratus*, *Salsola richteri*, *Haloxylon persicum*, *H. aphyllum*, *Halimodendron*, *Ephedra lomatolepis* and *Hedysarum,* each of which has special status in sabulous and sandy soils.

Petrophytes. These plants grow in rocks and reefs of the mountains of arid regions. Their habitat has favorable conditions in terms of humidity due to the accumulation of rainwater in depressions where the plant's root is located. Petrophyte shrubs are xero-mesophyte and have bigger leaves. These plants include species of *Zygophyllum, Tetraena, Rhamnus* and so on.

Gypsophytes. These plants grow on plains and flat places with surface soil structure and high salinity; they are mostly small with short and consumptive leaves such as species of *Salsola, Anabasis, Ephedra* and *Hamada.*

Mesophytes. Mesophyte plants usually grow in an environment that is not too dry and not too moist. They are susceptible to dehydration: water reduction of even 1–2% causes dehydration. Then if the air is dry, these plants lose more water, wither and die. They have well ventilated soil. The nutrients consumed are not very attenuated like aquatic plants and not inspissated like xerophytes. Their roots have many branches, and the volume and length of the root is often equal to the volume and height of the stem.

The leaves of mesophytes grow relatively high and their epidermal surface is covered with a thin layer of cuticle. Abundant chloroplast kernels and many stomata can be seen on the surface of their leaves. Stomata are sometimes scattered on both surfaces of the leaf, but its lower surface has more stomata than the upper surface. In mesophyte plants that need adequate water and moist air, if the air is dry, transpiration will be increased and because their roots are not able to compensate for the lost water with dry air, stomata will be closed but the plant loses water through cuticle transpiration. In the event of continued drought, the plants will fade and wither. Among mesophyte shrubs are the species *Caragana, Cerusus, Amygdallus* and *Spiraea.*

2.3.2 Plant Community of the Deserts of Iran

The plant community in Iran, including desert areas, has been listed in detail in a rangeland rehabilitation report (No. 2). Generally, varieties of *Haloxylon sp.*, *Tamarix sp.*, mesquite, *Acacia sp.*, wild almond, thistle, *Calligonum sp.*, maurorum, camel thorn, *Sophora sp.*, milkweed, *Prosopis juliflora*, *Vachellia nilotica*, *Panicum sp.*, *Ziziphus sp.*, *Cactus sp.,* etc. are the main trees and bushes that can be planted to prevent desertification and for reclamation of desert land.

Each of the plants mentioned has various types; for instance, there are more than 10 species of *Calligonum* and several species of *Tamarix* and *Haloxylon* in Iran. A desert plant that has been less discussed and is relatively unfamiliar is *Casuarina*. The crucial point is that a plant like *Haloxylon* that is resistant to desert loses water at the rate of just 1/4300 of its own weight per day on hot days of summer, while plants in rainy regions lose water at the rate of 5 times their weight per hour. Therefore, temperate and rainy plants lose water about 500,000 times more than plants in desert regions. These features are well observed in succulent sclerophyllous plant communities. On the other hand, the roots of desert plants are 30–50 times greater than organs above the soil. The huge amount of root production supplies water and nutrients in desert lands.

2.3.3 The Effect of Climate and Physiographical Properties on Desert Vegetation

2.3.3.1 Precipitation

Plant density is reduced as precipitation reduces in desert conditions and sparse vegetation cover is created. This vegetation cover has a shallow root system and high levels of superficial growth. Very sparse vegetation in some desert areas means that there is virtually no interspecific and intraspecific competition. In fact, the struggle for survival is a struggle against the environment. In some cases such as *Parthenium argentatum*, the root of the plant secretes a substance in soil that prevents the growth of young plants in the same species. Also in *Encelia forinosa*, dried leaf and rotten material from the plant contain equivalent deterrent material. Growth inhibitors are soluble in water, so in precipitation, washing and plant aggregation are increased. Conversely, plants will be separated on a regular basis due to the lack of precipitation. This is a characteristic of most desert shrubs (Went 1955). Desert areas in which precipitation is sufficient to maintain such sparse vegetation are known as rain desert.

2.3.3.2 Relief

Relief plays a central role in the supply of water for desert plants. Water floods down slopes, collecting in lower regions. So the amount of moisture in these areas may be much larger than the amount of rainfall.

