AN ABSTRACT OF THE THESIS OF

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Title: Soil Genesis, Classification, and Nitrogen Cycling in Forest Ecosystems of the Northwestern Rif Region of Morocco.

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Abstract approved:

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Soil-related information is lacking in the forest ecosystems of the Rif region. Detailed soil descriptions, and chemical, physical, and mineralogical information are necessary for planning and management.

Soils of the forested area around Chefchaouen, Morocco, were described along altitudinal gradients, and classified using soil taxonomy. Nitrogen mineralization was measured in the laboratory, using anaerobic and aerobic incubations, and in the field with trenched plots.

The dominant forest species were *Quercus suber*, *Quercus perinaïca*, *Abies marocana*, *Pinus pinaster* var. *moghrebiana*, *Pinus radiata*, and *Cedrus atlantica*. Most of the soils were shallow, unstable, and were limited in their productive capability. They were classified as Entisols, Inceptisols, Mollisols, Alfisols, and Ultisols. The main soil development processes were weathering, decalcification, melanization, mineralization,

humification, rubifaction, leaching, lessivage, gleization, and erosion. There were some differences in clay minerals related to parent material.

The potentially available soil nitrogen, N_{min} from anaerobic incubation and N_0 from aerobic incubation, in the survey experiment did not show significant differences among sites, because of the large within-site variability. N_{min} ranged from 22 to 87 mg-N kg^{-1} in the mineral surface horizons and from 3 to 31 mg-N kg^{-1} in the subsurface horizons. N_0 ranged from 48 to 143 mg-N kg^{-1} and from 18 to 57 mg-N kg^{-1} in the upper and lower horizons respectively. The rate constant of N mineralization (k) ranged from 0.130 to 0.253 $week^{-1}$ in the surface horizon and decreased significantly with depth. The values of N_{min} and N_0 measured in trenched plot experiment were lower than those measured in the survey experiment. N_{min} ranged from 11 to 46 mg-N kg^{-1} and N_0 from 29 to 54 mg-N kg^{-1}, with a significant decrease with depth for both. Yearly net N mineralization measured in the field varied from 6 to 29 kg-N ha^{-1} yr^{-1} in the surface soil (ranging from 0-10 to 0-40 cm), and from 9 to 14 kg-N ha^{-1} yr^{-1} in the subsurface horizon (ranging from 10 to 70 cm). Yearly net N uptake by plants was highly correlated with net N mineralization and varied from 17 to 25 kg-N ha^{-1} yr^{-1}.

Soil Genesis, Classification, and Nitrogen Cycling in Forest Ecosystems of the Northwestern Rif Region of Morocco

by

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Soil Genesis, Classification, and Nitrogen Cycling in Forest Ecosystems of the Northwestern Rif Region of Morocco

INTRODUCTION

In its scenery, Morocco is a microcosm of northern Africa. Its monuments reflect the rich and varied traditions of Islamic civilization. This land, first known to the Arabs as El Maghreb al aqsa, "farthest west", is bounded by two seas, a mountain chain (Rif and Atlas), and the immensity of the Sahara (Figure 1). Morocco is diverse, with a wide range of climatic zones, snow-capped mountains, immense agricultural lands, and a forest cover of approximately 9,400,000 ha.

The arch-shaped Rif mountains occupy the northwestern part of the country. This mountainous band extends along the south of the Mediterranian Sea from Tangier on the west to the mouth of Moulaouya River on the east. It has a length of 360 km and a width of 80 km in its central part (Maurer, 1968).

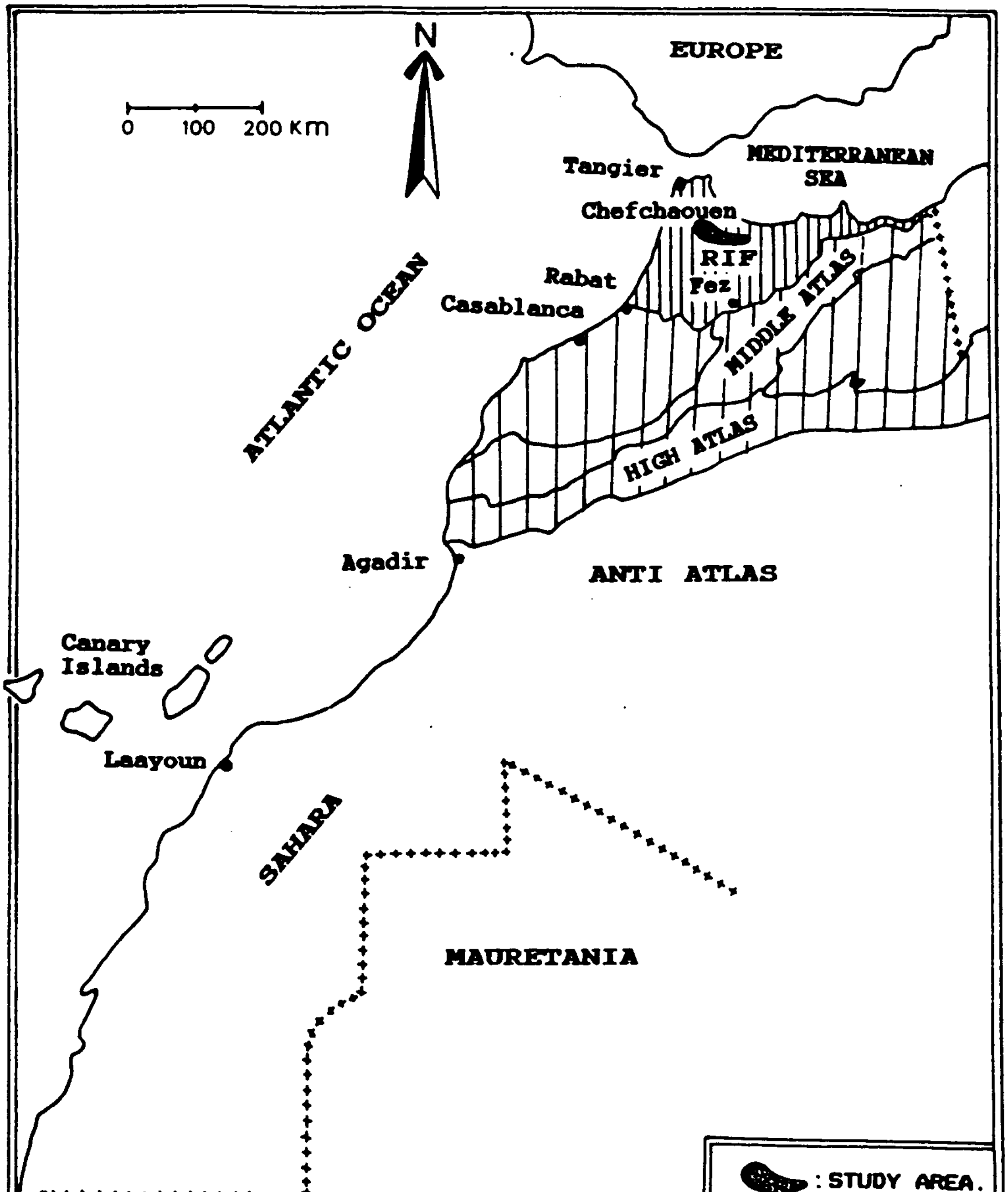
Soil is an important part of the forest environment. The big expansion of interest in the nature of soils derives from attempts to understand their properties and their suitability for different uses such as woodland, rangeland, recreational land, cropland, and land undergoing urban development.

In forest ecosystems of the Rif, soil related information is lacking. Detailed soil descriptions, chemical, physical, and mineralogical soil properties, however, are the basic information necessary to interpret soil productive capabilities and limitations. Such data delineate the most logical and profitable use for the soil.

The area under investigation was in the western part of the Rif mountains, especially the forested area extending from Jbel Alam (northwest of Chefchaouen) to Ketama, east of Chefchaouen (Figure 1).

The main objectives of this study were: i) to classify soils and use their properties as a guide to forest site quality and potential land use, ii) to characterize the soils and study their genesis under different forest stands and different parent materials along altitudinal gradients (toposequences), and iii) to study nitrogen mineralization in different forest soils around Chefchaouen under both field and laboratory conditions.

Four chapters comprise this study. The first chapter provides general information concerning the geology, the geomorphology, the climate, the vegetation, and the



<u>Figure 1</u>: Map of Morocco, geographical situation of Rif Mountains, and study area.

erosion hazard and human impact. The three other chapters correspond to the three objectives, respectively, and are presented in manuscript format.

CHAPTER I

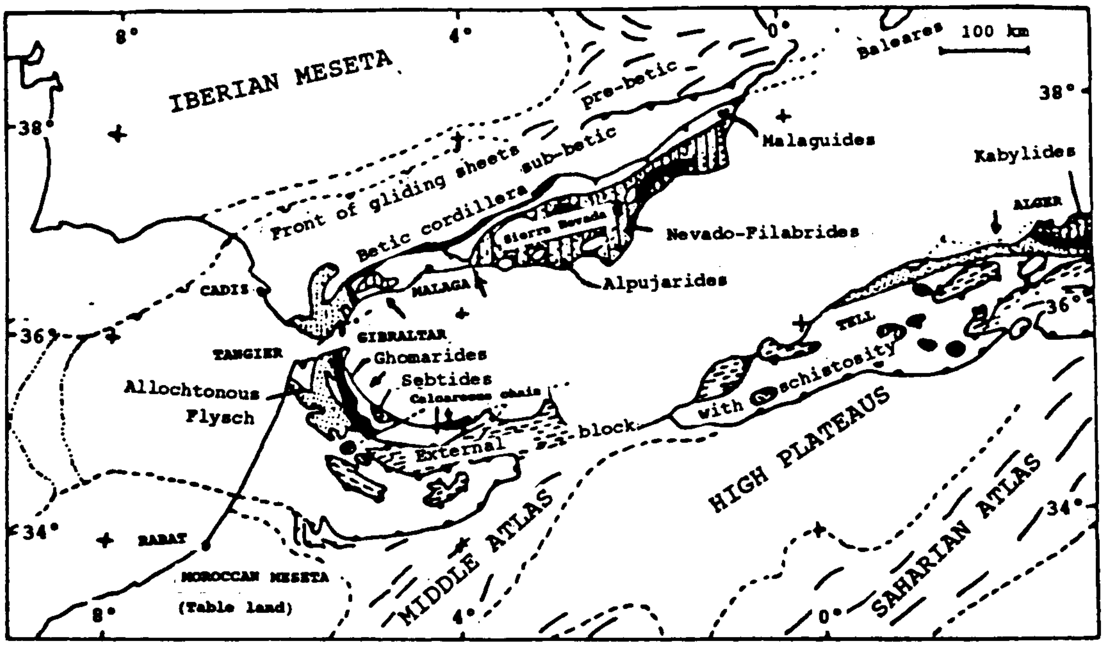
DESCRIPTION OF THE AREA

I.1- GEOLOGY.

The study area has been the subject of many geological and geomorphological studies (Griffon, 1965; Maurer, 1968; Michard, 1976; El Gharbaoui, 1981).

The Rif mountains are one of the wide alpine Mediterranean chains (Figure 2). The highest summit is Tidighine Mountain (Jbel Tidighine) with an altitude of 2,452 m. From west to east, the other high peaks are: Jbel Kelti (1,927 m); Jbel Lakraa (2,170 m); Jbel Tizirene (2,101 m). These mountains form an arch of relief and separate the chain into two sides: the Mediterranean, which is steeper, and the Atlantic side, which extends down progressively toward the lowland and plains of the Gharb.

One of the theories most favored by geologists (Durand-Delga and Mattauer, 1960; Mattauer, 1963; Durand-Delga, 1963; Andrieux, 1971; Raoult, 1975; Michard, 1976) is that the Rif mountains are derived from two furrows separated one from the other by a calcareous dorsal. The south furrow is called the external furrow and the north is known as the internal or ultra furrow. The former is a marly schistous complex deposit of which the western-most



<u>Figure 2</u>: Rif position in Alpine arc of Gibraltar and Betico-Rifo-Tellian unit (Durand-Delga, 1969; Andrieux et Al., 1971; Michard, 1976).
Loose dashes: External folded area without schistosity.
Tight dashes: External area with schistosity.
Dots: Sheets of internal zones.
White at periphery of arc: Gliding sheets.

part is called Tangier unit[1] and the latter gave the ultra-riffan nappes[2]. According to their origin, the structural units of the Rif chain are explained by the paleogeography of the Mesozoic and the beginning of the Cenozoic period, which preceded the important tectonic movements of the late Oligocene and Miocene.

The study area does not have all the geological structures of the Rif chain. The most common in the study area are:

I.1.1. Calcareous Dorsal.

This unit lies on the north and east of Chefchaouen and is considered as a part of the Median Domain. The dominant materials are limestone and dolomite of Mesozoic age (Mattauer, 1960; Maurer, 1968).

I.1.2. Numidian Sheet and adjacent formations.

On the north, east, and south of Chefchaouen, Bni Ider, Numidian Sheets, and Tangier Unit constitute most of the geological structures.

- Tangier Unit: It is a part of the external domain. It consists of Cretaceous grey marl and marly calcareous

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[1] Unit= Autochthon and para-autochthon geological formation.

[2] Nappe= Geological formation concerned with more or less important thrusting movements (thrusting sheet or thrusting formation)

rocks of Eocene age and grey to greenish sandy marl of Oligo-miocene age.

- Bni Idere Sheet: Mainly flysh of Oligocene age.
- Numidian Sheet: Essentially sandstone material of Oligocene age, with flysh in some spots. The principal summits from north toward south east are: Jbel Alam, Jbel Bouhachem, Jbel Sougna, and Jbel Khezana.

I.1.3. **The formations lying further east.**

These formations are the ones supporting oak forest around Bab Berred and cedar forest around Ketama.

- Tizirene Sheet: It is a part of the Ultrariffan Sheets which material is mainly flysh (Oligocene age) that overlies the external domain.
- Ketama Unit: It is a portion of the external domain. It is mostly schist and quartzitic sandstone (Cretaceous and Jurassic age).

I.2. **GEOMORPHOLOGY.**

Because of the broken topography in the area of study, the main features of the relief are crests, bare and steep slopes, valleys, relict torrential forms, and pediments (erosional and accumulation glacis[3])(Birot and Dresch, 1966). Crests are numerous and relatively low (2,000 m). Bare slopes or colluvium-covered steep slopes mostly connect the crests to deep valleys. This succession of crests and valleys gives the area a mountainous relief in which flat plains and basins are not very extended. Many studies show that the history of the area goes back to the beginning of the Pliocene age (6 million years B.P.) (Maurer, 1968; Paskoff, 1970; Michard, 1976; Huntley and Birks, 1983; Birks, 1986). During Pliocene time (6-1.8 million years B.P), uplifting processes began to form the future mountain chain. The rock alteration was primarily of chemical nature under a humid tropical climate where the dominant clay was kaolinite. The Rif mountains were caused by uplift following the Pliocene period. The highest steep slopes were formed by nivation niches, rubble stone flow, and the downward movement of colluvium. These phenomena are linked to the glacial ages of higher latitudes. During these glacial periods, Mediterranean regions with lower altitude (below 1,600 m) were affected by an appreciable decrease of temperature and by considerable increase of precipitation (pluvial regime).

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[3] French geographers used this term "glacis d'erosion" for surfaces which truncate soft sedimentary rocks and the term "pediment" when they cut granitic outcrops because the conditions of genesis would not be exactly similar in both cases. American scientists however, do not differentiate between these two phenomena and use the single term pediment.

Fine detrital deposits are related to an oceanic temperate climate (sandstone, quartzitic, calcareous gravels, and vermiculite clay type) (Maurer, 1968).

I.3. **CLIMATE.**

The general climate is Mediterranean. Precipitation is concentrated in the mild winter months and summer drought is tempered by fogs and cool humid sea breezes. The western part of the Rif is the wettest area of Morocco (Giordano, 1965; Maurer, 1968; Ben Abid, 1982; M'Hirit, 1982), because of its geographical position between the Atlantic ocean on the west side and the Mediterranean sea on the north side.

The most important climatic features are the Mediterranean aspect, which is dry, and the Atlantic aspect, which receives more precipitation. Site specific climate data are difficult to obtain for several reasons:

- Weather stations don't cover all the highland area and most of the existing ones are located below 1,000 m.
- Weather data registered are incomplete.

Detailed climatic studies have been done by different investigators (Maurer, 1968; Ben Abid, 1982; M'Hirit, 1982). Data of the weather stations nearest to the study sites are represented on Tables 1 and 2.

Table 1 : Monthly and yearly precipitation means (mm) (Ben Abid, 1982; M'Hirit, 1982; Maurer, 1968; Forest service for recent data). N = Mean number of precipitation days.

