4. Soils and soil conditions

4.1 General characteristics

4.1.1 Soil-forming processes

Most soils of the Bardenas area show no distinct characteristics of soil development. Except in the ancient alluvium of the mesas, soil-forming processes have had little time to act upon the very recent parent materials of alluvial and colluvial origin. Moreover, the climate being characterized by a marked aridity, an excess of water rarely occurs owing to the low amount of precipitation and its even distribution. Therefore, except for the soils of the mesas, there is little soil profile development. The soils of the mesas, formed over a much longer period, have diagnostic cambic and calcic, or petrocalcic horizons. The other soils, apart from an ochric epi-pedon, show the beginnings of argillic, calcic, gypsic and even salic horizons but only in a very incipient stage.

Two soil-forming factors are relevant in understanding the origin and extent of the salt-affected soils of the area. These factors are parent material and the relative position of each soil association within the landscape.

4.1.2 Parent materials

Parent materials can be grouped into three classes. First is the ancient coarse alluvium of the mesas, which consists of well-rounded stones, gravel, and coarse sand. Above this layer a reddish loamy generally stoneless layer occurs. Both the coarse and the reddish layers are rich in calcium carbonate and are salt-free.
Second are the parent materials of alluvial origin brought by the two main water courses flowing through the area - the Aragón and Riguel rivers - whose catchment areas are respectively outside and just at the edge of the Miocene-Oligocene sedimentation basin. The parent materials of the Aragón valley soils are salt-free coarse alluvium in the medium and higher terraces and loamy sands in the lower terrace. In the Riguel valley a fine alluvium is found, which consists of clay loam and is salt-free in the upper part of the valley. Both clay content and salinity increase towards the lower end of the valley. A narrow sandy levee not sufficiently wide to be represented on the map can be distinguished.

The third class of parent materials are those derived from the saline mudstone and siltstone, which are characterized by a very high percentage of silt. In the alluvial valleys and fans a fine alluvium has been deposited and in the lower parts of the slopes a fine colluvium. Both occur mixed in the fluvio-colluvial valleys. In the upper part of the piedmont slopes the parent material is mainly weathered mudstone. As these rocks are widespread throughout the area, soil texture varies within a narrow range, silt loam and loam being the most common textures. Salinity, though always present in these parent materials, is highly variable. In general the amounts of salts are highest in the low-lying alluvial formations (Chaps. 2 and 3).

High calcium carbonate content (>40%) is a common property of the soils. In non-saline soils pH varies between 7.5 and 8. In soils with higher sodium content higher pH-values are common (8 to 8.5).

4.1.3 Topography

The soils of the mesas, fluvial terraces, and alluvial valleys and plains are flat. The eroded plain has an undulating topography with gentle slopes and flat low-lying fluvio-colluvial valleys. Stony ridges and mesa escarpments have a pronounced slope.

Topography has had a marked effect on the redistribution of salinity. The colluvial and piedmont slopes have lost salts which have accumulated in the lower flat areas (Chap. 3).
4.1.4 Land and water management

Where the soils of the slopes have been levelled, the original soil profile has been truncated. Sometimes less pervious and more saline layers, previously deep, form the present surface soil. The flat soils of the mesas and alluvial valleys required only a slight smoothing of the land and the present soil represents only a slight re-arrangement of the original profile.

Irrigation has also played a role in the redistribution of salts. The percolation losses inherent in surface irrigation have leached the salts from the more permeable soils and carried them to other soils, particularly to soils deficient in natural drainage.

4.2 Mapping units

During the reconnaissance survey which formed the basis upon which the soil map was prepared, the physiographic approach was applied. The objective of the reconnaissance survey was to delineate the saline and potentially saline areas for their subsequent reclamation under irrigation. The mapping units are therefore based on those conditions that were relevant to the specific practical agricultural purpose of the survey, namely the salinity hazard and the land reclamation possibilities.

The mapping units thus represent landscape units based on the geomorphological features of land forms, slope, elevation and relative situation, parent materials, and drainage conditions. As has been described in the preceding chapters, all these features contribute to soil salinity.

The soil map prepared in this way is shown in Figs. 4.1 and 4.2. The main mapping unit is a landscape or geomorphological unit. Some subdivisions were made on the basis of soil salinity level and drainage conditions. Erosion hazard also had to be added because it is a condition that radically affects the land suitability for irrigation.
Each mapping unit is equivalent to a broad soil association but with a similar salinity range and similar drainage conditions.