Most runoffs are collected in the beds of narrow watercourses and the accumulation area is very small in relation to the basin. Watercourses (dry river beds) and other depressions may contain soft alluvial soils that are better than the surrounding desert rock slopes in terms of water and fertility. Areas where annual precipitation is <100 mm and soil moisture is not enough even to create sparse vegetation are known as run-off desert. In these areas, most plants will gather in depressions. In deserts where rainfall is less than the survival needs of plants, dominant plants (vegetation types that face a shortage) are less drought-resistant than scattered types of vegetation that occur under conditions of more precipitation. Vegetation types faced with a shortage have a deeper root system, which of course it is not surprising, because if we consider that run-off from annual precipitation of 50 mm or less is collected in a limited area, it is equivalent to 500 mm or more rain falling in this place.

The majority of the Syrian and southern Iraqi deserts are among rain deserts, while the Egyptian deserts, many parts of Sinai and Negev areas that have less rainfall, are run-off deserts. The critical rainfall level above which scattered vegetation is caused depends on relative humidity, temperature and soil type, but it varies between 50 and 100 mm. However, where a sandy soil layer is located on a layer of fine-textured soil (like los), 50 mm of rainfall may be sufficient to create sparse vegetation.

2.3.4 Profitable Plants of Arid and Desert Areas

Historically, desert plants obviate many requirements of the desert's residents. Food, spices, fibers, drugs, shelter and weapons can be obtained from various organs of desert plants. Some of these are described below.

- Fruit: *Opuntia* and various species of *Agave* are the main producers of fruit in the deserts of North America. Of course, succulent *euphorbia* contains a lot of toxic alkaloids.
- Limbs filled with starch: There are edible roots, rhizomes, tubers and bulbs in many desert plants. Crispy interior parts of many species (such as *Agave, Yucca*, etc.) after roasting are the main food for many tribes of North American Indians.
- Seed: Pods of legumes and acorn are an important source of food. The seeds of many annual and perennial species such as grasses, plants of the chicory, legume, beet and mustard families and so on are collected and consumed fresh, dried, roasted or soft.
- Green parts of plants: New buds or leaves of many desert plants are consumed as salad or spice.
- Drugs and medicines: Many desert plants contain biochemical compounds with medicinal uses. The dry or soft parts of plants as well as their extract are traditionally used for these purposes. Fibers: Fibers are collected from desert plants, mainly *yucca* and *agave*.
- Other uses: Desert plants are a major producer of building materials, weapons, tools, decorative materials, color, gum, soap, cosmetics and so on.

The most interesting desert plants are those containing compounds not adversely affected by droughtand which have a high business value per unit weight. Plants containing alkaloids, essential oils and enamels are among this group. Plant species with valuable components such as fibers or food reserves that depend on the vegetative growth and have relatively little real commercial value are not of great interest.

The number of desert plants containing alkaloids is relatively limited, but the amount of the alkaloids can be very high. The plants of the potato family (*Solanaceae*) are among the richest of these resources. The most important alkaloids of desert plants are among hyoscine and hyoscyamine groups including *Datura inoxia*, *D. stranonium*, *Hyoseyamus mutieus*, *H. albus* and *Physochalania praelata*. Steroidal alkaloids have been extracted from different species of *Solanum*, such as *S. cardinense* and *S. xanthocarpum*. There is ephedrine in several species of *Ephedra*.

The second important compound found in desert plants is essential oils. Oil secretion from the plant is related to drought resistance characteristics. The main sources in this field are plants of the *Labiateae* family, such as *Sativa officinalis*, *Lavandula officinalis*, *L. latifolia* and *Plasmarinus offanals* and of the *Apiaceae* family, such as *Foeniculum vulgaris*, *Pimpinella*, *Ferula alliacea, F. asefoetida, F. foetida* and *F. galbanifolia*. The *Artemisia* genus of the *Asteraceae* family is among other sources of aromatic oils.

The third group consists of plants with mucilaginous substances producing medical gums. This group includes various species of *Acacia* and *Butea monosperma* (*Fabaceae*). Low moisture content of air and soil is favorable for gum production.

Different species of *Hyoseyamus* are specific to some desert areas. Thus, *H. muticus* is native to Egypt, the Near East, Iran and India. Efforts to cultivate this plant in other countries have been inconclusive. Even the amount of alkaloid in cultivated plants is less than its amount in wild plants in Egypt and the alkaloid percentage is at its maximum in arid conditions in these plants.