Weather station	Altitude (m)	J	F	M	A	M	J	J	A	S	O	N	D	Total	N
Tetouan	5	110	115	116	60	35	9	0	2	20	60	96	124	747.0	83
Bni Aross	190	160	116	121	76	51	10	0	4	15	77	139	197	966.0	65
Chefchaouen CT	280	181	163	127	74	46	15	0.5	2	9	74	113	200	1004.5	59
Bab Taza	880	239	248	202	128	76	24	1.5	1.5	21	111	165	266	1483.0	76
Bab Berred	1220	180	171	201	121	85	33	4	6	29	98	174	215	1317.0	70
Ketama	1520	299	256	200	136	87	25	4	4	25	108	202	271	1617.0	75

Table 2: Monthly and yearly temperature means (°C) (Ben Abid, 1982). Q_2 = Pluviothermic coefficient of Emberger, M = Average daily maximum temperature in the hotest month (degree Kelvin), and m = Average daily minimum temperature in the coldest month (degree Kelvin).

Weather station	J	F	M	A	M	J	J	A	S	O	N	D	Mean	M	m	Q_2
Tetouan	12	13.5	16	17.5	20	23	24.5	24	20.1	17.5	14	12	17.8	30.9	8.0	112.5
Bni Aross	11.5	12.5	15	16.5	19.2	22.5	25	23.5	20.5	17	13	11.2	17.3	36	4	103
Chefchaouen CT	11	13	15	17.5	20	25	26	25	23	17	13	11	18.0	33.5	5.5	122.7
Bab Taza	9	10.5	12	14.5	16.5	21	24.5	22.5	19.5	14.5	10.5	8.5	15.3	32.5	2.5	170
Bab Berred	5.5	7.5	11	15	17.5	21.5	23	20	15	9	7	5	13.1	29.1	2.1	135.5
Ketama	4	5.5	6.5	10	12.5	17	21	19	17	10.5	6	5	11.2	27.9	0	201.7

These data show that the yearly precipitation means increase with altitude. They range from 747 mm (Tetouan) to 1,617 mm (Ketama). An opposite trend is shown for yearly temperature means, except for Chefchaouen C.T., which has a higher value than Tetouan and Bni Aross. The range of mean annual temperature varies from 18°C (Chefchaouen CT) to 11.2°C (Ketama). The average maximum temperatures in the hottest months (M) range from 27.9°C (Ketama) to 36°C (Bni Aross) and the average minimum temperatures in the coldest months (m) range from 0°C (Ketama) to 8°C (Tatouan).

Normally the first showers begin in September, reach a maximum in winter (December, January, February) and decline in intensity by the end of spring (April and May). Little precipitation occurs in summer (July and August). Snow occurs at higher altitudes (over 800 m); however, it does not last long except in the highest mountains where it persists until summer time. The yearly mean number of snowfall days are 5 (Bab Taza), 9 (Bab Berred), and 12 (Ketama).

These climatic results are tempered by the presence of a fog belt, which is almost constantly present over altitudes of 1,000 m. This fog bank covers the area most of the year, even in summer. It gives the high lands a relatively high humidity.

In the study area, the altitudinal gradient is the most important factor that influences local climatic variations besides aspect and continentality. Because of the lack of weather stations at the highest elevations, precipitation and temperature must be estimated by extrapolation from data of the nearest climatic station. The linear equations formulated by M'Hirit (1982) are shown on Table 3.

Table 3: Linear climatic models (M'Hirit, 1982). R^2 = Coefficient of determination and Alt = Altitude (m).

Climatic features	Altitudinal range (m)	Linear model $Y = A + 100\ BX$	R^2
Maximal temperatures	500-1800	$M = 34.9 - 0.47\ Alt$	78
Minimal temperatures	500-1800	$m = 9.3 - 0.65\ Alt$	91
Precipitation	500-1800	$P = 507.5 + 49.6\ Alt$	75

Using the data from Tables 1 and 2 and from other weather stations, the models established in this study are shown on Table 4.

Table 4: Linear climatic models of the study area.
r = Coefficient of correlation and
Alt = Altitude (m).

Climatic features	Altitudinal range (m)	Linear model $Y = A + 100\ BX$	r	Number of weather stations
Maximal temperatures	400-1600	$M = 38.24 - 0.70\ Alt$	- 0.73	9
Minimal temperatures	400-1600	$m = 9.22 - 0.64\ Alt$	- 0.86	9
Precipitation	0 -1600	$P = 618.75 + 66.61\ Alt$	+ 0.79	23
Mean temperature	0 -1600	$T = 18.46 + 0.43\ Alt$	- 0.97	16

The values predicted by the models are important because of the role they may play in the estimation of climatic regimes at the altitudes where data are lacking.

Climatic diagrams of Bagnouls and Gaussen (1953) show the general variation of temperature and precipitation and the importance of dry season (Figure 3). The dry season always coincides with summer time. Along the coast the dry season becomes longer from north to south and from west to east. On the Atlantic coast, Tangier has 4 dry months and Larache 4.5 months. On the Mediterranean coast, Sebta has 5 months, Martil has 5.5 months, and Oued Laou has 6 months. Altitude is another factor that influences the duration of the dry season. Chefchaouen C.T. (280 m) has 4.5 dry months, Bab Taza (880 m) has 3.5 months, and Ketama (1,520 m) has only 3 months of dry season. Shorter periods of 2 months occur on the

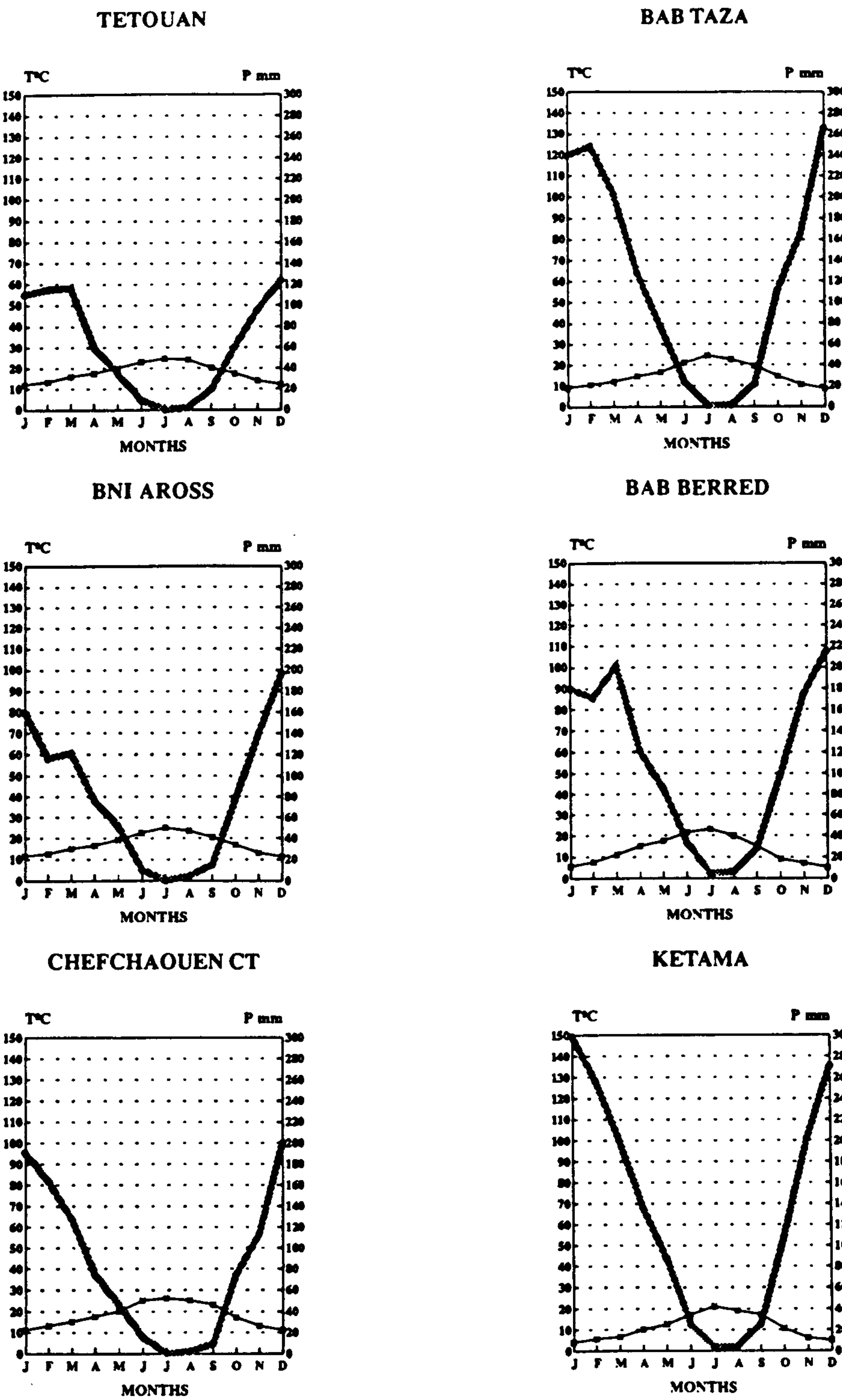

Figure 3: Ombrothermic curves.

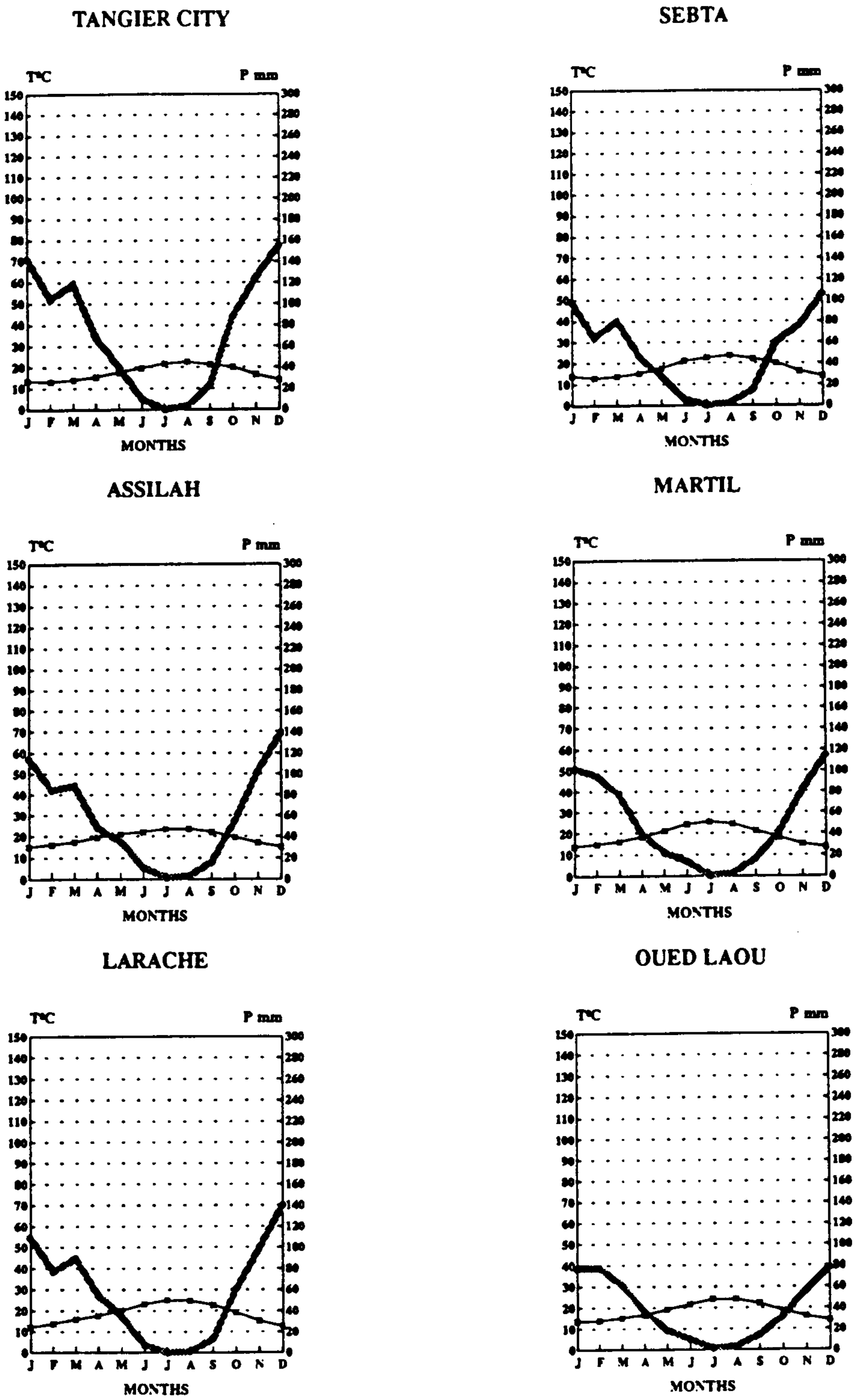

Figure 3: Continued.

highest mountain summits. The pluviothermic coefficient of Emberger (1955) is calculated from:

$$Q2 = \frac{1000\ P}{\frac{(M + m)}{2}(M - m)} = \frac{2000\ P}{M^2 - m^2}$$

P = Yearly mean precipitation (mm)
M = Average daily maximum temperature in the hotest month (degree Kelvin).
m = Average daily minimum temperature in the coldest month (degree Kelvin).

This coefficient differentiates well among different Mediterranean climatic types (Emberger, 1955). The pluviothermic diagram is plotted with Q_2 as the ordinate and m as the abscissa. The bioclimatic types presented are: Saharian, arid, semi-arid, subhumid, humid, and superior humid or perhumid. In general character, the types of climate in the study area vary from warm humid to mild humid. Most of the forests around Chefchaouen are subhumid to humid bioclimatic types. High lands have either humid or perhumid bioclimatic types (Figure 4).

I.4. **VEGETATION.**

Elevation, precipitation, temperature, parent rock, and the distance from the coast are important factors that lead to the diverse vegetation and remarkable patterns

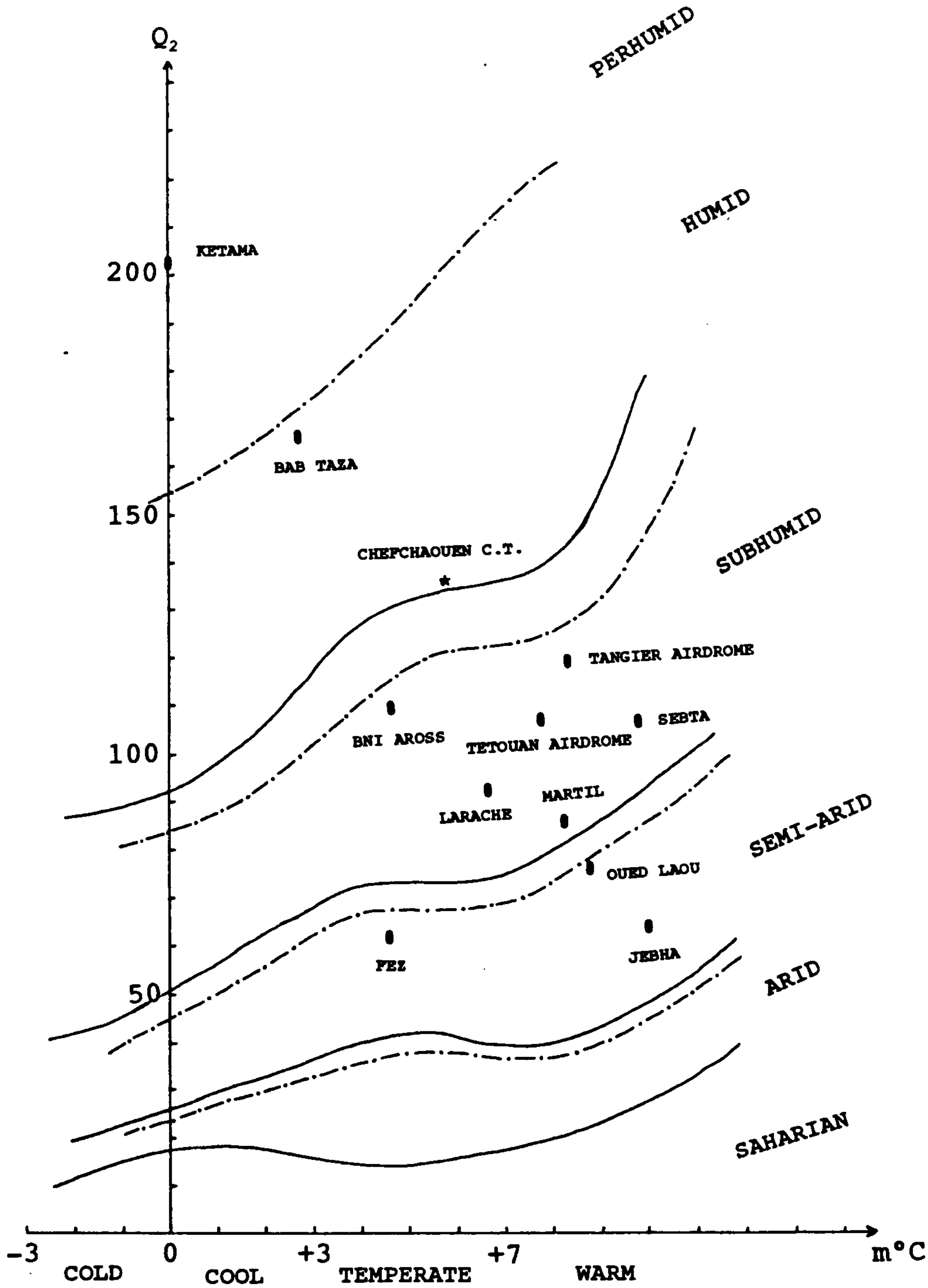

Figure 4: Pluviothermic diagram of Emberger.
_______ Bioclimatic belt limits (Sauvage, 1962 & 1963).
_._._._ Modified bioclimatic belt limits (Ben Abid, 1982).

that have been the subject of classic vegetation studies (Emberger et al. 1928; Sauvage, 1962 & 1963; Giordano, 1965; Maurer, 1968; Ben Abid, 1982). In addition to extensive agricultural development, most of the area is covered with forests and shrublands, with some patches of grassland. The greater proportion of the current forest vegetation consists of _Quercus suber_ (cork oak), _Quercus rotundifolia_ (green oak), _Cedrus atlantica_ (cedar), _Pinus pinaster_ var. _moghrebiana_, _Pinus radiata_, _Pinus nigra_, and _Pinus halepensis_ (pine), _Tetraclinis articulata_ (thuja), _Abies pinsapo_ subsp. _marocana_ (fir), _Quercus faginea_, _Quercus canariensis_, and _Quercus pyrenaïca_ (deciduous oak). Representative shrubs are _Erica sp._, _Cistus sp._, _Arbutus unedo_, and _Myrtus communis_. Besides these species, which form natural forests, there are areas of conifer plantations. The legend of the forest map established by the mapping division in collaboration with the Forest Service (1987) shows that the total forested area (including scrubland) around Chefchaouen makes up about 174,710 ha (43 % of the total province area). A detailed inventory of species in the Chefchaouen area is shown in Table 5.