Some miscellaneous land types are also included. They indicate land with little or no soils, which serve no purpose for irrigated agriculture, and whose soil conditions were therefore not studied.

To standardize the various investigations and to ease correlation with soils of other areas, representative soil profiles were morphometrically classified. Descriptions of soil profiles are in conformity with the Soil Survey Manual (1951). Most of the soil analyses were done in line with those of Agric. Handbook No.60 of the USDA (1955). Soil classification was based on Soil Taxonomy, Agric. Handbook No.936, USDA (1975).

Four main zones, each of them related to a drainage basin, can be distinguished on the soil map (Chap.3).

The northern "Rough Eroded Plain" has a complicated soil pattern (cross-section in Fig.2.8). It comprises residual siltstone outcrops in the highest position and saline alluvial soils in the low-lying fluvio-colluvial valleys and plains. The transition between the two mapping units is formed by soils of eroded slopes in the upper part of the hills and soils of colluvial slopes in the middle and lower parts of the slope.

The north-western part of the area is dominated by the "Aragón Alluvial Valley" (see cross-section in Fig.2.7) where soils of fluvial terraces are found. In the south this zone is bordered by a high mesa situated outside the irrigation scheme. Between the alluvial soils of the valley and the higher soils of the mesa, transitional soils occur on piedmont slopes.

The same soil pattern dominates the south-eastern zone of the area as well (Fig.2.10). The soils of the mesas occupy the highest position and the soils of the Riguel alluvial plain the lowest. The soils of the piedmont slopes form a transition between the two.

The south-western major zone of "Piedmont slopes" has a highly irregular
soil pattern (Fig.2.12). It is composed of residual soils of the stony ridges and miscellaneous land in the highest position, and saline alluvial soils in the low-lying alluvial valleys and fans. Eroded slopes are situated between the residual soils and the depositional ones.

The mapping units and their main features for irrigated agriculture are described in the following paragraphs.

Fig.4.1: Physiographic soil map of the Bardenas area. Sheet I - Aragón basin. (Base map drawn from aerial photographs on an approximate scale of 1: 31 000).

For legend, see p.50.
LEGEND

PHYSIOGRAPHIC SOIL MAP OF THE BARDENAS AREA

Physiographic soil units

1. Residual soils of mesas and hills
   1.1 soils of the mesas (sasos)
   1.2 soils of the mesas, isolated phase
   1.3 rough mountainous land
   1.4 siltstone outcrops
   1.5 soils of the stony ridges
   1.6 stony ridges, eroded phase
   1.7 gypsum ridges

2. Eroded soils and badlands
   2.1 terrace escarpments
   2.2 soils of the piedmont slopes, slightly eroded phase
   2.3 soils of the piedmont slopes, slightly saline-alkali phase
   2.4 eroded slopes
   2.5 erosion valleys
   2.6 soils of alluvial fans, eroded phase
   2.7 soils of the colluvial slopes

3. Soils of valleys and terraces
   3.1 mixed alluvial land of the Aragón river
   3.2 soils of the low Aragón terrace, excessively drained phase
   3.3 soils of the middle Aragón terrace
   3.4 soils of the high Aragón terrace, slightly eroded phase
   3.5 soils of the Riguels river plain
   3.6 soils of the Riguels river plain, saline-alkali phase
   3.7 soils of the gypsum valleys
   3.8 soils of the fluvio-colluvial valleys, imperfectly drained and saline-alkali phase
   3.9 soils of the fluvio-colluvial valleys, slightly saline-alkali phase
   3.10 soils of the alluvial plains, imperfectly drained and saline-alkali phase
   3.11 soils of alluvial valleys, saline-alkali phase
   3.12 soils of alluvial fans, slightly saline phase
   3.13 soils of alluvial fans, saline-alkali phase
Fig. 4.2: Physiographic soil map of the Bardenas area. Sheet II - Riguel basin. (Base map drawn from aerial photographs on an approximate scale of 1: 25 000).
4.2.1 Mesas

Mesa soils (Mapping Unit 1.1) are the more developed soils of the area because the ancient coarse alluvium from which they derived had infiltration and percolation rates high enough to allow an illuviation of calcium carbonate and even clay during former periods of wetter weather. Calcidic (Profile 2) and petrocalcic (Profile 1) horizons were thus formed.