Citrullus colocynthis (*Cucurbitaceae* family) is a native of Saudi Arabia, Syria, Egypt and India. Its immature fruit contain material that is used as a laxative. In the past in Egypt, *C. colocynthis* was collected and exported. Now this plant is grown in Cyprus and Spain.

Species of *Ephedra* are often found in arid regions of temperate areas. Dry young branches of this plant are a source of ephedrine alkaloids with properties similar to adrenaline. Species of *Ephedra* are well cultivated in the USA, Kenya, the UK and Australia. Different species of *agave* (*Amaryllilaceae* family) are cultivated to provide sapogenin in Italy. In *Agave roseana*, 2.5% of the plant's dry weight is a steroidal sapogenin and is used to obtain cortisone and steroidal hormones.

Another species called *A. siselana* is used to produce industrial fiber for raffia on a large scale in North Africa and India. A variety of *agave* is widely cultivated to produce fibers in the Pueblo Desert in Mexico, but attempts to plant *Agave siselana* in arid regions of Israel (200–250 mm rainfall) have not been successful.

Stipa tanacissima is collected to produce paper in North Africa. *Yucca* (*Lipiaceae* family) is a genus of the plants that has maximum saponoside steroids. These species are found in semidesert regions of Mexico and south-west America and are used commercially for their long fibers. After the fiber is extracted, residues contain a large amount of saponoside. Plant growth is very slow and it needs a long time to achieve operation.

Aloe (*Liliaceae* family) is a genus of xerophytes and is native to Eastern and Southern Africa. This plant is grown on very poor soils. Its concentrated sap contains the medicinal substance aloe which is a mixture of glucoside and is used as a laxative. Some species are cultivated in South Africa, Saudi Arabia and India and *Aloe vera* is cultivated in the Dominican Republic, Venezuelan coast and Aruba Island to produce aloe.

The species of *Artemisia* (*Asteraceae* family) are plentiful in the arid steppe regions of Europe, the American West, South Africa and South America. Species of *Artemisia* containing santonian (for treatment of stomach worms) are found in Russia, Turkmenistan and Iran (mostly *Artemisia cina*). So far, attempts to cultivate *A. cina* outside these areas have been inconclusive. *Artemisia herba-alba* is abundant in the desert of North Africa. Although this species is lacking in santonian, it has anthelmintic properties. An oil with strong pharmacological effect and digestive-stimulant property is extracted from *A. absinthium,* which is native to North Africa and Afghanistan and is cultivated in the United States.

Rumex hymenosepalus is found in arid regions of the USA and Mexico. Its wild plants are used to produce tannin. After a dramatic reduction in this species in the wild, many efforts at commercial planting were made, but they were not able to compete with other plants in the long term.

Parthenium argentatum is a small semi-desert shrub that contains 10–18% caoutchouc with good quality. Planting these species is economically justifiable in favorable areas.

Plants such as *Scorzonera tau-saghys* and *Taraxacum kok-saghys* which are caoutchouc producers, were regarded as wild in the Tien Shan Mountains of Asia. *Euphorbia antisyphilitica* is a source of candillila wax which has various industrial uses and a long history of commercial use.

The seeds of many desert plants contain a large percentage of protein and oil. Some species contain oils that are rare combinations of fatty acids. Among these species are *Fendleri lesquerella,* native to the semi-arid regions of North America. Its seed contains 20–40% oil which has potential industrial applications.

2.3.5 The Mechanisms of Plants' Resistance to Salinity

Halophytes are of two basic types:

(1) Voluntary halophytes that are relatively resistant to salinity but grow better in soils without salinity.
(2) Real halophytes that grow relatively better in saline soils. These plants have at least two properties enabling them to grow in saline soils: they can increase the osmotic pressure inside their tissues rather than increasing the osmotic pressure

of soil solution; and they can gather significant amounts of soluble salt in their tissues.

The protoplasm of their cells has not been destroyed easily by the accumulation of sodium salts.

According to recent studies, the problem with halophytes is mostly their inability to adapt to soil stress, not the ability of the plants to regulate the amount of absorbed salt and the adverse effects of salt on the plant's protoplasm. If plasma is sufficiently resistant to salinity, water absorption is facilitated through the capture and storage of salt in cells, and the ability to absorb water from the saline soil is increased by creating suction pressure from the plant. Of course if the plasma is less resistant to salinity, suction pressure is not enough and the plant is unable to absorb water and nutrients from the saline soil. The concentration of salt inside plants in crisis mode may be halophytes or non-halophytes. The salt concentration inside halophyte plants may be too high. Studies show that 25–50% of plant dry matter consists of salts and about 20–50% of it is sodium salts.