Table 5: Species repartition in Chefchaouen area (Moroccan Forest Map, 1987).

Species	Area (ha)	percentage %
- Natural species		
• cedar	3600	2.1
• evergreen oak	300	0.2
• cork oak	28700	16.4
• thuja	2000	1.1
• natural pine + fir	6800	3.9
• others (shrubs)	117700	67.4
Subtotal (1)	157700	91.1
- Planted species		
• coniferous (pine)	15100	8.6
• broad leaved (Eucalyptus)	500	0.3
Subtotal (2)	15600	8.9
Total (1) + (2)	174700	100 %

Most of the stands are natural forests (91 % of the total forest area). However, if we deduct all the scrublands (about 65 % of the total forests) from this value, the real forest stands represent only 25 % of the total forest lands or 14 % of the total province area. These are shared between cork oak (16 %) and the other species such as green oak, thuja, pine, cedar, and fir (7 %). An additional 9 % is covered with coniferous planted species (pine).

It should be emphasized that about 30 % of the province's forested area is no longer natural forest stands but are stands that have been impacted by human use. This degeneration of forest converts rich forest communities to an open dwarf forest or heath shrubland.

A good description of the forest stands and their relationships to climatic sequences and geologic substrata is given in Table 6 (Ben Abib, 1982). The variables considered are climatic sequences, such as perhumid, humid, subhumid, semi-arid (Emberger, 1955), and geologic substrata, such as marl, limestone, sandstone, or schist.

- *Olea europea* is dominant on marly subhumid low hills. In other climatic sequences, this species is either rare or associated with other species: *Quercus coccifera* and *Quercus rotundifolia* for humid sequences and *Tetraclinis articulata* for the semi-arid sequence.

- *Abies marocana* develops only in the perhumid sequence of calcareous and marly calcareous substrata (Talassamtane forest on Jbel Lakraa). This species grows on slopes between 1,500 and 2,000 m. Within this range, some lower limits are occupied by clusters of *Pinus nigra* var. *mauretanica* and stands of *Pinus pinaster* var. *maghrebiana*. Below 1,500 m, fir is mixed with or dominated by *Quercus rotundifolia* and *Quercus faginia*. The high ridges are covered with *Cedrus atlantica*.

- *Cedrus atlantica* stands are well developed on schistous sandstony flysh of the Tizirene Sheet and the Ketama Unit further East.

Table 6: The relation between vegetation, climate, and geological substrata (Ben Abid, 1982).

Climatic sequences / Substrate	Perhumid or Superior humid	Humid	Subhumid	Semi-arid
Marly low hills		Dominant -Quercus coccifera -Quercus rotundifolia Rare -Olea europea	Dominant -Olea europea	Dominant -Tetraclinis articulata Rare -Olea europea -Pinus halepensis
Calcareous and marly calcareous rocks	Cold and cool climates -Abies marocana (Fir) -Pinus nigra var. mauritanica -Pinus pinaster var. maghrebiana -Quercus alpestris (cool depressions) -Quercus rotundifolia (slopes) -Quercus faginea Temperate and warm climates -Quercus coccifera		Cold and cool climates -Quercus rotundifolia (green oak) -Pinus pinaster var. maghrebiana may be pure or in mixture together Temperate and warm climates dominant -Quercus coccifera (highland) -Tetraclinis articulata (lowland) -Olea europea (colluvium) Rare -Quercus rotundifolia (depression)	Dominant -Tetraclinis articulata
Sandstone and shist	Cold climate -Cedrus atlantica (Tizirene) -Quercus rotundifolia -Pinus pinaster var. maghrebiana (deep eastern slopes) Cool climate -Quercus pyrenaica -Quercus canariensis (deepsoil) -Quercus suber -Pinus pinaster var. maghrebiana (deep easternslopes) Temperate climate -Quercus pyrenaica (dominant) -Quercus canariensis (dominant on slopes) -Quercus rotundifolia (rare) -Pinus pinaster var. iberica (Tangier region)		Cold climate -Cedrus atlantica -Quercus rotundifolia -Quercus suber -Pinus pinaster var. maghrebiana Cool climate -Quercus canariensis -Pinus pinaster var. maghrebiana . Temperate and warm climates -Quercus suber (dominat) -Pinus pinaster var. iberica	Tetraclinis articulata Pinus halepensis

- Quercus canariensis and Quercus pyrenaïca stands dominate on sandstone and schist of the perhumid and humid sequences.

- Quercus suber, the most dominant forest species in the Chefchaouen area, may grow at elevations of up to 1,500 m. Well developed stands extend over Jbel Alam, J. Bouhachem, J. Sougna and J. Khezana, especially on silicic rocks.

The understory of oak forests is dominated by shrub species such as Genista monspessulana, Cistus salviifolius, Cistus crispus, Cistus populifolius, Cistus varius, Cytisus triflorus, Daphne gnidium, Arbutus unedo, Erica arborea, Erica australis, Erica ciliaris, Erica scoparea, Erica umbellata, Calluna vulgaris, Lavandula stoechas, Myrtus communis, and Chamerops humilis. All these understory species, along with others, may also exist as a degeneration sequence of oak forests when human impact reaches an advanced stage.

I.5. **EROSION HAZARD AND HUMAN IMPACT.**

Soil loss from forested areas is normally minimal. The western part of the Rif is one of the most forested areas in Morocco. However, geologic, geomorphic, and climatic features coupled with human activities are important factors that lead to the sensitivity of the area to erosion.

In the Chefchaouen area, and in the western part of the Rif in general, the main causes of land degradation and soil erosion stem from indiscriminate human interference in the natural ecological balance, from abuse and mismanagement of the soil and water resources, and from farming land beyond its capability. Specific quantitative studies of erosion hazard in the area have not been reported in the literature, however.

Historically, one of the principal causes of land degradation was the regular clear cutting of forests practiced in the area by Spanish forest services before the independence of Morocco. Cedar, fir, and pine wood was used for timber production. Deciduous species of oak were used for railroad construction in Spain, green oak for firewood, and cork oak for cork (Ben Abid, 1985). During recent decades, most forest lands have become sensitive to erosion because of arable farming along slopes, grazing of animals beyond the carrying capacity of pasture, unplanned forestry operations, and population pressure. Because of population increases and the lack of other work opportunities, forests have a great socio-economic role in the area, either directly producing income through wood cutting or indirectly through clearing and conversion of forests to agricultural lands. At Bni Bounsar region (further east), 17 Mg of woody branches per house per year are taken from forests (Ben Abid, 1982). Inventory of cedar forests by the Forest Service shows that 200,000 poles were cut during a recent decade (1970-1979). This represents 8,000 m^3 yr^{-1} (much greater than the regular cutting by the Forest Service, which is 4,400 m^3 yr^{-1}). A personal investigation shows that the main unlawful activities in forest in relation to land degradation are overgrazing, wood cutting, and clearing for cultivation. Table 7 gives data concerning these activities during the decade 1980-1989. Another consequence of these activities is the siltation of rivers and reservoirs. An example is the siltation volume of the oued El Makhazine dam (Table 8). The decrease in the volume of silting materials observed in 1987 may be explained by the decrease in precipitations and, therefore, runoff water during this time.

Table 7: Legal cases of violations related to human activities in forests (Chefchaouen Forest Service).

Activities in forest	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	Mean values
Grazing	27	15	12	12	12	7	1	22	23	8	14
Wood cutting	130	96	44	55	33	59	61	48	26	25	58
Clearing for cultivation	375	460	105	64	58	70	365	710	818	266	329
Totals	532	571	161	131	103	136	427	780	867	299	401

Table 8: Siltation volumes of Oued El Makhazine dam (Agricultural Development Project of Loukkos Watershed (1989)).

Years	Yearly silting of dead portion of the dam reservoir (millions of cubic meters)
Before 1982	1.40
1982 - 1985	1.15
1986	1.80
1987	1.02

The following three chapters are devoted to study soil classification, soil genesis, and nitrogen cycling in forest areas of the northwestern Rif region and to give forest managers and planners a basic background of soil related information.

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CHAPTER II

SOIL CLASSIFICATION

ABSTRACT.

Soils of the northwestern part of Morocco are one of the least studied component of these forest ecosystems. Soil classification and survey are important for any management purpose and planning.

The study area included the forests of Jbel Alam, Talassamtane, Madissouka, Chefchaouen, Khezana, Bab Taza, and Ketama. The dominant forest species were Quercus suber (oak), Abies marocana (fir), Pinus pinaster var. moghrebiana and Pinus radiata (pine), and Cedrus atlantica (cedar). The study area was subdivided into four broad geological groups comprised of colluvium-residuum deposits derived from calcareous and dolomitic materials, sandstone, mixed schistous sandstone, and mixed quartzitic sandstone deposits.

Forty-four soil profiles were described by genetic horizons within altitudinal gradients (toposequences), according to vegetation type and lithological substrata. A total of 182 horizon samples were analysed for physical, chemical, and mineralogical soil characteristics. Soils of the forests around Chefchaouen were classified using soil taxonomy and morphogenetic classification (C.P.C.S.).

All major factors of soil formation (climate, parent material, relief, time, and vegetation) vary widely within the highland forests as does their relative influence on soil characterestics. Most of the soils were shallow, unstable and were limited in their productive capabilities. They were classified as Entisols or Inceptisols (soils lacking or with little development, irrespective of parent material); Mollisols or Alfisols (both on calcareous parent material); and Ultisols (on acidic parent material).

These soils showed good to moderate nutrient levels. The main factors maintaining fertility through the cycling of nutrients were the recycling of literfall and the high base levels of some of the parent materials. The most suitable use of the soil in the area is the retention as woodland. Where clearing and cultivation of soil becomes necessary, poorly drained soils of concave spots on midslopes and valley bottoms could be used for cultivated field crops provided artificial drainage is feasible. In the sites where reforestation is required, adequate selection of adapted species and appropriate plantation techniques are imperative.

II.1. INTRODUCTION.

The forests around Chefchaouen are characterized by geological and geomorphological complexity of the terrain, contrasting types of climate, and diversity of vegetation.

The population of the area is presently undergoing umpreçedented growth and urbanization. The natural forests are of particular interest for the local population as a source of income and for grazing. Under the effect of the growing urban population, and the spreading of urban development, the present tendancy is the creation of mixed rural-urban areas. If these areas are to be used successfully, it is essential for the land manager to have a good understanding of forest ecosystems.

The geology, geomorphology, climatology, and vegetation of the area have been relatively well studied (Griffon, 1965; Maurer, 1968; Michard, 1976; El Gharbaoui, 1980; Ben Abid, 1982; M'Hirit, 1982). However, there has been little study of the soils.

Soil properties exert a strong influence on the manner in which man uses land. Soils are an irreplaceable resource, and mounting pressures upon land are constantly making this resource more and more valuable. A need exists, in any comprehensive regional planning program to examine not only how land and soils are presently used but how they can best be used and managed.

Most of the soils were previously classified as Mediterranean red soils or Brown forest soils (Giordano, 1965; El Gharbaoui, 1980; Ben Abid, 1982). Due to the nature of parent material and the mountainous relief, most of the soils are considered fragile or unstable, and whatever capacity they have for sustained productivity could be rapidly lost by misuse and mismanagement. If the soils are to continue to produce and sustain an increasing population, it is essential that they be properly used; and for this purpose they should be characterized and appropriately classified.

The objective of this study was to examine soils from different forest types and different parent materials along altitudinal gradients (toposequences) and characterize the relationship of their properties to site quality and management.

II.2. MATERIALS AND METHODS.

The study sites were selected to represent the principal forest stands that extend along a geographical band from Jbel Alam near Holly Moulay Abdessalam (20 km northwest of Chefchaouen) to Ketama (about 60 km east of Chefchaouen).

The dominant species in the forest stands were:

- Quercus suber (cork oak); at Jbel Alam, Aïn Rami, Amlay, and spots in Talassamatane and Khezana.

- Quercus faginea and Quercus pyrenaïca (deciduous oak); at Khezana and Bab Berred.

- Abies marocana (fir); at Talassamtane.

- Pinus pinaster var. moghrebiana and Pinus nigra (natural pine); at Talassamtane and Madissouka.

- Pinus pinaster var. moghrebiana and Pinus radiata (pine plantations); at Aïn Rami, Bab Taza and Bab Berred.

- Cedrus atlantica (cedar); at Ketama.

II.2.1. **Field study.**

Initial field studies were conducted in several forest stands. These consisted of preliminary observations from road cuts, cut banks, and auger holes (Summer 1988). Detailed field studies from pits (1 m x 2 m x depth to parent rock materials) were carried out during repeated visits to the field (1989-1990). The pits were located in different stands at representative slope positions along altitudinal gradients (toposequences). In each pit, one side was kept undisturbed for profile description. Site features and morphological soil descriptions were recorded at each site using conventional procedures (Soil Survey Staff, 1975) on description forms from the Soil Science

Department of Oregon State University. Forty-four profiles were sampled by genetic horizons from 10 representative forest stands. A total of 182 soil samples were collected on a horizon basis and analysed for selected physical and chemical characteristics.

The toposequences were given names of the localities where they occur and soil profiles indicated by the initial letters of corresponding locations. The geographical distribution of the sites sampled is shown on Figure 5.

II.2.2. Soil classification.

Soil classification is a technique by which soils can be aggregated into categories that are useful for understanding soil genesis, properties, and behavior (Girald, 1981). The soil profiles were classified according to two systems being used in numerous countries, i.e., soil taxonomy (Soil Survey Staff, 1975) and the French classification system (Aubert G., 1968; C.P.C.S, 1967). Morpho-analytical features were used to place soils in both systems.