Part of the original surface soil has been removed by erosion so that the soils are shallow with a limited rooting depth. On lower-level mesas however, a deep reddish fine soil overlies the semi-consolidated alluvium. In some small depressions the coarse alluvium is not found and the soils lie immediately on the impervious mudstone.

This mapping unit is a broad soil association in which effective depth of cultivable soil and soil texture vary (Fig.4.3).

Fig.4.3: Landscape of a soil of the mesas.
As the purpose of the survey was to map saline areas and as this soil association is in general free of salinity, phases of slightly different soils were not defined, except in an isolated phase (1.2) for remnants of eroded mesas which are out of the irrigation command.

The general soil properties of the mesa soils are:

a) Depth above the petrocalcic horizon varies between 30 and 80 cm. Root proliferation is well developed in the surface soil and even the petrocalcic horizon is occasionally penetrated.

b) Textures vary from sandy loam to silt loam, although soils may become more sandy with depth.

c) In the shallowest soils the degree of stoniness is high, but in general the surface soil is free of stones and gravel.

d) Structure is weakly to moderately developed although the surface soil generally has a strong crumb structure.

e) Infiltration and percolation rates are more than adequate to allow water to pass through the soil profile. The transmissivity value is sufficient to permit adequate drainage (Chap.3). Total moisture-holding capacity varies with the soil textures and effective depths of soil.

f) Salinity is uncommon but slight salinization can occur in depressions where the coarse alluvium is only shallow over underlying impervious mudstone (Chap.5).

g) There is a rapid increase in calcium carbonate content with depth, being highest in the calcic and petrocalcic horizons.

h) Soil colour above the calcic and petrocalcic horizons is normally 7.5 YR 4/4.

Where the soils of the mesas are moderately deep (Fig.4.4), prosperous irrigated agriculture has been established. Maize, lucerne, sugar-beet, barley, and tomato are the main crops.

Effective depth of cultivable soil and moisture-holding capacity are the main soil features on which land suitability for irrigation depends.
4.2.2 Fluvio-colluvial valleys, slightly saline-alkali phase

These soils (Mapping Unit 3.9) constitute a minor mapping unit related to the major unit of the mesa soils. They have developed from the mixed alluvium-colluvium deposited by the water courses flowing from the erosion valleys of the mesas (Fig. 4.5). The parent material was originally slightly saline, being partly derived from the underlying mudstone of the mesas. Apart from an ochric epipedon no profile development can be discerned, soil-forming processes having little time to act (Profile 3).

The general properties of these soils are:

a) Depth of cultivable soil is normally more than 1.5 m.

b) Soil textures vary from loam to clay loam. Discontinuous inter-
bedded gravel layers are found, although the surface soil is in general free of gravel and stones.

c) Soil structure is weak although some structure development can be seen in the subsurface horizons (an incipient cambic horizon).

d) Infiltration and percolation rates are sufficient to allow normal irrigation losses to leach the original salts if drainage conditions are maintained.

e) Present salinity is variable but the overall level is low.

Fig. 4.5: Profile 3.
Where lateral seepage from the adjoining mesas is controlled by an interceptor drain and the main drains function properly, the water table is maintained below the rootzone. Otherwise these soils are affected by a shallow water table (Fig. 4.6).

*Fig. 4.6: Shallow water table in a soil of the fluvo-alluvial valleys within the mesas.*

For the permanent use of these soils under irrigated agriculture, adequate water management and drainage are a must.

4.2.3 Piedmont slopes, slightly saline-alkali

The soils of the piedmont slopes (Mapping Unit 2.3) are colluvial soils which show very little evidence of profile development. They have an ochric epipedon and an incipient cambic horizon (Profile 4).
Variation in these soils is considerable as their only common features are a certain degree of slope and their situation in water-transit areas. In addition an eroded phase (2.2) is distinguished.

Any discussion of general properties can only consider the most commonly occurring soils, the general properties of which are:

a) Effective depth, though variable, is always greater than 50 cm.
b) Textures vary from loam to silt loam. Surface stoniness is rare.
c) Development of structure in the surface soil is moderate and infiltration rate is adequate. The subsoil shows little structure development and hydraulic conductivity is low on the finer textured soils. The degree of compactness increases with depth and the less pervious layer generally consists of a siltstone or mudstone layer.
d) Salinity is highly variable. Though it is not always evident in the surface soil, it is frequently encountered in the subsoil. There is an overall degree of intrinsic salinity in this unit (Chap.5).