Plants receive salt along with water absorption from the ground. Transpiration leads to salt accumulation in plant tissues. Some of the plants are able to cope with the excess accumulation of salt using the following mechanisms:

(a) Salt rejection through gland-like cells of the leaf. Salt rejection is an active process in terms of metabolism but only a small number of halophyte plants are able to do it.
(b) Hydration: Morphological changes in the plant occur by increasing the salt concentration in the cell. Thick cuticle and blocking stomata are among other changes. Water reservoir organs are swollen and leaves thicken. These changes are usually associated with longitudinal re-decline. The water content of the tissue will increase along with the potential dilution of the salt concentration in the tissue.
(c) Defoliation: When the salt concentration increases in leaves, old leaves will be destroyed and shed earlier than usual (for example in *Atriplex halimus*). The longer this action is delayed, the better adapted to salt the plant will be. Plants lacking regulatory mechanisms will die in a specified concentration of salt. Halophyte plants may be resistant to drought, but salt resistance is not to the same as drought resistance.

2.3.6 The Mechanisms of Plants' Resistance to Drought

Plants adapt to drought in three ways: escaping dry periods; maintaining the water balance inside the plant and thus delaying the negative effects of drought; and drought tolerance or survival during drought.

Escaping dry periods. This is one of the simplest ways of adaptation to desert conditions. Many desert plants germinate in the early rainy season and their growth period is short and limited to the precipitation period. The gap between seed germination and maturity is only 5 to 6 weeks. These plants are found in wet years, but may not appear in dry years and remain in the form of seed or fruit.

Stagnation (sleep) and germination. The seeds of many plants do not germinate at high temperatures, but they begin to germinate at various stages from stoppage time to roots and shoots development. The presence of germination inhibitors in seeds allows germination when rain has fallen to wash inhibitors.

Plant precocity. In areas with intermittent rainfall and drought, plant precocity before drying soil is one of the basic adaptation of crops to drought. In this regard, the precocity of wheat and barley varieties is among plant-breeding strategies in Mediterranean and semi-arid regions of India and Australia. However, shortening the period of growth will reduce production.

Effective absorption of water. The root system of xerophyte plants has a wide variety of adaptations. Among them is the response to soil conditions, such as drought time, type of soil composition and salinity. Adaptation to drought conditions works by the root system spreading, and not through changes in its structure. Desert plants often have shallow roots, but they can adapt to local and seasonal fluctuations in soil moisture and physical ground condition through root branches in order to develop root depth.

There are plants in arid areas that have very deep roots, are able to access groundwater by root in entirely dry conditions and have good growth. Two prominent examples of these are *Alhaji maurorum* and *Prosopis stephaniana* which produce roots up to 15 m or more deep. Plants differin the development, depth and effectiveness of roots. The number of rootlets per unit main root length in sorghum is twice that in common corn. It seems that this is one of the main reasons for greater resistance to drought.

One of the interesting adaptation strategies of the root in some xerophyte plants such as some species of *Aristida* and *Pennisetum* in the Sahara and *Lygeum spartum* (one of the Mediterranean grasses) is dense growth of hair roots that release an adhesive material. This material causes adhesion of soil particles around the roots and creates a protective layer against root drying.

Another adaptation is the production of secondary roots which are created 2–3 h after rainfall and react to re-moisten the soil (rainy roots). Plants in Hamadas and heavy soils of rainy deserts respond to water with rapid growth. Drought resistance in spring wheat is related to the speed of initial root production.

A high ratio of roots to shoots (R/T) is one effective way for plants to resist drought. The transpiration area is reduced, but the roots of plants absorb water from a large volume of soil. As the climate becomes drier, the R/T ratio of the plant increases.

In the case of perennial desert plants, seedlings may only have a few leaves that they will destroy after a few months, but still the roots continue their activities. One-year seedlings of *Erodium hirtum* germinated in dry conditions have roots 20–30 cm deep, while the growth of shoots is 1–3 cm. Meanwhile the root-to-shoot ratio is very low in humid climates. The root depth in *Aristida pennata* reaches one meter 20–25 days after germination, but shoot growth is negligible.