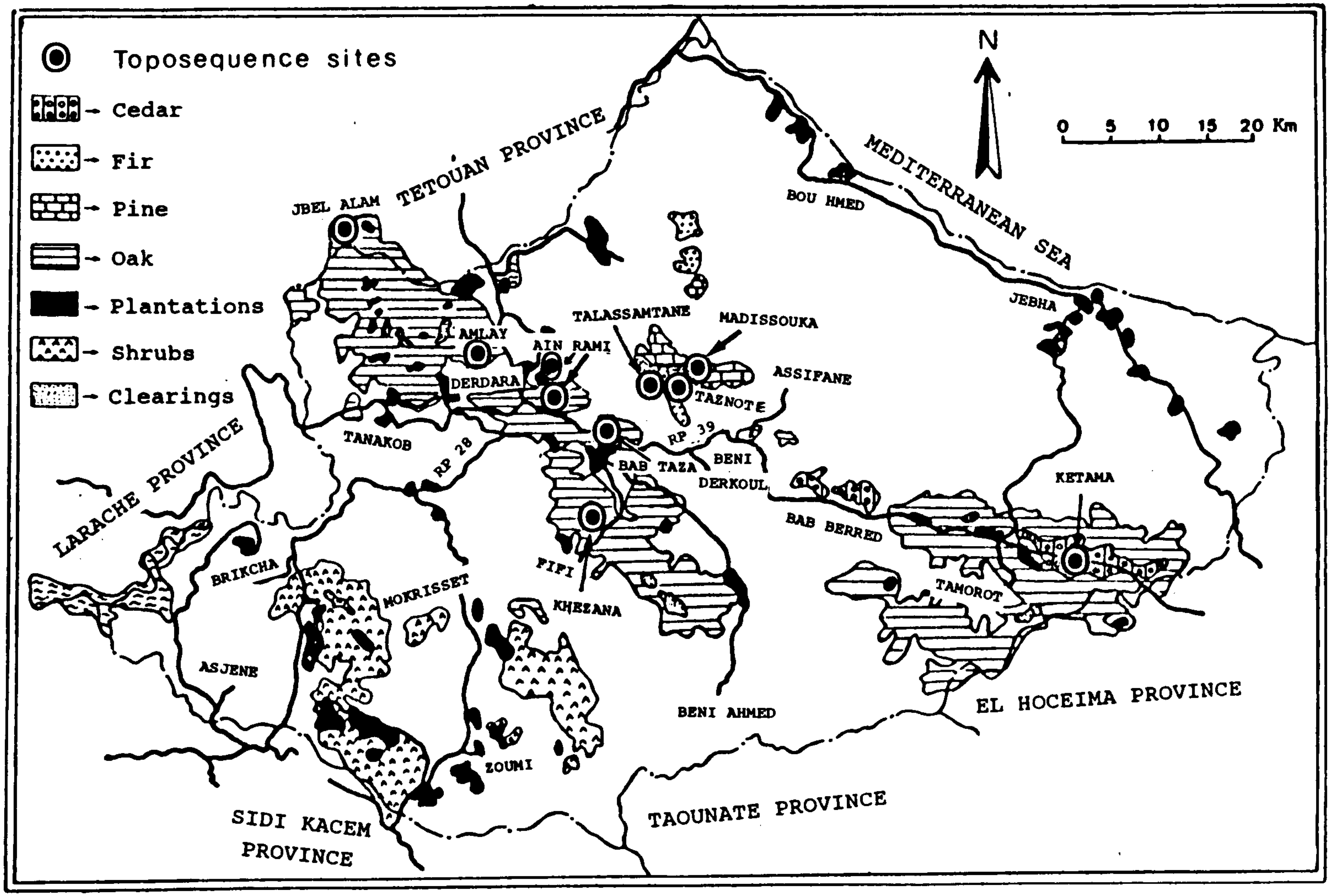

Figure 5: Geological location of toposequences.

II.2.3. Laboratory analyses.

Chemical analyses were conducted on each horizon sampled from these profiles. The soil was air-dried at laboratory temperature and crushed to pass a 2-mm sieve. The techniques used are the ones adopted by the soil analysis laboratory of both the Agronomic Research Institute and the Forest Research Division in Rabat, Morocco (Sefrioui et al., 1971). Properties considered were available phosphorus (extracted with sodium bicarbonate at pH 8.5 for calcareous soils and with sulfuric acid at pH 3.5 for acid to neutral soils), total Kjeldahl nitrogen (digested with a concentrated H_2SO_4 and K_2SO_4 catalyst mixture), exchangeable cations (ammonium acetate method and atomic absorption determination), organic carbon (potassium dichromate and concentrated H_2SO_4 reactions), active carbonate (fine carbonate fraction), with ammonium oxalate and sulfuric acid reaction, total carbonate (with 0.05 N HCl reaction), pH (glass electrode and saturated soil paste), cation exchange capacity (ammonium acetate reaction and Kjeldahl distillation for non-calcareous soils, and sodium acetate reaction, atomic absorption for calcareous soils). The particle size analysis was performed according to standard techniques (Aubert, 1978).

II.3. RESULTS AND DISCUSSION.

II.3.1. Soil classification.

II.3.1.1. Soil taxonomy.

Soil taxonomy is a natural comprehensive system of soil classification, which classifies soil properties for many uses. A major advantage of the system is its ability to be modified in order to fit new knowledge, and hence it is considered an open-ended system.

In Morocco, the first attempts to use the U.S. system were in 1965 (Mediterranean Pedology Conference). It is important to note that not all profiles were easy to fit into the soil taxonomy system. In several cases, the use of new subgroup names was necessary.

The soil profiles examined in this study include the following orders: Inceptisols (34.1 %), Ultisols (25.0 %), Mollisols (25.0 %), Alfisols (9.1 %), and Entisols (6.8 %). Entisols, even if they represent only 6.8 % of the profiles occurred in the landscape in as high a proportion as Inceptisols. Entisol sampling was limited because most of these soils were very shallow. These results are similar to those published in 1972 by the U.S Soil Conservation Service, representing Morocco on the World Soil Map. Soils of the Rif Mountains were classified dominantly as Entisols and Inceptisols at higher altitudes and by Xeric great groups of Entisols, Inceptisols, Mollisols, Ultisols, and Alfisols at lower altitudes. The udic moisture regime at higher elevations is due to the cold temperatures, precipitation, fog, and the prevalence of shade under trees. The frequency with which different soil orders occur in the toposequences is shown in Table 9.

Table 9: Frequency with which different soil orders occur in the forest stands (toposequences). Toposequences have names of the localities in which they occor. Profile names are the initial letters of the corresponding locations.

	Soil orders				
Toposequence	Entisols	Inceptisols	Mollisols	Alfisols	Ultisols
Jbel Alam		AL2,AL3,AL4			AL1, AL5, AL6
Khezana		Kh13,Kh14,Kh15			
Madissouka	M12	M9,M10	M7,M8,M10',M11		
Talassamtane			TL25,TL27,TL27'	TL22,TL23,TL26, TL28	
Taznote			T19,T20,T21,T24		
Aïn Rami-Amlay		AR33,AR41,AR42			A35,A36,AR34,AR40
Bab Taza	BT17	BT16			BT18
Ketama		K29,K30			K31
Bab Berred		BB32			
Mouzel	Mo39				Mo37,Mo38
Number of profiles Percent of total	3 (6.8 %)	15 (34.1 %)	11 (25.0)	4 (9.1 %)	11 (25.0 %)

Entisols and Inceptisols occurred in most toposequences, with a wide range of parent materials, climate and vegetation. Mollisols were found only on calcareous and dolomitic parent materials and with a perhumid type of climate. For Alfisols, the only common factors seem to be fir vegetation and calcareous and dolomitic parent materials. Ultisols were mainly under oak forest on sandstony parent material. Characteristics of the main environmental units and classification are shown in Table 10.

II.3.1.2. **Morphogenetic classification: C.P.C.S..**

As stated by Buol et al. (1980), this classification system has been strongly influenced by the Russian pioneers in pedology and by certain European soil scientists who emphasized the use of chemical methods to differentiate among soils (Ramann, 1911, 1918; Sigmond, 1938). Kubiana's classification (1948) emphasized ecological conditions to differentiate among soils. In the morphogenetic classification system, considerable emphasis was given to genetic and morpho-analytical grouping of soils as a function of moisture regime (aeropedic, hydropedic, etc.) and fundamental processes such as gleization, calcification, salinization, and clay formation.

Table 10: Characteristics of the main environmental units and examined soil profiles.

Toposequence Lithology & vegetation	Pedon	Elevation (m)	Exposure	Soil classification		
				Soil Taxonomy (USDA) higher categories	French classification (CPCS)	Family Soil Taxonomy
Jbel Alam. Sandstone material. Cork oak forest.	AL1	1030	SW	Umbric-ruptic hapludult	Sol brun lessivé humifère à A_2 peu differencié	Loamy skeletal mixed mesic
	AL2	960	E	Eutric typic haplaquept	Sol hydromorphe peu humifère à gley profond	Fine mixed mesic
	AL3	970	E	Aquic haplumbrept	Sol brun humifère à pseudogley	Fine mixed mesic
	AL4	820	NNE	Dystric xerochrept	Sol peu evolué xérique à tendance brun lessivé	Sandy mixed mesic
	AL5	1190	WNS	Pachic umbric hapludult	Sol brun lessivé humifère à A_2 peu différencié	Fine mixed mesic
	AL6	450	SE	Aquic haploxerult	Sol brun acide faiblement lessivé à pseudogley	Fine mixed mesic
Khezana. Sandstone material. Deciduous oak.	Kh13	1030	NE	Typic humaquept	Sol hydromorphe, humifère à gley	Fine mixed mesic
	Kh14	1100	SSE	Cumulic haplumbrept	Sol brun acide humifère	Sandy mixed mesic to thermic
	Kh15	1140	SSE	Lithic haplumbrept	Sol peu evolué humifère	Coarse Sandy mixed mesic
Madissouka. Calcareous and dolomitic material. Pine forest.	M7	1120	NNE	Cumulic haplaquoll	Sol hydromorphe peu humifère à gley	Calcareous loamy mixed mesic
	M8	1120	NNE	Fluventic hapludoll	Sol peu évolué humifère d'apport alluvial	Calcareous fine mixed mesic
	M9	1170	N	Rendollic eutrochrept	Sol brun modal carbonaté	Calcareous fine loamy mixed mesic
	M10	1220	NE	Rendollic eutrochrept	Sol brun modal carbonaté	Calcareous fine mixed mesic
	M10'	1260	NE	Lithic rendoll	Rendzine brunifié	Calcareous coarse mixed mesic
	M11	1150	S	Typic rendoll	Rendzine humifère à moder	Calcareous sandy mixed mesic
	M12	1170	S	Lithic udorthent	Sol lithocalcique peu humifère	Calcareous sandy mixed mesic

Table 10: Continued.

Toposequence Lithology & vegetation	Pedon	Elevation (m)	Exposure	Soil classification		
				Soil Taxonomy (USDA) higher categories	French classification (CPCS)	Family Soil Taxonomy
Talassamtane . Calcareous and dolomitic material . Fir forest :	TL22	1680	NW	Lithic hapludalf	Sol brun eutrophe	Loamy mixed mesic
	TL23	1640	NE	Mollic hapludalf	Sol brun eutrophe	Fine mixed mesic
	TL25	1750	SE	Typic argiudoll	Sol brun carbonaté	Fine loamy mixed mesic
	TL26	1700	SE	Umbric vertic hapludalf	Sol brun fersiallitique, lessivé, vertique	Clayey montmorillonitic mixed mesic
	TL27	1710	SE	Lithic argiudoll	Sol brun fersiallitique, humifère, faiblement lessivé	Fine skeletal mixed mesic
	TL27'	1730	SE	Lithic argiudoll	Sol brun calcaire, faiblement lessivé rendziniforme	Fine mixed mesic
	TL28	1770	SE	Abruptic hapludalf	Sol brun lessivé	Fine loamy mixed mesic
Tazaote . Calcareous material . Mixed oak-fir forest.	T19	1570	SW	Entic rendoll	Rentzine peu humifère	Fine loamy to sandy skeletal mixed mesic
	T20	1620	SW	Fluventic hapludoll	Sol brun calcaire hydromorphe	Fine loamy mixed mesic
	T21	1650	SW	Lithic rendoll	Sol peu évolué humifère	Fine loamy skeletal mixed mesic
	T24	1560	-	Fluventic haplaquoll	Sol hydromorphe humifère a gley peu profond	Fine clayey mixed mesic
Aïn Rami . Mixed schistous sandstone material . Cork oak .	AR33	550	W	Umbric distrochrept	Sol brun fersiallitique acide	Fine sandy mixed mesic to thermic
	AR34	430	SW	Aquic haploxerult	Sol rouge fersiallitique lessivé hydromorphe	Clayey mixed mesic to thermic
	AR40	600	SW	Aeric albaqualt	Sol hydromorphe planosolique ferrugineux à pseudogley	Very fine clayey mixed mesic to thermic

Table 10: Continued.

Toposequence Lithology & vegetation	Pedon	Elevation (m)	Exposure	Soil classification: Soil Taxonomy (USDA) higher categories	Soil classification: French classification (CPCS)	Soil classification: Family Soil Taxonomy
Ain Rami . Mixed schistous-sandstone material . Pine plantations .	AR41	750	NW	Fluventic dystrochrept	Sol rouge fersiallitique oligotrophe brunifié	Fine mixed mesic to thermic
	AR42	640	NW	Aquic, ultic, ruptic dystrochrept	Sol rouge fersiallitique oligotrophe à pseudogley	Fine clayey skeletal mixed mesic to thermic
Amlay . Sandstone material . Cork oak forest .	A35	460	NE	Ruptic aeric albaquult	Sol hydromorphe planosolique lessivé à pseudogley	Very fine clayey mixed mesic to thermic
	A36	360	E	Fluventic aquic typic haploxerult	Sol rouge fersiallitique lessivé à pseudogley	Very fine clayey skeletal mixed mesic to thermic
Bab Taza . Mixed schistous-sandstone material . Pine plantations .	BT16	580	SE	Entic xerumbrept	Sol peu evolué humifère	Fine sandy over skeletal mixed thermic
	BT17	500	SE	Lithic umbric xerorthent	Sol peu evolué humifère	Fine skeletal mixed thermic
	BT18	640	NNW	Typic albaquult	Sol brun faiblement lessivé à pseudogley	Fine mixed thermic
Ketama . Mixed quartzitic-sandstone material . Cedar forest .	K29	1610	N	Umbric dystrochrept	Sol brun acide	Fine loamy mixed mesic
	K30	2030	N	Umbric ruptic dystrochrept	Sol brun acide	Fine loamy skeletal mixed mesic
	K31	1550	-	Umbric hapludult	Sol brun acide faiblement lessivé	Fine loamy mixed mesic
Bab Berred . Schistous sandstone . Deciduous oak .	BB32	1380	N	Lithic haplumbrept	Sol peu evolué brunifié acide	Fine loamy skeletale mixed mesic
Mouzel . Mixed schistous-sandstone material . Green oak forest .	Mo37	1300	W	Alfic-vertic haplohumult	Sol brun acide lessivé	Fine loamy mixed mesic
	Mo38	1290	E	Aeric albaquult	Sol hydromorphe planosolique à pseudogley	Fine clayey mixed mesic
	Mo39	1310	E	Lithic udorthent	Sol peu evolué faiblement humifère	Fine mixed mesic

The modern French system established by the Commission of Pedology and Soil Cartography (C.P.C.S. 1967) was mostly used in France and French-speaking countries. This system is based on pedogenic criteria, following mainly the lines developed by Duchaufour (1963) and Aubert (1968). Although a limited number of diagnostic properties have been established for the definition of the taxa in the higher categories, the system as a whole is pedogenetic with the taxa defined and named according to soil forming processes rather than the current soil properties resulting from soil formation. The disadvantage of this system is that the processes to be classified are often incompletely understood and frequently debatable. The other danger of the genetic approach is that certain pedogenic processes might not be recognized and hence not included in the classification. A summary of French Classification units is shown in Table 10.

II.3.1.3. **Comparison of the two systems.**

A universally valid correlation between taxa of the two systems used in this study is very difficult, if not impossible, because of the difference in diagnostic criteria used in defining the taxa in each system. The principal discrepancy between the two systems is the importance given by the French System to the ferralitization process (ferralitic, fersiallitic, and ferrugineux soil classes). Soils in this study with fersiallitic characteristics include A36, AR33, AR34, AR41, and AR42 in the Aïn Rami-Amlay toposequence, i.e., xerults and ochrepts. Another difficulty in correlation between the two systems is interpretation of what is called hydromorphic soil in the French system. It is shown in the literature (Greenland, 1981), and found from working in the field with French pedologist, that hydromorphy is invoked rather rapidly. Hence, many soils classified as "sols hydromorphes" of some kind in the French system would not be placed in an aquic suborder of Soil taxonomy. In this study, most the soils classified as hydromorphic soils were placed in aquic suborders. However, the soils with aquic criteria at the subgroup level were classified in the French system only as "intergrades" or other borderline classes with hydromorphic criteria in lower categories.

II.3.2. Physical and chemical characteristics and potential land use.

II.3.2.1. Entisols.

Entisols are soils without significant genetic development. In this study, Entisols occurred mainly near the crests and on steep slopes, where hard bedrock and mass wasting inhibit soil development independent of type of parent material, and mostly on south or southeast facing slopes. In such sloping landscapes, erosion acts on the soil surface, resulting in the loss of topsoil. In most slope positions where forest vegetation was cleared for agricultural purposes, soil mantle erodes in four or five years (personal observation). For this reason, Entisols are most extensive in the area. Representatives of Entisols are profiles M12, Bt17, and Mo39 (Tables 9 and 10).