Soil and water management require careful attention. Irrigation systems that need only minor earth moving should be preferred to those that require land levelling. Irrigation with water in excess of the needs of the crop is required to leach salts to deeper layers, but careful water control is needed to avoid secondary salinization by lateral seepage in adjacent low lands. Irrigation by sprinkler could achieve both objectives.

4.2.4 Riguel river plain

The soils of the Riguel river plain (Mapping Units 3.5 and 3.6) are yellowish brown alluvial soils derived from the fine alluvium deposited by the Riguel river in recent times. They thus show no diagnostic horizons apart from an ochric epipedon. The beginning of profile development is evident in incipient subsurface structure and in the slight movement of calcium down the profile, though no significant concentration of calcium has been detected (Profile 5).
Their general properties are:

a) Depth is generally greater than 2 m, but root proliferation is limited to 50 cm.

b) Textures vary down the profile and signs of stratification are evident, as could be expected in young alluvial soils. The surface textures are mainly clay loam. Stones are rare.

c) Structure development is weak and often non-existent, particularly in the subsoil.

d) Soil moisture-holding capacity is the highest of all the soils of the studied area. Infiltration and percolation rates, though low, are sufficient to allow surface irrigation. In general no water table is found in the upper 3 m (Chap.3).

e) The surface soil is free of salts but below 2 m soil salinity increases to an overall value slightly higher than 4 mhmhos.

Profile 5 represents a characteristic soil of the middle valley. The clay content increases in the lower part of the plain (Profile 7). The narrow natural levee of the river consists of very recent sandy soils (Profile 6, Fig.4.7).

In the lower valley soil salinity varies in accordance with the amount of leaching achieved under normal irrigation. It has been separated as a general saline phase, however, because its overall degree of salinization is higher than in the upper and middle valley (Mapping unit 3.6). A halophyte vegetation, which does not occur in the non-saline phase (Fig.4.8), is found in this unit.

With the present drainage system of open ditches desalinization is possible as the percolation rate is sufficient to allow leaching (Chap.5).

Together with the deeper non-saline soils of the mesas, the non-saline soils of the Riguel river plain are the best soils in the area. They are under irrigated agriculture, the main crops being lucerne, wheat, and barley.
4.2.5 High and middle Aragón terraces

On both the high and middle Aragón terraces (Mapping Units 3.3 and 3.4) similar soils are found. They derive from a similar parent material which consists of a coarse alluvium deposited by the Aragón river (Fig. 4.9). Above this coarse substratum a finer layer occurs (Profile 8).
These loamy alluvial soils show a moderate profile development. Structures are better developed than in the soils of the lower terrace and overall there is slightly more clay present. Incipient clay skins are frequent in the subsurface horizon. Calcium is present as mycelia but is insufficient to allow a calcic horizon to be diagnosed. The underlying coarse layer contains such high levels of calcium carbonate that it is impossible to state which is depositional and which is intrinsic.
In general the profile development of these soils (Fig. 4.10) is less intense than that of the soils of the mesas which are the oldest soils of the area.

Fig. 4.10: Profile of a soil of the highest Aragón river terrace.

Their general properties are:

a) A minimum of 50 cm depth of cultivable soil, limited by a continuous layer of semi-cemented rounded stones. The possibility of root proliferation into this substratum is only slight.

b) The most common texture of the surface soil is loam, with a slight increase of clay content in the subsurface horizon. Surface stoniness is frequent and the coarse fragment percentage increases with depth.

c) There is good structure development in the cultivated surface soil. Below 25 to 30 cm structure is weakly blocky down to the conglomerate substratum.
d) Internal drainage is extremely good and no water table is found. The infiltration rate is high, and the moisture-holding capacity moderately low because of the lack of deep fine-textured soil.

e) As the parent material is non-saline and drainage conditions are excellent, the soils are free of salinity.

The main restrictions for irrigated agriculture are depth of cultivable soil and surface stoniness, which prevent the cultivation of sugar beet and lucerne. Cereal crops, maize, and soya bean are cultivated successfully, but need frequent small irrigation applications.

4.2.6 Low Aragón terrace

The soils of the low Aragón terrace (Mapping Unit 3.2) represent only a small part of the total area. They are deep sandy loam alluvial soils with no profile development (Fig.4.11). Stratification is evident at moderate depth, with gravel and coarse sand layers interbedded between the sandy loam layers (Profile 9).