Reduction of water loss by inhibiting water dissipation mechanisms. One of the features of xerophytes is the reduction of water losses and their ability to reduce transpiration. Apart from reducing the level of aerial parts, one of the simplest ways is to reduce the leaf area and leaf torsion at times of water scarcity. These characteristics can be seen in many of the grass plants. Leaf torsion leads to up to 55% reduction in transpiration in plants in semi-arid regions and up to 75% in xerophyte plants in arid regions.

One adaptation to drought is represented by the tiny leaves of plants such as *Euphorbia*. Many desert plants such as Artemisia have two types of leaves: large winter leaves which fall off at the end of rainy season, and very small summer leaves that replace them. In other species such as *Cerdicuim microphyllum* in the Sonoran desert, leaves are converted to the annex and photosynthesis is performed by green stems.

Some desert species such as *Hammada salicornica* and *Retana cactum* have no leaves except organs that have very short life.

Leaf structure. Characteristics of the leaf including thick cuticle, waxy surface, closed stomata, to be barbed and so on can be seen in relation to the reduction in the rate of transpiration that makes it possible for the plant to survive in dry conditions.

When enough water is available to the plant, transpiration in the leaves of xerophyte plants is greater than in the leaves of non-xerophyte plants. So the plant will efficiently use water during the short humid periods thatare characteristic of a desert environment. After reaching the critical moisture level, stomata are closed again and morphological adaptation begins to take place.

Drought stimulates the production of epidermal appendages in some species. The existence of fluff on the leaves not only reduces transpiration, but also increases albedo. However, some desert plants are able to absorb water through fluff on the leaves in conditions of high air humidity.

Hydration. Plants such as cactus have thick cuticles and a few stomata. Some desert plants in addition to features that reduce water loss through transpiration, have morphological characteristics that reduce radiation absorption in the range of wavelengths of visible light and infrared.

Number and place of stomata. When stomata are few in number, respond quickly to water reduction and then close, the effects of water scarcity are delayed. Some desert plants contain fewer than 100 stomata per square cm, whereas this number in hydrophyte plants is 1000 stomata per square cm. Stomata in some species (such as *Retama raetam* and *Nerium oleander*) are placed on troughs or holes of the leaf surface so that it can also effect more transpiration reduction by limiting airflow contiguity.

The stomata of desert euphorbia and cactus are usually closed during the day and open at night. Thus, transpiration is reduced at times of high evaporation rates. Drought tolerance in sorghum and some varieties of corn and peanuts is partly because their stomata are capable of resuming their activities immediately after water stress.

Survival power in long dry periods. Plants grown in temperate areas have 10 atm osmotic pressure, but the plants studied in arid areas have 20 atm osmotic pressure.

Table 2.19 Osmotic pressure in some species in different habitats

Habitat	Plant species	Osmotic pressure (atmosphere)	
		Winter	Summer
Sand dunes	*Zilla spinosa* *Artamisia monosperma* *Calligonum comosum*	7–14	15–16
Different habitats	*Acacia raddiana* *Dchradenus baccatus*	13	17–22
Salt marshes	*Arthrocnemum glaucum* *Suaeda monoica* *Sotetrandra*	28–50	89–113
Hamadas	*Reaumoria palaestina*	39	203

Along with physiological adaptations, internal high osmotic pressure prevents drying inside the cell and as a result, the plasma is resistant to drought.

If plants grow in the natural environment, osmotic potential is 10–20 atm in crops, 30–40 atm for xerophytes and more than 100 atm in halophytes. If different ecological groups of plants are cultivated under the same conditions of water stress, these differences will decrease. The osmotic potential of plants in different habitats is shown in Table 2.19.

Some xerophyte plants store water in swollen organs and often in large underground organs. Underground tubers of *Pachypodium bispinosum* grown in South Africa constitute 95% of the total plant weight and 91% of the water content of plants.

Succulent plants are a special group of plants that are widespread in the deserts of North America, South America and South Africa, rare in the deserts of Asia and Sahara and do not exist in the deserts of Australia. These plants are usually found in arid regions with short rainy seasons, and they are able to survive periods of absolute drought by economizing on water saved in their organs during wet periods; the environment does not affect the growth of aerial and underground organs during drought. For example, the amount of storage water in *Carnegiea gigsntea* is estimated at between 2000 and 3000 L per plant.