A/ Physical characteristics.

Entisol profiles did not exceed 0.15 m in thichness. The surface A or AC horizon had a dark color due to brunification (melanization). The textures were loamy fine sand for M12 and Bt17, and sandy clay loam for Mo39. The clay fraction is important in giving the soil a good structure when mixed with organic matter (crumb structure of Mo39). Coarser textures had granular structures (M12 and Bt17). Morphological and physical features are given in Table 11.

Chart 1: Abbreviation chart for soil description.

Color

(Munsell notations)

Texture

l	loam
sl	sandy loam
fsl	fine sandy loam
vfsl	very fine sandy loam
ls	loamy sand
lfs	loamy fine sand
lvfs	loamy very fine sand
s	sand
vcos	very coarse sand
cos	coarse sand
sil	silt loam
si	silt
c	clay
sic	silty clay
sicl	silty clay loam
cl	clay loam
sc	sandy clay
scl	sandy clay loam

g	gravelly
k	cobbly
st	stoney
bo	bouldery

Structure

Grade :
- ms : massive
- 1 : weak
- 2 : moderate
- 3 : strong

Size :
- vf : very fine
- f : fine
- m : medium
- c : coarse
- vc : very coarse

Type :
- gr : granular
- cr : crumb
- pl : platy
- pr : prismatic
- abk : angular blocky
- sbk : subangular blocky

Horizon boundary

Distinctness
- a : abrupt
- c : clear
- g : gradual
- d : diffuse

Topography
- s : smooth
- w : wavy
- i : irregular
- b : broken

Soil Survey Manual : USDA-SCS (1966), with minor modifications .

Table 11: Morphological and physical properties of examined Entisols. (See abbreviation chart for soil description, page 47).

Profile symbols	Elevation m	Slope %	Horizon	Depth cm	Boundary	Munsell color (moist)	Texture	Structure	Clay %	Silt %	Sand %
M_{12}	1170	5	A	0-5	as	10 YR 3/3	lfs	vfgr	4.0	14.8	81.2
			R	+ 5	Calcareous and dolomitic rocks						
Mo_{39}	1310	10-15	AC	0-5	gs	10 YR 3/3	scl	f2cr	24.7	25.8	49.5
			R	+ 5	-	10 YR 3/3	sl	f2gr	16.2	17.0	66.8
BT_{17}	500	15	A	0-10	cs	10 YR 2/2	lfs-fsl	vfgrms	3.7	24.3	72.0
			AC	10-15	as	7.5 YR 4/4	lfs	vffgr	4.6	13.7	81.7
			Cr	+ 15		5 YR 5/8	scl	fgrms	29.6	12.4	58.0

Table 12: Chemical properties of examined Entisols. CEC = cation exchange capacity, PBS = percent base saturation.

Profile symbols	Horizon	Depth cm	pH		Total $CaCO_3$	C	N	C/N	Available P_2O_5 mg/Kg	CEC	Ca	Mg	K	Na	PBS %
			H_2O	KCl	%					meq/100g					
M_{12}	A	0-5	7.7	7.3	80.2	2.73	0.15	18.2	101.1	9.6	5.3	2.1	0.1	0.0	78.1
	R	+ 5			Calcareous and dolomitic rocks										
Mo_{39}	AC	0-5	6.5	5.7	nd Ø	2.98	0.17	17.5	81.3	21.9	7.0	1.5	0.5	0.7	19.0
	R	+ 5	6.6	5.2	nd	0.61	0.04	15.3	62.5	9.1	4.5	1.0	0.3	0.4	68.1
BT_{17}	A	0-10	6.1	4.9	nd	3.00	0.14	21.4	17.5	26.6	8.0	2.1	0.1	0.2	39.1
	AC	10-15	5.8	4.6	nd	1.20	0.08	15.0	12.5	16.0	3.6	3.5	0.0	0.2	45.6
	Cr	+ 15	5.4	4.2	nd	0.25	0.04	6.3	20.0	16.4	2.3	1.4	0.0	0.9	28.0

Ø : not done .

B/ Chemical characteristics.

The usefulness of soil pH as a measure of soil acidity and alkalinity differs according to the nature of parent material. Lower values (5.4 to 6.5) were shown for Bt17 and Mo39 (sandstony parent material) and higher pH (> 7) for M12 (calcareous material). Buol et al. (1980) pointed out that, for pH between 5.8 and 6.5, soil acidity originated from hydroxy-aluminium and organic functional groups. For soils from calcareous deposits (pH from 6.5 to 8) with the colloidal soil complex fully base saturated, no exchangeable Al is present but free $CaCO_3$ might be present if well protected inside soil aggregates. The sum of exchangeable cations was higher for Mo39 and Bt17 than M12. Lower values for calcareous material are probably due to less clay and/or lower exchange capacity of the clay. In general, low values of CEC (cation exchange capacity) reflected the dominance of kaolinite, illite and chlorite clays in these soils.

According to the norms established by Bonneau (personal cummunication[4]) for organic and mineral

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[4] For organic horizons (> 7 % O.M.), infertile soils have values lower than 0.6, 1.0, 0.6 (meq/100 g) and 150.0 mg/Kg for K, Ca, Mg and P_2O_5, respectively. Soils with good fertility have values higher than 1.0, 2.0, 1.0 (meq/100 g) and 300.0 mg/Kg for K, Ca, Mg and P_2O_5, respectively. For mineral soils, infertile soils have values lower than 0.12, 0.6, 0.06 (meq/100 g) and 60 mg/Kg for K, Ca, Mg and P_2O_5, respectively. Soils with good fertility have values higher than 0.20, 1.0, 0.15 (meq/100 g) and 110.0 mg/Kg for K, Ca, Mg and P_2O_5, respectively. In both cases, moderate soil fertlity corresponds to intermediate values.

horizons, A horizons of Entisols are relatively fertile. The only exceptions were the low value of potassium in M12 (less than 0.12 meq/100 g soil) and low exchangeable phosphorus for all Entisols. These low values of phosphorus were probably because of insoluble calcium phosphate salts in neutral to alkaline soils and hydrous oxides in acidic soils.

As reported by van der Paauw (1966), we assume that the decomposition of soil organic matter is paralleled by changes in the amounts of mineralized nitrogen. Total Kjeldahl nitrogen decreased with soil depth (Bt17 and Mo39). The C/N ratio can be used as an indicator of soil organic matter decomposition. A lower C/N ratio indicates relatively faster organic matter decomposition. This was shown for Mo39 where the dominant species is green oak. Under conifers (M12 and Bt17), higher values of C/N are seen. This confirmed the high degree of decomposition of organic matter observed under oak relative to conifers. Chemical properties are given in Table 12.

C/ Potential land use.

Even with the relatively good fertility of the A horizon, these soils are not suited for agricultural purposes. Erosion in such mountainous landscapes would lead rapidly to the loss of these shallow soils. Forest vegetation helps to stabilize steep slopes by providing additional cohesion from roots and by reducing soil water content through transpiration (Grassy, 1977). Another factor commonly associated with stability of shallow soils on slopes and attributed to forest management or forest clearing for cultivation purposes is the increase of soil moisture in cleared or harvested area. Reduced interception and transpiration allow more water to move through the soil and down slopes, leading to the impoverishment of surface soil and the downslope transport of soil material. The best use of these soils is to keep them under forest with limited grazing by cattle and sheep.

II.3.2.2. **Inceptisols.**

This order contains soils that had not developed features diagnostic for other orders but had some features in addition to the ochric epipedon and albic horizon permitted in Entisols (Buol et al., 1980; Wilding et al., 1983). Inceptisols are the most common order in the study area (34 % of the studied profiles), probably because of the young age of soils (steep slopes and natural or man-made erosional inpact).

A/ Physical characteristics.

The physical features of concern here are soil color, texture, and structure. The color characteristics of the soils resulted mostly from three pedogenic processes: 1) darkening with organic matter (melanization), 2) dryness and hydration of iron oxides (rubifaction), and 3) gleization.

The darkening process is different among different parent materials and soil textures. Soils derived from sandstone parent rocks with textures that are relatively fine lacked the darkening of deep horizons (AL2, AL3, AL4, AR33, AR41, AR42, BT16, K29, K30, and BB32). Conversely, soils with coarser textures had dark colors deeper in the profiles (M9, M10, Kh13, Kh14, and Kh15).

Rubifaction is the decomposition of primary iron bearing minerals with the release and accumulation of hematite, the dispersion of iron particles, and their progressive oxidation or hydration, giving rise to reddish, brown or yellowish color to soils. At lower elevations (higher mean temperatures) reddish and yellowish colors were more or less expressed according to the degree of hydration in soils (dry soils are more red).

The gleization process and the associated color characteristics, particularly gray colors, were dominant in the sites where water table fluctuates (AL2, AL3, Kh13, and AR42).

In general, soils from sandstony material had relatively finer textures (clay and clay loam). The structure also showed differences according to parent material. Where clay was dominant (sandstone materials), the structure was mostly subangular blocky, prismatic, or massive. Coarse textured soils from calcareous rocks had dominantly crumb or granular structure. Detailed physical characteristics of Inceptisols are shown in Table 13.

B/ Chemical characteristics.

■ Soil acidity and carbonates.

The main distinguisting feature observed in these soils was between profiles with acidic pH and the ones with alkaline pH. The latter were from calcareous and dolomitic parent materials. Acid soils formed from sandstony parent material. At higher altitudes of the Calcareous Dorsal under pine forest, soils had higher values of total carbonates and lower values of active carbonates compared to the Mollisols developed under fir forest. Under fir forest, the degree of decalcification seems more advanced (TL22). The pH variation with depth did not follow a similar trend: sometimes it declined (BB32, K30, AR33, AR41, AR42, and AL3), sometimes it

Table 13: Morphological and physical properties of examined Inceptisols. (See abbreviation chart for soil description, page 47).

Profile symbols	Elevation m	Slope %	Horizon	Depth cm	Boundary	Munsell color (moist)	Texture	Structure	Clay %	Silt %	Sand %
Al_2	960	12-15	A	0-12	cs	10 YR 4/2	c	f1sbk	41.8	25.3	32.9
			AB	12-28	cs	2.5 Y 5/2	c	m2sbk	42.9	27.0	30.1
			BAg	28-53	ds	7.5 YR 5/6	c	fmgr	48.3	26.8	24.9
			Bwg	53-78	cw	7.5 YR 5/6	scl	fmgr	28.2	9.8	62.0
			Cg	+ 78		7.5 YR 5/6	gc	fmgr	56.3	23.8	19.9
Al_3	970	20	A	0-20	cw	10 YR 3/2	scl	f2sbk	28.6	26.8	44.6
			Bw1	20-46	cs	10 YR 6/3	cl	f3sbk	38.4	17.2	44.4
			Bwxg2	46-80	ds	7.5 YR 5/6	c	c1sbk	48.4	22.7	28.9
			Cg	+ 80		7.5 YR 5/6	c	c1sbk	61.2	26.9	11.9
Al_4	820	12-15	A1	0-6	as	10 YR 3/1	cosl	m2gr	10.8	15.2	74.0
			A2	6-15	cs	10 YR 5/2	coscl	f2sbk	29.2	13.9	56.9
			A3	15-32	cs	10 YR 4/3	coscl	f2sbk	23.1	11.4	65.5
			Bw1	32-58	gd	10 YR 3/2	coscl	fm3sbk	30.2	9.9	59.9
			Bwx2	58-95	cw	2.5 Y 5/2	coscl	m2sbk	33.4	8.7	57.9
			BC	+ 95	cw	2.5 Y 5/2	c	fmgr	56.3	22.6	21.1
Kh_{13}	1030	1	Ag	0-12	ds	5 YR 5/6	cl	f1cr	34.1	45.3	20.6
			Bwg1	12-30	ds	5 YR 5/6	l	f1cr	15.8	33.0	51.2
			Bwg2	30-45	ds	10 YR 3/2	cl	f1cr	34.9	35.3	29.8
			Cg	+ 45	-	10 YR 3/2	cl-c	f1cr	39.6	33.0	27.4
Kh_{14}	1100	10	A1	0-11	as	10 YR 3/3	coscl	m1cr	24.6	16.7	58.7
			A2	11-22	ds	10 YR 3/2	cosl	m1cr	9.2	19.9	70.9
			A3	22-34	ds	10 YR 3/3	sl	m1cr	9.9	20.7	69.4
			AB	34-46	ds	10 YR 3/2	coscl	vffgr	20.5	25.9	53.6
			Bw1	46-73	ds	10 YR 3/2	l	vfgr	21.7	34.1	44.2
			Bw2	73-94	ds	10 YR 3/3	cosl	fgr	17.8	28.1	54.1
			Cr	+ 94		10 YR 3/3	l	fmgr	20.6	31.9	47.5
Kh_{15}	1140	45	A	0-15	as	10 YR 3/2	coscl	m2cr	20.0	16.5	63.5
			R	+ 15		Hard sandstone rocks					
N_9	1170	2	A1	0-18	gs	10 YR 3/2	cosl	fgr	10.4	23.9	65.7
			A2	18-24	gs	10 YR 3/3	lcos	vfgr	5.9	10.0	84.1
			AB	24-45	gi	10 YR 4/4	fs	vfgr	4.1	6.6	89.3
			BAw	45-50	gi	10 YR 5/4	lfs	vfmgr	7.7	15.4	76.9
			Bw	50-60	gi	10 YR 6/4	sil	mgr	6.3	67.8	25.9
			C	+ 60		10 YR 7/4	sil	cgr	13.3	65.4	21.3

Table 13: Continued.

Profile symbols	Elevation m	Slope %	Horizon	Depth cm	Boundary	Munsell color (moist)	Texture	Structure	Clay %	Silt %	Sand %
M_{10}	1220	5	A	0-13	cs	10 YR 3/2	sl	f1cr-sbk	3.8	34.4	61.8
			AB	13-20	cs	10 YR 3/3	l-sl	f1cr-sbk	7.1	41.4	51.5
			Bw	20-46	gs	10 YR 6/4	si-sil	vfgr	12.3	81.1	6.6
			Cr	+ 46		10 YR 6/4	sil		8.3	68.6	23.1
AR_{33}	550	5	A1	0-18	ds	10 YR 3/2	sl	fgr	13.8	15.0	71.2
			A2	18-42	gs	7.5 YR 3/4	sl	fgr	19.1	13.4	67.5
			Bw1	42-80	ds	5 YR 4/6	scl	fgr	27.4	12.3	60.3
			Bw2	80-145	ab	5 YR 5/8	scl	fgr	30.3	14.2	55.5
			Cr	+ 145		Sanstone rocks					
AR_{41}	750	0-1	A1	0-18	ds	10 YR 4/3	sl	fgr	15.1	23.7	61.2
			A2	18-36	ds	10 YR 4/3	sl	fgrms	16.4	20.0	63.6
			Bw	36-67	ds	5 YR 3/3	sl	fgr	17.7	19.6	62.7
			BC	67-90	as	10 YR 4/3	scl	fgr	25.8	16.3	57.9
			Cr	+ 90		Sandstone rocks					
AR_{42}	640	3	A	0-20	as	10 YR 4/3	cl	fm2cr	34.6	33.6	31.8
			Bwg1	20-53	ds	5 YR 5/8	c	m2sbk	55.1	14.5	30.4
			Bwg2	53-90	gs	# Variegated	c	m2sbk	64.1	18.2	17.7
			R	+ 90		Schistous rocks					
BT_{16}	580	3	A1	0-8	cs	10 YR 3/2	lfs	vfgr	6.0	14.4	79.6
			A2	8-25	aw	7.5 YR 3/2	lfs	vfgr	5.2	18.9	75.9
			BC	25-60	cs	5 YR 5/8	fsl	vfgrms	10.3	19.0	70.7
			Cr	+ 60		10 YR 6/6	sc-cl	vfgrms	38.4	15.3	46.3
K_{29}	1610	5-10	A1	0-14	gs	10 YR 3/3	l	fgr	21.8	38.9	39.3
			A2	14-34	gs	7.5 YR 4/4	l	vffgr	26.2	44.8	29.0
			Bw	34-64	ds	10 YR 5/6	sicl	vfgr	38.1	44.0	17.9
			Cr	+ 64		Altered mixed quartzitic sandstone rocks					
K_{30}	2030	15	A	0-25	ds	10 YR 3/3	l	fgr	24.9	32.9	42.2
			AB	25-45	gs	7.5 YR 4/4	l-cl	fgr	26.7	31.8	41.5
			Bw	45-70	ds	10 YR 5/6	cl	fgr	29.5	32.9	37.6
			Cr	+ 70		Altered mixed quartzitic sandstone rocks					
BB_{32}	1380	5-10	A	0-20	as	7.5 YR 3/2	l	f1cr	21.4	31.4	57.2
			AC	20-33	gs	7.5 YR 3/4	cl	f1cr	27.7	39.2	33.1
			R	+ 33	-	Sandstone rocks					

: 5 YR 5/8, 2.5 Y 6/4 & 5 Y 7/1 .