The general properties are:

a) Depth of cultivable soil, though variable, is greater than 50 cm. It is limited by the cobbles and gravel layers which appear at varying depths. The coarse alluvium is completely loose, as might be expected with an immature soil.

b) Textures vary from loam to sandy loam. Surface stoniness is rare.

c) Structure is almost non-existent, though slight structure development appears in the cultivated surface soil.

Soils are excessively drained and no water tables were found in the studied profiles. The main restrictions for irrigation are the high infiltration rate and the low moisture-holding capacity. Percolation losses under surface irrigation are therefore high.
The soils are non-saline and a permanent irrigated agriculture is maintained, maize being the most common crop.
4.2.7 Gypsum valleys

Some light brown alluvial soils occur within the gypsum valleys (Mapping Unit 3.7). They have no diagnostic horizons but an ochric epipedon and a cambic horizon. Calcium sulphate accumulation in the horizon underlying the cambic horizon is tending to become a gypsic horizon (Profile 10).

The general properties are:

a) Effective depth of cultivable soil is generally more than 1 m. There are abundant roots in the upper 50 cm.

b) Soil texture varies from silty clay loam to clay, with indications of clay movement down the profile. Some gravel layers occur at depth, but in general no lateral continuity of the soil profile exists.

c) Some structure development is occurring in the surface soil, but decreases with depth.

d) The soils are affected by salinity, sodium chloride being the most common salt. Calcium sulphate accumulations are observed at depth (Chap.5).

At present these soils are not cultivated. The observed leaching of calcium sulphate by rain water means that the percolation rate would be sufficient to leach more soluble salts if the amount of leaching water were to be increased with irrigation.

4.2.8 Stony ridges

The soils are derived from an ancient colluvium of coarse fragments. They have developed in the same manner as the mesas soils and in general consist of similar horizons, namely a reddish sandy clay loam surface soil overlying a cambic horizon which in turn overlies a light yellowish brown petrocalcic horizon (Fig.4.12). The cobbles and gravel of the stony ridges are less rounded than those of the coarse alluvium of the mesas owing to the colluvial origin of the former. Their slopes are greater than on the mesas and they are more severely eroded.
There is great variation in soil conditions due to the different degrees of erosion. Erosion may be so intense that only a thin soil layer remains, which is of such a skeletal nature that it is barely worth considering a soil. An eroded phase has therefore been separated as a different mapping unit (1.6) with no possibilities for agricultural development. Profile 11 can be considered representative of the soil of the ridges.

The general properties are:

a) Depth of cultivable soil is variable, though generally not more than 50 cm. Root proliferation through the petrocalcic horizon is limited.

b) Textures of the surface soil vary from sandy loam to sandy clay loam. Below the petrocalcic horizon is a silty clay layer derived from the residual mudstone.

c) Moderate granular structure development can be seen in the surface soil, but the subsoil below the petrocalcic horizon is structureless.

d) The soils are free of salinity because the infiltration rate and drainage conditions are so favourable that the original salts deposited within the coarse colluvium have been leached by rain water.
Land use for irrigated agriculture depends mainly on the effective depth of cultivable soil and the relative size of non-eroded areas.

4.2.9 Colluvial slopes

The soils of the colluvial slopes (Mapping Unit 2.7) are brown soils with only an incipient profile development. They derive from a mixture of colluvium and material from the underlying Miocene-Oligocene sediments.

The only profile development is a cambic horizon underlying an ochric epipedon, and the movement of calcium carbonate and soluble salts down the profile. The underlying substratum is generally siltstone, often interbedded with mudstone. Both are saline sediments with very low permeability (Profile 12).

The general properties are:

a) Average depth of cultivable soil is variable but always more than 50 cm above the slowly permeable substrata. Depth over decomposing mudstone and siltstone is variable depending on slope and situation, but where erosive forces are less the depth can be more than 2 m.

b) Textures vary from sandy loam to silty clay loam. The decomposition of the siltstone produces fine structureless sandy loam textures and the mudstone silty clay loam textures with partial structure development. There is very little gravel.

c) Soil structure is not well developed. It is moderately fine granular in the surface soil and subangular blocky in the subsoil. The underlying substrata are structureless.

d) Soil salinity is variable. Some of the studied profiles were free of salt and in others salt content increased in the deeper layers. Nevertheless there is an overall slight salinity in the unit.

Though most of these soils are under irrigation command, dry farming is practised. As deeper layers are less pervious and more saline than the