Putting the plants in conditions of a moderate dryness, low temperatures or in the exposure of materials which postpone plant growth for a few days would improve plant resistance to drought. Plants which have survived in a period of drought would be lesser damaged in a water stress period.

If the protoplasm of the plant has adapted, its water-holding capacity will be better. Resistant plants demonstrate faster photosynthesis, less respiration and a higher root-to-shoot ratio. The plant's resistance to drought can be increased by wetting and drying seed before cultivation.

Resistance to heat is as important as resistance to drought conditions. If the plant is irrigated, heat resistance is particularly important. The principal enzymatic reactions stop completely at certain temperatures and this leads to inhibition of certain metabolic products required for plant growth. Where the specific metabolic materials influenced by high temperature can be detected for each plant, increased production is possible in high temperatures.

Researchers have shown that spraying zinc solution on the leaf surface increases resistance to heat, because it increases the activity of some enzymes and stimulates oxidation in vegetative cells.

2.4 Animals of Desert Areas

Desert is a significant habitat for animal populations, like any other ecosystem, nd the peculiar characteristics of desert climates such as high temperature, low humidity, little water, soil type and so on place some limitations on settlement. Animals have therefore produced several adaptations in order to survive in such environments.

It is obvious that the biological adaptation of organisms to their environment varies according to the characteristics of their existing inner structure. The study of these adaptive changes contributes to the survival of these organisms and their natural environment and helps prevent unconscious interventions that may confuse the natural order of the ecosystem.

General mechanisms by which animals adapt to drought conditions are as follows:

- obtaining additional water by eating succulent tissues of plants or drinking dew;
- direct use of atmospheric moisture;
- using water available in foods;
- reducing water loss by feces and urine concentration;
- non-permeable body cover;
- reducing water loss by inactivity and flaccidity.

Animals of desert areas are important due to the enormous impact they have on the soil and other ecosystem components. In some arid regions soil fauna are dominated by termites, which are an important factor in the displacement of soil particles and changing the soil's physical and chemical properties. They make their nests in the form of hill-like ridges near the ground and inside the roots and stems of favorite plants. This diversity in nesting, which is directly related to the ecological conditions of the habitat, causes the movement of soil particles which are sometimes transferred several kilometers by rain and wind. Since the displaced particle diameter varies from about 0.0015–5 mm, termites can cause considerable changes over time in the soil texture.

Ants in desert areas affect the soil in two ways; during construction of their nest and corridors system, the soil particles are separated and carried, or organic matter is mixed and cemented. A lot of seeds and plant foliage are collected by termites and ants in the nest, and organic matter and other elements in the soil increase after decomposition.

Rodents, which are important as pests and in transmission of diseases, cause damage to various crops. Their numerous harmful activities in protected forest areas, sand dune stabilizer plants, agricultural fields and native rangelands are particularly significant in arid and semi-arid areas. The underground and nesting activities of some rodents sometimes damage irrigation systems. Rodents are one of the main elements in the food chain. The interactions of plants and carnivorous animals as well as birds of prey such as owls, eagles, albino, sparrow hawk, hawk and so on in the food pyramid are connected to rodents. Excavations by most desert rodents have more specific effects on desert soil and plants than the activity of ungulate grazing. Rodents may be in competition for plant material with herbivores such as sheep. So the groups of plant and animal species along with small mammals are wider in arid ecosystems than the ungulates.

Desert herbivores include livestock, deer, camel and Camel can make better use of vegetation due to their specific adaptations in desert ecosystems. An examination of its physiological characteristics shows that the anatomy of the camel is different from other mammals, so that it is adapted to live in the harsh environmental conditions of desert, drought, lack of water and extreme heat. Among its most important physiological characteristics is tolerance to thirst stress and high temperature on hot days of desert. The camel reduces the bodily water loss as much as possible, so that feces are dry and urine volume is also low: part of the urea which must be excreted is returned to stomach through the liver as a part of the urea cycle in the body and thus less water is needed to urinate. Camels can tolerate a 30% reduction of their body weight at the time of thirst. They can drink up to 125 L of water at once and compensate for dehydration at the same time. The commercial characteristics of camels relate directly to products such as meat, milk and wool.

Reclamation of Arid Lands
Jafari, M.; Tavili, A.; Panahi, F.; Zandi Esfahan, E.;
Ghorbani, M.
2018, XI, 267 p. 46 illus., 24 illus. in color., Hardcover
ISBN: 978-3-319-54827-2