Table 14: Chemical properties of examined Inceptisols. CEC = cation exchange capacity, PBS = percent base saturation.

Profile symbols	Horizon	Depth cm	pH		Total $CaCO_3$	C	N	C/N	Available P_2O_5 mg/Kg	CEC	Ca	Mg	K	Na	PBS %
			H_2O	KCl	%					meq/100g					
AL_2	A	0-12	6.6	5.1	nd ∅	2.00	0.24	8.3	3	67.1	16.5	8.7	0.5	9.5	52.5
	AB	12-28	6.9	5.7	nd	1.20	0.18	6.7	20	63.4	16.0	8.6	0.6	8.2	52.7
	BAg	28-53	7.0	5.3	nd	0.60	0.14	4.3	113	51.5	14.3	8.2	0.5	8.2	60.6
	Bwg	53-78	6.0	3.8	nd	0.40	0.07	5.7	5	36.3	0.3	1.3	0.3	7.8	26.7
	Cg	+ 78	7.3	6.1	nd	0.40	0.12	3.3	180	51.2	16.8	9.6	0.6	8.5	69.3
AL_3	A	0-20	6.5	5.0	nd	3.20	0.30	10.7	28	60.4	11.0	4.8	1.3	0.8	29.6
	Bw1	20-46	5.8	4.1	nd	0.80	0.18	4.4	85	52.3	6.0	4.2	0.6	1.3	23.1
	Bwxg2	46-80	5.7	4.0	nd	0.40	0.15	2.7	18	48.8	8.8	5.4	0.4	1.1	32.2
	Cg	+ 80	5.6	3.9	nd	0.40	0.12	3.3	8	49.3	11.0	7.0	0.5	0.8	39.1
AL_4	A1	0-6	5.2	4.3	nd	6.00	0.31	19.4	15	47.9	4.3	3.8	0.8	1.1	20.9
	A2	6-15	5.0	4.1	nd	1.60	0.12	13.3	5	38.6	1.0	2.8	0.3	1.5	14.5
	A3	15-32	5.8	4.4	nd	1.75	0.12	14.6	8	34.5	1.3	3.1	0.3	1.2	17.1
	Bw1	32-58	5.5	4.3	nd	1.30	0.14	9.3	10	41.1	0.5	1.9	0.4	0.7	8.5
	Bwx2	58-95	5.6	4.6	nd	0.75	0.10	7.5	10	48.8	0.3	1.2	0.3	1.3	6.4
	BC	+ 95	6.7	5.8	nd	0.40	0.13	3.1	163	58.1	17.5	8.5	0.5	2.0	49.1
Kh_{13}	Ag	0-12	5.8	4.9	nd	5.00	0.39	12.8	47.5	36.9	9.8	6.7	0.3	1.9	50.7
	Bwg1	12-30	5.7	4.3	nd	3.00	0.17	17.7	27.5	38.9	6.5	4.9	0.2	1.6	33.9
	Bwg2	30-45	5.9	4.3	nd	2.00	0.32	6.3	52.5	33.8	3.3	4.0	0.2	1.1	25.4
	Cg	+ 45	5.9	4.3	nd	1.50	0.16	9.4	30.0	31.2	5.3	4.7	0.2	0.6	34.6
Kh_{14}	A1	0-11	5.4	4.0	nd	3.00	0.20	15.0	45.0	30.2	6.3	3.2	0.8	0.6	36.1
	A2	11-22	5.5	4.1	nd	3.00	0.21	14.3	40.0	32.8	6.8	3.6	1.0	0.5	36.3
	A3	22-34	5.4	4.0	nd	2.50	0.17	14.7	35.0	32.1	4.3	3.0	0.8	1.0	28.4
	AB	34-46	5.4	4.0	nd	2.70	0.21	12.9	32.5	33.3	3.8	2.6	0.6	0.6	22.8
	Bw1	46-73	5.2	4.0	nd	4.20	0.30	14.0	30.0	39.4	5.3	2.5	0.5	1.0	23.6
	Bw2	73-94	5.5	4.2	nd	2.60	0.24	10.8	42.5	34.9	3.5	1.6	0.3	0.7	17.5
	Cr	+ 94	5.7	4.3	nd	2.50	0.22	11.4	62.5	33.4	2.0	1.1	0.2	1.0	12.9
Kh_{15}	A	0-15	5.5	4.1	nd	2.90	0.20	14.5	42.0	29.9	6.1	3.2	0.8	0.5	35.5
	R	+ 15			Hard sandstone rocks										
N_9	A1	0-18	7.7	7.2	68.4	2.22	0.16	13.9	122.5	15.2	7.5	3.8	0.2	0.0	75.7
	A2	18-24	7.7	7.2	80.3	1.14	0.08	14.3	95.0	8.4	5.0	2.3	0.1	0.0	88.1
	AB	24-45	8.0	7.7	85.1	0.24	0.03	8.0	80.0	5.3	3.0	1.7	0.1	0.0	90.6
	BAw	45-50	8.0	7.6	83.0	0.24	0.03	8.0	82.5	7.9	4.0	2.4	0.1	0.0	82.3
	Bw	50-60	8.1	7.5	76.5	0.36	0.05	7.2	95.0	10.2	5.3	3.3	0.4	0.2	90.2
	C	+ 60	8.3	7.7	83.6	0.36	0.03	12.0	65.0	9.4	4.5	2.7	0.1	0.3	80.9

∅ : not done .

Table 14: Continued.

Profile symbols	Horizon	Depth cm	pH		Total $CaCO_3$	C	N	C/N	Available P_2O_5 mg/Kg	CEC	Ca	Mg	K	Na	PBS %
			H_2O	KCl	%					meq/100g					
N_{10}	A	0-13	7.5	7.2	58.8	2.34	0.15	15.6	265.0	14.5	8.0	3.3	0.2	0.0	79.3
	AB	13-20	7.6	7.4	80.2	1.26	0.08	15.8	100.0	10.1	5.3	2.5	0.1	0.0	78.2
	Bw	20-46	8.1	7.9	85.4	0.24	0.06	4.0	87.5	8.6	4.3	2.7	0.1	0.0	82.6
	Cr	+ 46	8.4	8.3	85.9	0.06	0.03	2.0	75.0	7.7	3.5	2.4	0.0	0.9	88.3
AR_{33}	A1	0-18	5.6	4.3	nd ●	2.40	0.11	21.8	70.0	26.1	1.0	1.1	0.1	0.2	9.2
	A2	18-42	5.6	4.5	nd	1.40	0.08	17.5	65.0	24.6	0.0	0.6	0.0	0.1	2.8
	Bw1	42-80	5.4	4.3	nd	0.50	0.04	12.5	57.5	22.6	0.3	0.7	0.1	0.1	5.3
	Bw2	80-145	5.4	4.1	nd	0.34	0.04	8.5	37.5	31.1	0.0	0.4	0.1	0.1	1.9
	Cr	+ 145						Sandstone rocks							
AR_{41}	A1	0-18	5.2	4.0	nd	2.59	0.11	23.6	44.5	19.3	1.3	0.8	0.1	0.4	13.5
	A2	18-36	5.1	4.0	nd	1.38	0.13	10.6	23.7	18.2	0.3	0.3	0.1	0.3	5.5
	Bw	36-67	5.1	4.0	nd	1.43	0.14	10.2	24.6	15.2	0.5	0.3	0.0	0.5	8.6
	BC	67-90	5.1	3.8	nd	0.66	0.07	9.4	11.4	16.4	0.5	0.4	0.0	0.7	9.8
	Cr	+ 90						Sandstone rocks							
AR_{42}	A	0-20	6.0	4.6	nd	4.52	0.12	37.7	77.7	27.2	7.5	3.6	0.3	0.7	44.5
	Bwg1	20-53	5.0	3.5	nd	0.50	0.07	7.1	8.6	28.0	4.0	3.3	0.3	0.4	28.6
	Bwg2	53-90	5.0	3.4	nd	0.39	0.06	6.5	6.7	36.8	1.3	2.4	0.1	0.3	11.1
	R	+ 90						Schistous rocks							
BT_{16}	A1	0-8	5.9	5.1	nd	3.00	0.09	33.3	88.5	22.2	5.3	1.8	0.1	0.6	35.1
	A2	8-25	5.7	4.5	nd	2.50	0.07	35.7	122.5	21.8	3.8	1.4	0.1	0.5	26.6
	BC	25-60	5.9	4.5	nd	0.50	0.03	16.7	25.0	17.2	2.3	1.3	0.0	0.4	23.3
	Cr	+ 60	4.9	3.9	nd	0.80	0.05	16.0	27.5	39.5	2.5	2.2	0.0	0.7	13.7
K_{29}	A1	0-14	5.4	4.6	nd ●	5.00	0.24	20.8	75.0	59.3	7.0	2.6	0.3	0.2	17.0
	A2	14-34	5.3	4.1	nd	3.80	0.24	15.8	77.5	25.9	2.3	1.3	0.3	0.3	16.2
	Bw	34-64	5.4	3.9	nd	1.20	0.09	13.3	43.8	36.6	0.8	0.6	0.1	0.3	4.9
	Cr	+ 64						Altered mixed quartzitic sandstone rocks							
K_{30}	A	0-25	5.4	4.3	nd	3.00	0.18	16.7	97.5	48.9	0.8	0.7	0.8	0.4	5.5
	AB	25-45	5.4	4.3	nd	2.40	0.16	15.0	123.8	42.6	0.5	0.3	0.5	0.3	3.8
	Bw	45-70	5.2	4.0	nd	0.40	0.08	5.0	36.3	27.7	0.5	1.0	0.3	0.3	7.6
	Cr	+ 70						Altered mixed quartzitic sandstone rocks							
BB_{32}	A	0-20	5.60	5.40	nd	5.60	0.31	18.1	61.3	55.1	12.5	2.2	0.5	0.6	28.7
	AC	20-33	5.20	4.40	nd	3.00	0.25	12.0	68.8	38.1	11.0	1.4	0.5	0.1	34.1
	R	+ 33	-	-	nd			Sandstone rocks							

increased or stayed constant (AL2, AL4, Kh13, Kh14, Kh15, M9, M10, Bt16, and K29). The pH in the surface horizon varied from 7.7 under pine on a calcareous and dolomitic deposits (M9) to 5.2 under cork oak on sandstone parent material (AL4 and AR41). The fact that pH declines as one moves from calcareous and dolomitic material to sandstone material suggests that the base saturation should decline (Table 14).

■ Exchangeable cations.

The major cations: calcium, magnesium, potassium, and sodium are derived from parent material alteration, organic matter decomposition, or from aerosols. Soils from calcareous parent material were rich with calcium and magnesium, relative to soil from other materials. In general, a somewhat opposite trend was shown for potassium and sodium, with the higher proportions found in soils from sandstony materials.

For the same toposequence, vegetation type seems to correlate with level of exchangeable cations, particularly for the Jbel Alam toposequence, where grassy (AL2) and fern (AL3) spots from open forest sites are compared with oak forest sites. The highest values of exchangeable cations are related to soils from grassy spots and the lowest to cork oak sites. Soils derived from calcareous material were more fertile than those from sandstone. Some of the profiles showed decreasing fertility with depth. Lower values of Ca and Mg, which indicate poor to medium fertility levels, were related particularly to cambic horizons from sandstony parent material (Table 14).

For these elements, the fertility level was assessed for soils from each parent material. From the more fertile to the less fertile the probable sequence is: 1) calcareous and dolometic parent material, 2) sandstone parent material, with some differences related to the nature of vegetation, 3) mixed quartzitic sandstone, and 4) mixed schistous sandstone with higher values under pine plantations relative to cork oak.

- <u>Sum of exchangeable bases, cation exchange capacity, and percent base saturation.</u>

The sum of exchangeable cations reflects the total amount of exchangeable bases in soil horizons. The total negative charges on the colloidal soil complex was measured by determining cation exchange capacity (CEC). The difference between CEC and the amount of exchangeable bases gave an estimation of the proportion of exchange sites occupied by soil acidity causing cations (mostly Al hydroxides and H^+). Percent base saturation (PBS) is defined as the proportion of exchangeable bases on the soil colloidal complex.

The sum of exchangeable bases (SEB) followed to some extent the same trend of variation as Ca and Mg, which occupy most of the negative sites of the soil colloidal complex. The values vary according to the type of parent material, and for the same parent material, according to vegetation type. The highest values were found for calcareous and dolomitic parent material. For sandstone parent material, the type of vegetation is related to differences among soils. Soils with grassy vegetation (AL2) had higher values compared to fern covered (AL3) and cork oak covered soils (AL4). In comparison to soils from mixed schistous or mixed quartzitic sandstones, soils from sandstone parent material showed higher values. The effect of vegetation on SEB was also observed for soils from mixed schistous sandstone material. Sites under pine plantations had higher values than the sites under cork oak.

In general, the soils showed some decrease of SEB with soil depth. CEC also varied among soils. The rating from the highest to the lowest values of CEC and SEB is: 1) calcareous and dolomitic parent material, 2) sandstone parent material, and 3) both mixed schistous sandstone and mixed quartzitic sandstone parent material.

On calcareous parent material, Inceptisols under pine forest (M9 and M10) had higher PBS than some Alfisols under fir forest (TL22) where the high altitudes and favorable acidifying conditions of climate, soil and vegetation permitted a higher degree of decalcification (see soil pH). On sandstone parent material, the comparison of PBS between a grassy site (AL2) and an oak forest site (AL4) showed higher values for the former. The PBS values for grassy sites from sandstone material (AL2) were of the same magnitude as the ones from calcareous material (TL22). Also, for mixed schistous sandstone material, higher values of PBS characterized pine plantation sites compared to cork oak sites. Under cedar forest (quartzitic sandstone material), PBS values were intermediate compared to pine plantation and cork oak sites on mixed schistous sandstone material (Table 14).

- Organic matter, carbon, nitrogen, and available phosphorus.

Soil carbon and nitrogen are continuously cycled through the plant-soil ecosystem and mostly derived from organic matter decomposition. Organic carbon was about 2 to 3 times as concentrated in the surface as in the subsurface horizon. The highest amounts of total Kjeldahl nitrogen reached 0.4 percent (Kh13) which is 4 times the minimum level specified by Bonneau for good fertility (personal communication). However, lower values (0.09 to 0.16) were found for profiles from calcareous parent material, particularly under pine forest (M10 and M9) and from mixed schistous sandstone material under pine plantation (BT16) and cork oak (AR33). Because nitrogen is mainly stored in organic forms, its availability to plants depends primarily on the rate of organic matter decomposition.

Soil phosphorus is also cycled through the plant-soil ecosystem. However, it tends to be in inorganic rather than organic forms. Soil phosphates are mostly fixed by clay minerals, calcium carbonate, and hydroxylated surfaces of soil colloids (Hingston et al., 1968). If the phosphate (and other nutrient anions) bound by the soil colloids can be released later to the soil solution at a reasonable rate for plant uptake, then the fixation is not necessarily disadvantageous. Low values of exchangeable phosphorus in soils from sandstone parent material (AL3, AL2, AL4, Kh14, and Kh13) indicated poor fertility levels. Other soils showed medium to good fertility levels for phosphorus.

The N content of organic residues, as reflected by C/N ratio, is considered of primary importance in regulating the activity of the opposing processes of mineralization and immobilization (Stevenson, 1985). For forest tree residue, C/N ratios greater than 22 generally result in lower mineral nitrogen reserves because of net immobilization by microorganisms. Residues with C/N below 15 lead to an increase of mineral nitrogen through mineralization. Intermediate values (between 16 and 22) give rise to equilibrium between mineralization and immobilization.

In this study all Inceptisol profiles from sandstone and calcareous parent material, had C/N ratios below 15 that favor an increase of mineral nitrogen. Low to intermediate conditions for mineralization were observed in soils from mixed schistous sandstone and mixed quartzitic sandstone materials (C/N from 16 to over 22). The decrease of C/N ratio with depth characterized all the profiles (Table 14).

C/ Potential land use.

In the area of study, most Inceptisols investigated (85 %) occur on acidic parent material. On calcareous and dolomitic material, most of the less developed soils are considered as Mollisols. Topography is an important ecological factor that differentiates among Inceptisols.

In undulating, gentle topography where most soils have coarse to medium textures, effectiveness of precipitation is maximized and erosion and runoff minimized. The soils developed are generally deep and stable.

At steep slope positions, shallow depth to bedrock is a critical soil feature. Precipitation effectiveness decreased, erosion hazard is higher and soils are less productive because of reduced moisture and nutrient capacity.

At concave spots and valley bottoms most Inceptisols developed hydromorphic features and finer textures. Trees seldom occupy these soils because of poor physical conditions for regeneration.

Because most of the forests in the area are subject to clearing and cultivation, some recommendations seem necessary regarding their use. Inceptisols on steep slopes are best suited for woodland.

If forest plantations are to be used, *Pinus halepensis* may give good results for both acidic and calcareous parent material on flat or sloping positions, provided that low temperatures and hydromorphy are not limiting. The useful range of this species may extend from cool humid to cool semi arid climates. *Pinus brutia* and *Pinus radiata* are well adapted to higher elevations. Well drained, deep soils of subhumid to humid climates are best suited for *Pinus pinaster* var. *moghrebiana*. At higher elevations (humid to perhumid climate) *Cedrus atlantica* grows well in deep, well drained soils.

If clearing and cultivation of soil becomes necessary, poorly drained Inceptisols of concave spots on midslopes and valley bottoms can be extensively used for cultivated field crops, provided artificial drainage is feasible.

II.3.2.3. Mollisols.

The main feature of Mollisols is a deep, dark relatively fertile topsoil (mollic epipedon). In general, Mollisols occur in grasslands of steppes and prairies. Exceptions include poorly drained Aquolls of lowland hardwood forests, some well drained Udolls (Brown Forest Soils), and Xerolls, which are very extensive in drier forests of the western U.S. (Buol et al., 1980).

Mollisols are characterized by the existence of a mollic epipedon with more than 1 % organic matter, dark color (value less than 3.5 moist and less than 5.5 dry, and chroma less than 3.5 moist), and base saturation of more than 50 %. An argillic horizon, which is a mandatory criteria for Alfisols and Ultisols, is not required but is permitted for Mollisols.

In this study, Rendoll suborders had no argillic horizons. Rendolls occurred mainly near the crests or on steep slopes (T21, T19, M11, and M10'). All Mollisols that showed hydromorphic characteristics were situated down slope in depressions, i.e., Aquoll suborders (M7 and T24). Udolls were found on gentle slopes where conditions allowed the formation of an argillic horizon (TL25, TL27, and TL27'). Mollisols in this study were developed in grassy openings in forest. Profiles transitional with other orders that did not satisfy all the criteria for a mollic epipedon were classified as umbric or dystric subgroups of Alfisols, Ultisols, or Inceptisols, according to color, base saturation, and presence of an argillic horizon, respectively.

The dominant pedogenic process that leads to the formation of a mollic epipedon is darkening or melanization.

A/ Physical characteristics.

The dominant colors that characterized these Mollisols were dark to very dark colors derived from the process of melanization, and the gray to olive subsoil colors in the profiles with hydromorphic characteristics (gleization). The texture and structure were variable among the soils. Mollisols from the Talassamtane profiles had clay loam surface textures and clayey textures in subsoil horizons (mainly Bt horizon). The structure types were crumb and subangular blocky for surface and subsurface horizons, respectively. In the Madissouka profiles, texture ranged from loamy fine sand to clay loam and structure ranged from crumb and granular to massive. Crumb structure was mainly in horizons rich in organic matter (surface horizon or mollic epipedon). Physical characteristics are shown in Table 15.

B/ Chemical characteristics.

■ Soil acidity and carbonates.

Mollisols from calcareous and dolomitic parent material were characterized by the presence of carbonates and pH values over 7. These carbonates were mainly inherited from the parent material and provide the colloidal soil complex with high amounts of calcium and magnesium. The highest amounts of total carbonates (between 50 and 85 %) were found in the Madissouka profiles (M11, M7, M8, and M10') and the lowest values (between 0 and 25 %) in the Taznote profiles (T19, T20, T21, and T24). The Talassamtane profiles had intermediate values (between 7 and 75 %) (TL25, TL27, and TL27).

Active carbonate (fine silt and clay size carbonate) is defined as the portion of carbonates easily soluble in water charged with carbonic gas (CO_2) and humic acids. Active carbonates were a very small proportion (less than 6 %) of total carbonates in these soils. The highest values of active carbonate were found in the Talassamtane

<u>Table 15</u>: Morphological and physical properties of examined Mollisols. (See abbreviation chart for soil description, page 47).

Profile symbols	Elevation m	Slope %	Horizon	Depth cm	Boundary	Munsell color (moist)	Texture	Structure	Clay %	Silt %	Sand %
M_7	1120	10-15	A1	0-25	as	10 YR 3/1	sil	m2cr	7.8	53.1	39.1
			A2	25-50	ds	10 YR 3/1	sl	m2cr	6.3	44.0	49.7
			AB	50-65	ds	10 YR 3/1	l	m2cr	17.7	43.0	39.3
			Bwg1	65-95	ds	10 YR 3/1	l	m1cr	26.8	35.8	37.4
			Bwg2	95-120	gs	10 YR 3/2	l	fmgr	26.1	47.2	26.7
			Bkwg3	120-130	gs	10 YR 4/1	sicl	fmgr	30.7	59.7	9.6
			CBkg	130-150	gs	10 YR 4/1	sil	fmgr	23.8	60.7	15.5
			Ckg	+ 150		10 YR 4/1	cl	fmgr	29.3	50.8	19.9
M_8	1120	5	A	0-10	as	10 YR 3/2	sil	m1cr	15.1	51.8	33.1
			AC	10-24	as	10 YR 2/2	cosl	m1cr	1.8	31.3	66.9
			2A	24-34	ds	10 YR 3/2	cosl	m1cr	6.3	33.0	60.7
			2AC	34-51	cs	10 YR 3/2	cosl	m1cr	7.5	40.6	51.9
			3A	51-61	as	10 YR 2/1	cosl	m1sbk	4.4	29.7	65.9
			3ACg	+ 61		10 YR 3/2	sl	m1cr	3.7	47.0	49.3
M_{10}'	1260	40	A	0-15	as	10 YR 2/2	sl	fm2cr	5.2	34.9	59.9
			R	+ 15		Calcareous rocks					
M_{11}	1150	5	A1	0-7	cs	10 YR 3/2	lfs	vfgr	3.5	11.6	84.9
			A2	7-14	cs	10 YR 3/3	lfs	vfgr	3.4	15.2	81.4
			Cr	+ 14		10 YR 6/4	lfs	vfgr	0.0	17.1	82.9
TL_{25}	1750	10	A	0-30	as	10 YR 3/2	sil	fmgr	9.7	62.9	27.4
			ABk	30-45	as	10 YR 3/2	sil	fmgr	17.8	54.2	28.0
			Bt	45-75	as	10 YR 4/3	c	m1sbk	48.0	33.5	18.5
			R	+ 75		Calcareous rocks					
TL_{27}	1710	15	A	0-17	as	10 YR 3/2	cl	fm1cr	28.1	37.4	34.5
			Bt	17-33	as	5 YR 4/3	sic	fm1sbk	45.2	41.5	13.3
			R	+ 33		Calcareous rocks					

Table 15: Continued.

Profile symbols	Elevation m	Slope %	Horizon	Depth cm	Boundary	Munsell color (moist)	Texture	Structure	Clay %	Silt %	Sand %
TL_{27}'	1730	5-10	A	0-10	as	10 YR 3/2	cl	fm2cr	10.2	63.0	26.8
			Bt	10-30	as	10 YR 3/2	c	f1sbk	48.0	33.7	18.3
			Cr	+ 30		Altered calcareous and dolomitic rocks					
T_{19}	1570	12-15	A1	0-10	gs	10 YR 3/3	l	mgrms	13.5	40.3	46.2
			A2	10-22	gs	10 YR 4/4	sl	m1-2cr	14.1	32.0	53.9
			ACg	22-30	gs	5 Y 5/4	sl-l	mgr	13.2	36.3	50.5
			Crg	+ 30		5 Y 6/4	l	mgr	16.0	34.1	49.9
T_{20}	1620	10	A	0-20	as	10 YR 3/2	cl	mscpr	30.7	26.6	42.7
			Bw1	20-40	gs	5 Y 5/2	cl	msvcpr	39.1	17.9	43.0
			Bw2	40-60	gs	5 Y 5/2	cl	vffgrms	34.7	34.6	30.7
			BC	60-75	gs	5 Y 5/3	cl	fmgrms	29.5	26.9	43.6
			C	+ 75		5 Y 5/1	cl	fmgrms	38.5	25.8	35.7
T_{21}	1650	50	A	0-15	as	10 YR 3/2	cl	fgrms	32.7	45.3	22.0
			R	+ 15		Calcareous rocks					
T_{24}	1560	0	A1	0-20	ds	10 YR 3/2	sl-l	vfgr	13.5	35.2	51.3
			A2	20-35	gs	10 YR 3/3	cl	vfgr	39.8	37.5	32.7
			Bwg1	35-55	gs	2.5 Y 5/6	c	vfgr	50.1	38.7	11.2
			Bwg2	55-75	gs	2.5 Y 5/6	c	vfgrms	47.4	42.2	10.4
			Cg	+ 75		2.5 Y N6/	c	vfgrms	42.6	39.4	18.2

<u>Table 16</u>: Chemical properties of examined Mollisols. CEC = catio exchange capacity, PBS = percent base saturation.

Profile symbols	Horizon	Depth cm	pH H_2O	pH KCl	Total $CaCO_3$ %	C %	N %	C/N	Available P_2O_5 mg/Kg	CEC meq/100g	Ca meq/100g	Mg meq/100g	K meq/100g	Na meq/100g	PBS %
M_7	A1	0-25	7.5	7.3	52.7	1.89	0.25	7.8	112.5	28.5	19.5	2.9	0.3	0.1	80.0
	A2	25-50	7.9	7.3	45.4	1.29	0.24	5.4	180.0	26.7	17.3	6.8	0.2	0.1	91.4
	AB	50-65	8.0	7.3	45.8	1.29	0.24	5.4	110.0	29.9	19.0	7.2	0.1	0.9	91.0
	Bwg1	65-95	8.0	7.3	47.0	1.80	0.22	8.2	100.0	25.9	17.8	5.9	0.2	0.1	92.7
	Bwg2	95-120	8.0	7.4	53.1	1.62	0.15	10.8	105.0	24.8	15.8	5.9	0.2	0.1	88.7
	Bkwg3	120-130	8.0	7.4	62.4	0.63	0.11	5.7	92.5	21.6	12.5	5.2	0.1	0.1	82.9
	CBkg	130-150	8.1	7.5	67.0	1.02	0.08	12.8	82.5	19.0	12.3	4.1	0.1	0.0	86.8
	Ckg	+ 150	8.2	7.5	69.5	0.63	0.06	10.5	80.0	17.9	11.8	3.9	0.1	0.0	88.3
M_8	A	0-10	7.8	7.2	68.7	3.90	0.31	12.6	130.0	28.8	17.3	8.4	0.1	0.1	89.9
	AC	10-24	7.9	7.2	69.5	1.74	0.24	7.3	120.0	28.4	19.0	8.0	0.1	0.1	95.8
	2A	24-34	8.0	7.2	62.1	4.68	0.34	13.8	100.0	37.9	21.8	10.0	0.1	0.1	84.4
	2AC	34-51	8.1	7.4	65.4	2.82	0.24	11.8	110.0	26.7	17.8	6.8	0.1	1.0	96.3
	3A	51-61	8.0	7.2	56.7	5.04	0.38	13.3	102.5	36.1	20.3	9.2	0.1	0.7	83.9
	3ACg	+ 61	7.8	7.2	55.4	1.44	0.22	6.6	87.5	29.6	17.0	8.8	0.1	0.1	87.8
$M_{10'}$	A	0-15	7.4	7.2	60.1	2.40	0.12	20.0	251.0	22.1	10.2	5.3	0.2	0.0	71.0
	R	+ 15						Calcareous rocks							
M_{11}	A1	0-7	7.8	7.3	83.8	2.48	0.09	27.6	82.5	8.9	5.0	2.2	0.1	0.0	82.0
	A2	7-14	7.8	7.3	85.9	1.34	0.23	5.8	92.5	7.7	4.3	2.2	0.1	0.3	89.6
	Cr	+ 14	8.2	7.3	85.8	0.41	0.03	13.7	117.5	7.2	3.5	2.1	0.0	0.0	77.8
TL_{25}	A	0-30	7.6	7.1	62.1	3.84	0.40	9.6	108.8	21.3	11.0	4.8	0.5	2.4	87.8
	ABk	30-45	7.5	7.1	51.7	2.88	0.27	10.7	85.0	18.4	10.0	5.1	0.3	0.4	85.9
	Bt	45-75	7.9	7.0	07.5	2.13	0.20	10.7	28.8	24.2	12.5	7.4	0.6	0.3	86.0
	R	+ 75						Calcareous rocks							
TL_{27}	A	0-17	7.1	6.6	08.3	9.90	0.71	13.9	235.0	39.6	20.8	8.3	1.3	0.5	78.0
	Bt	17-33	7.6	6.9	17.5	1.83	0.18	10.2	83.8	23.3	16.8	3.6	1.2	0.8	96.1
	Cr	+ 33						Calcareous rocks							

Table 16: Continued.

Profile symbols	Horizon	Depth cm	pH H_2O	pH KCl	Total $CaCO_3$ %	C %	N %	C/N	Available P_2O_5 mg/Kg	CEC meq/100g	Ca meq/100g	Mg meq/100g	K meq/100g	Na meq/100g	PBS %
T_{27}'	A	0-10	7.6	7.1	60.0	3.43	0.40	8.9	95.5	37.1	13.3	10.1	0.5	2.4	70.9
	Bt	10-30	7.5	7.0	49.7	2.34	0.20	11.7	26.0	45.1	19.4	12.0	0.6	0.3	71.6
	Cr	+ 30	Altered calcareous and dolomitic rocks												
T_{19}	A1	0-10	7.8	7.2	22.1	2.46	0.12	20.5	185.0	20.2	14.5	1.4	0.5	1.0	86.1
	A2	10-22	8.0	7.3	24.2	0.72	0.08	9.0	26.3	19.0	14.0	1.7	0.3	0.9	88.9
	ACg	22-30	8.0	7.3	21.7	0.30	0.05	6.0	35.0	19.4	13.5	1.6	0.2	0.8	84.0
	Crg	+ 30	8.1	7.3	25.9	0.24	0.04	6.0	21.3	18.4	13.0	1.9	0.2	1.0	87.5
T_{20}	A	0-20	6.7	6.0	00.0	3.06	0.09	34.0	100.0	34.7	15.3	2.5	1.4	0.3	56.2
	Bw1	20-40	7.5	6.8	01.3	0.72	0.07	10.3	150.0	23.3	12.5	2.3	1.0	1.2	78.5
	Bw2	40-60	7.9	7.0	02.9	0.30	0.07	4.3	87.5	20.1	11.9	3.1	0.8	1.0	83.6
	BC	60-75	7.9	7.0	05.0	0.60	0.07	8.6	28.8	18.0	11.0	3.1	1.0	0.6	87.2
	C	+ 75	8.0	7.0	04.2	0.84	0.06	14.0	22.5	19.2	9.5	5.5	0.8	0.4	84.4
T_{21}	A	0-15	6.6	6.1	nd #	5.00	0.41	12.2	676.3	53.5	25.0	7.3	1.9	0.2	64.3
	R	+ 15	Calcareous rocks												
T_{24}	A1	0-20	7.6	6.9	15.4	5.46	0.40	13.7	92.5	39.9	17.0	9.8	0.5	4.4	79.4
	A2	20-35	7.4	6.7	06.3	2.13	0.21	10.1	185.0	41.8	17.5	10.7	0.7	4.4	79.7
	Bwg1	35-55	7.5	6.8	03.8	1.17	0.12	9.8	47.5	36.6	17.0	10.1	0.7	4.4	88.0
	Bwg2	55-75	7.8	7.0	06.7	1.08	0.12	9.0	86.3	31.4	11.8	9.1	0.6	4.4	82.5
	Cg	+ 75	7.7	7.0	03.9	1.62	0.19	8.5	68.8	37.7	16.0	11.3	0.6	4.4	85.7

: not done .

profiles under fir forest (TL27) and the lowest in the Madissouka profiles under pine forest (M7) and in surface horizon of T20. The other profiles had intermediate values (M8, TL25, T19, and T24) except for T21 which is acidic (pH below 7). The highest pH values were found in subsoil horizons, particularly the B and C horizons (M7, M8, M11, TL25, T19, and T20). The profile (T24) located in a lower slope position had a clayey texture in subsoil horizons and showed a higher proportion of active $CaCO_3$ in subsoil. This may be explained by the down slope movement of clay and clay size carbonates (in water solution or suspension) that accumulate in the basin during the time of soil formation (these data are shown in Table 16).

- Exchangeable cations.

As indicated for Inceptisols, most of exchangeable cations of Mollisols originated from parent material, organic matter, and aerosols. The soil complex was saturated with Ca and Mg and the soils had good fertility. High values of K were found in the Talassamtane profiles (TL27) and Taznote profiles (T20 and T21). Taznote soils had the highest values of Na. The lowest values of all bases were in the Madissouka soils. Because the parent material of all these soils is calcareous, the differences are related to leaching as controlled by factors such as texture, vegetation type, altitude, precipitation, the degree of alteration of parent material, and permeability of horizons (Table 16).

- <u>Sum of exchangeable bases, cation exchange capacity, and percent base saturation.</u>

In addition to organic matter accumulation and the darkening processes that characterize Mollisols, the principal criterion defining the mollic epipedon is saturation of the colloidal soil complex with calcium and to a lower extent with magnesium. The relatively high cation exchange capacity is related to the high organic matter and clay content.

Because all Mollisols in this study were developed on calcareous and dolomitic material, with a perhumid climate at high elevations, and under more or less conifer dominated vegetation, only small variations were observed. Haplaquolls with grassy vegetation and hydromorphic characteristics (T24 and M7) had relatively high values of percent base saturation (Table 16).

- <u>Organic matter, carbon, nitrogen, and phosphorus.</u>

The darkening process that characterizes Mollisols is mainly influenced by the decomposition of organic matter, its humification, and its deep incorporation in soils. These processes are dependent on biological activity and are associated with a favorable environment. The highest concentrations of carbon and nitrogen were found under fir forest (Talassamtane) and relatively low concentrations under pine forest (Madissouka). Carbon and nitrogen decreased with soil depth but remained relatively high through B horizons of these Mollisols.

The carbon, nitrogen, and phosphorus levels of Mollisols and the continuous additions of organic matter under forest provide a good fertility level. The C/N ratio below 15 is favorable for mineralization in most Mollisols (Table 16).

C/ Potential land use.

In these soils, the high base status and organic matter content of Mollisols are desirable attributes for food production. However, most Mollisols in this study are rendolls on steep slopes and aquolls with high perched water tables. Thus, both are severely limited for agriculture purposes. They are more suited for woodland and limited grazing.

The principal forest species developed on these soils and their associated Alfisols are <u>Abies marocana</u> (Talassamtane), <u>Pinus pinaster</u> var. <u>moghrebiana</u> (Madissouka), <u>Quercus rotundifolia</u> (Taznote), <u>Pinus nigra</u>, <u>Cedrus atlantica</u>, and to a lower extent <u>Juniperus</u>

oxycedrus and Acer granatense. Grassy openings are common in these high elevations and occur mostly on flat benches and valley bottoms.

Soil, climate, grazing, and human impact in the area of study are not favorable for the regeneration of trees (Melhaoui, 1990). If reforestation is necessary, slopes are suited to either Pinus pinaster (south and southeast aspect) and Abies marocana (north and northwest aspect). The flat slope positions and the plateau region with deep soil and good drainage are best suited for Cedrus atlantica. The crests and steep slopes with rock outcrops are suited for Pinus nigra, if planted appropriately.

The other species that might be introduced in these high elevations of Calcareous Dorsal, with a humid to perhumid climate are: Pseudotsuga menziesii (Douglas fir), Prunus lusitanica (cherry), Juglans nigra and Juglans regia (walnut), Populus nigra (poplar or cottonwood), and Acer granatense (maple).

II.3.2.4. **Alfisols.**

The main prerequisites for Alfisols are the presence of layer lattice clay and sufficient accumulation of these clays in the subsoil to produce an argillic horizon (Bt).

In this study, Alfisols (udalfs) were most extensive in the perhumid climate under fir forest, particularly in association with Mollisols, over calcareous and dolomitic parent material (Talassamtane profiles: TL22, TL23, TL26, and TL28).

A/ Physical characteristics.

Probably because of their occurrence on calcareous and dolomitic parent material, surface horizons of Alfisols were characterized by very dark to dark colors. Organic matter and clays are floculated by Ca and Mg cations, giving the A horizon a dark color. Brownish and yellowish colors of subsoil horizons were due to hydration and oxidation of iron oxides. Loamy textures predominated in surface horizons; subsoils however, because of the translocation or in situ formation of clay minerals, had clay and silty clay textures. The organic matter and clay contents of the horizons were associated with their structural characteristics. The development of crumb structure in upper horizons was favored by the floculation of organic matter and clay with Ca and Mg cations. Prismatic and massive structure associated with subsoil horizons was related to the high content of 2:1 clay minerals. Physical characteristics of Alfisols are represented in Table 17.

Table 17: Morphological and physical properties of examined Alfisols. (See abbreviation chart for soil description, page 47).

Profile symbols	Elevation m	Slope %	Horizon	Depth cm	Boundary	Munsell color (moist)	Texture	Structure	Clay %	Silt %	Sand %
TL22	1680	10	A1	0-11	ds	10 YR 4/3	cosl	f1cr	10.8	31.8	57.4
			A2	11-22	ds	10 YR 4/3	l	fm1cr	17.9	42.0	40.1
			AB	22-42	aw	10 YR 4/3	l	m1cr	34.6	39.4	26.0
			Bt	42-50	as	10 YR 4/3	c	m1cr	42.2	37.7	20.1
			R	+ 50		Calcareous rocks					
TL23	1640	5-10	A	0-10	ds	10 YR 3/2	cosl	fm2cr	4.3	28.7	67.0
			E	10-20	gs	10 YR 4/4	l	fm1cr	26.2	30.7	43.1
			EB	20-32	ds	10 YR 4/6	c	f1cr	42.1	34.5	23.4
			Bt	32-55	as	10 YR 5/4	c	vc1pr	43.1	36.0	20.9
			R	+ 55		Calcareous rocks					
TL26	1700	15	A	0-18	as	10 YR 3/1	l-cl	vffm1cr	26.3	37.2	36.5
			Bt1	18-30	gs	5 YR 4/3	c	vffgr	50.4	39.5	10.1
			Bt2	30-110	as	5 YR 4/3	c	vffgr	52.6	40.9	6.5
			R	+ 110		Calcareous rocks					
TL28	1770	2	A	0-15	ds	10 YR 3/3	l	vffmgr	20.3	41.8	37.9
			Bt	15-40	aw	7.5 YR 3/4	c	vfgrms	59.5	26.1	14.4
			BC	40-60	cw	10 YR 4/3	sil	fmgrms	12.0	57.5	30.5
			CB	60-100	ds	10 YR 5/3	sil	fmgr	0.0	63.3	36.7
			Cr	+ 100		10 YR 5/2	sil	fmgrms	0.0	50.4	49.6

Table 18: Chemical properties of examined Alfisols. CEC = cation exchange capacity, PBS = percent base saturation.

Profile symbols	Horizon	Depth cm	pH		Total $CaCO_3$	C	N	C/N	Available P_2O_5 mg/Kg	CEC	Ca	Mg	K	Na	PBS %
			H_2O	KCl	%					meq/100g					
TL_{22}	A1	0-11	6.5	5.9	nd #	7.00	0.41	17.1	120.4	57.2	27.3	3.5	1.1	0.4	56.4
	A2	11-22	6.3	5.2	nd	2.80	0.16	17.5	48.2	61.3	16.0	2.0	0.5	0.3	30.7
	AB	22-42	6.5	5.2	nd	1.40	0.11	12.7	24.1	35.4	14.3	1.6	0.6	0.3	47.5
	Bt	42-50	6.5	5.4	nd	1.20	0.11	10.9	20.6	25.5	18.0	1.5	0.6	0.1	79.2
	R	+ 50	Calcareous rocks												
TL_{23}	A	0-10	6.2	5.5	nd	8.40	0.47	17.9	75.0	58.5	25.0	4.7	1.2	0.1	53.0
	E	10-20	6.2	5.5	nd	2.80	0.17	16.5	55.0	57.5	20.0	3.5	0.6	0.2	42.3
	EB	20-32	6.3	5.3	nd	1.40	0.10	14.0	103.8	49.9	19.8	4.2	0.6	0.2	49.7
	Bt	32-55	6.7	6.0	nd	0.80	0.09	8.9	243.8	38.5	22.3	8.2	0.6	0.2	81.3
	R	+ 55	Calcareous rocks												
TL_{26}	A	0-18	7.8	7.0	19.2	6.72	0.76	8.8	87.5	29.5	18.0	5.3	0.5	0.2	81.4
	Bt1	18-30	8.1	7.2	21.7	0.69	0.11	6.3	21.3	21.3	13.5	3.5	0.6	0.2	83.6
	Bt2	30-110	8.2	7.5	24.4	0.30	0.05	6.0	15.0	20.0	11.0	4.3	0.7	0.3	81.5
	R	+ 110	Calcareous rocks												
TL_{28}	A	0-15	7.7	7.2	50.8	3.20	0.13	24.6	115.0	29.0	13.8	7.1	0.8	0.3	75.9
	Bt	15-40	7.9	6.8	13.3	1.92	0.39	4.9	41.3	23.1	12.3	7.8	0.6	0.3	90.9
	BC	40-60	8.0	7.5	67.1	0.54	0.13	4.2	31.3	12.8	7.3	3.3	0.1	0.3	85.9
	CB	60-100	8.3	7.7	70.8	0.30	0.05	6.0	40.0	8.3	5.0	2.1	0.1	0.2	89.2
	Cr	+ 100	8.5	8.0	75.0	0.21	0.02	10.5	25.0	6.1	3.3	2.0	0.1	0.2	91.8

: not done .

B/ Chemical characteristics.

■ <u>Soil acidity and carbonates.</u>

As in the Mollisols, calcium and magnesium dominated the cation exchage complex of the Alfisols. Because these soils occurred at relatively high elevations with a perhumid climate, especially if under fir forest with acid litter, leaching of carbonates resulted in slightly acid pH values in some profiles (TL22 and TL23). Levels of pH and carbonates in the Alfisols indicated that fir forests were more effective in acidifying these carbonate rich soils than grass or mixed-oak-pine-fir vegetation (Table 18).

■ <u>Exchangeable bases, cations exchange capacity, and percent base saturation.</u>

Alfisols generally have a higher percent base saturation than Ultisols but not as high as Mollisols. The latter have values more than 50 percent throughout. The limit between Alfisols and Ultisols is specified as 35 percent base saturation in the lower part of the solum. The high base saturation of Alfisols in this study came from the calcareous and dolomitic parent material. Like Mollisols, the fertility of these soils is quite high. Exchangeable bases varied with depth among the profiles, but no specific trend was noticeable. Leaching of exchangeable bases was not apparent in calcareous profiles. When free carbonates leached, basic cations accumulated in the Bt horizon (TL22 and TL23). The high amount of organic matter seems to dominate over the effect of clay minerals in developing cation exchange capacity, particularly for soils under fir forest (TL22 and TL23). Comparison between vegetation types showed dissimilar trends for A and Bt horizons regarding cation exchange capacity. For A horizons, the highest values were under fir trees and the lowest values under mixed tree species (TL28). The Bt horizons had higher values under mixed tree species and lower values under grassy vegetation (TL26). Comparison with the other soil orders from different parent material showed high CEC values for soils from calcareous and dolomitic parent material. More leaching of bases was evident for TL22 and TL23, where bases have been translocated from the A and E horizons and accumulated in the Bt. The profiles under fir forest (TL22 and TL23) had a higher percentage of acidic cations, mainly Al and H, and lower pH with a corresponding trend between pH and base saturation with depth (Table 18).

- Organic matter, carbon, nitrogen, and available phosphorus.

In the same way as for the forested Mollisols, the high amount of organic matter and its cycling under forest provided Alfisols with adequate amounts of nitrogen. Horizons influenced by organic matter from decomposed and humified litter layers were relatively high in nitrogen. Under current conditions of forest organic matter cycling, soil fertility problems related to these elements were negligible. Fertility problems might rise following disturbance of organic matter cycling through clearing for agriculture, particularly if cropping was done on sloping erosive land.

In soils where free carbonates were present, the formation of insoluble phosphate salts (such as apatite) might alter phosphorus fertility. The current fertility level of phosphorus was considered only medium to poor. By comparison to other soils, the Alfisol C/N ratio were favorable for a good to moderate degree of mineralization (Table 18).

C/ Potential land use.

The high base status of these soils might be considered as favoring their use for agricultural purposes. However, the accelerated erosion due to grazing on steep slopes and the V-shaped topography, even under forest cover, indicated a serious hazard to future productivity of these soils. With exposure of the argillic horizons, because of natural or man induced erosion, the high clay content at the surface would not be a desirable medium for seed germination and plant development because of decreased water infiltration and droughty conditions at the eroded site. Increased flood hazard at lower portions of the adjacent landscape would also result. Consequently, the best use of these soils is to keep them under forest with limited grazing, especially on steep slopes.

II.3.2.5. **Ultisols.**

Ultisols are characterized by the presence of an argillic horizon, low base status in the lower part of the solum, and a mean annual soil temperature of more than 8°C.

In contrast to Alfisols that were preferentially developed from calcareous and dolomitic parent material, Ultisols had primarily formed on sandstony parent material. Most of the Ultisol profiles were under oak forest (AL6, AL1, AL5, A35, A36, AR34, and AR40), except for BT18 under a pine plantation and K31 under cedar forest.

The main features of the Ultisols are extensive leaching under a warm climatic regime.

In this study, most Ultisols were developed at lower elevations where the warmer climate promotes rapid mineralization of organic matter. The only Ultisols that have an umbric epipedon with relatively high organic matter content were found at higher elevations (AL1 and AL5) and were Umbric Hapludults. Ultisols that showed hydromorphic characteristics were classified either as Aquults (A35, AR40, and BT18) or as Aquic Haploxerults (AL6, A36, and AR34).

A/ Physical characteristics.

The color characteristics of the Ultisols are darkening by organic matter, reddish and yellowish colors through intense hydration and oxidation of iron oxides (rubifation), and gray colors due to restricted drainage (gleization). Most Ultisols in this study were at altitudes lower than 700 m except for the Jbel Alam toposequence, where they occur above 1,000 m (AL1 and AL5), and the Ketama toposequence with Umbric Hapludults at 1,550 m (K31). At low altitudes (Aïn Rami-Amlay toposequence), the dominant colors were yellowish and reddish. Yellowish colors characterized mainly soils with hydromorphic features (aquic suborder or aquic subgroup). The high elevation soils (AL1, AL5, and K31) under low temperatures and high precipitation with wetter profile conditions had yellowish or grayish colors.

The lessivage of clay was expressed by the development of an E horizon and a Bt horizon in these Ultisols, with the exception of profiles AL6 and K31. In these two cases, either masking of the E horizon by organic matter, or erosional disturbance of surface horizons with subsequent darkening by organic matter are possible. The surface horizons had loamy textures, and the subsoil horizons, particularly the Bt horizons, had clayey textures. At higher altitudes of the Jbel Alam toposequence (AL1 and AL5), soil profiles had gravelly and coarse sandy textures. Soil structure types developed in these Ultisols were generally crumb or granular in surface horizons and subangular blocky to massive in subsoil horizons. Physical data of Ultisols are shown in Table 19.

B/ Chemical characteristics.

■ Soil acidity.

The low base saturation of Ultisols is strongly correlated with acidic sandstone parent material. In contrast to calcareous and dolomitic parent material that conferred a high amount of Ca and Mg and hence a higher base saturation to the Mollisols and Alfisols, acidic sandstone material with low Ca and Mg content allowed the development of lower base saturation in Ultisols. pH values between 5 and 6 in all the Ultisols are caused by

Table 19: Morphological and physical properties of examined Ultisols. (See abbreviation chart for soil description, page 47).

Profile symbols	Elevation m	Slope %	Horizon	Depth cm	Boundary	Munsell color (moist)	Texture	Structure	Clay %	Silt %	Sand %
AL_1	1030	2	A	0-12	gs	7.5 YR 3/2	gsl	f1gr	11.3	30.1	58.6
			E	12-30	cs	7.5 YR 3/2	gscl	f1sbk	20.2	26.6	53.2
			EB	30-44	cs	7.5 YR 3/4	gscl	m1sbk	29.5	22.0	48.5
			Bt1	44-65	gs	7.5 YR 4/4	gsc	m2sbk	35.1	16.9	48.0
			Bt2	65-90	cw	7.5 YR 5/6	gscl	m2sbk	33.0	15.9	51.1
			Cr	+ 90		7.5 YR 5/6	gscl	mgrms	--	--	--
AL_5	1190	2-3	A	0-20	ds	10 YR 3/2	cosl	m2gr	13.5	23.2	63.3
			E	20-45	gs	10 YR 3/3	cosl	f2gr	15.4	25.0	59.6
			EB	45-70	cs	10 YR 4/3	coscl	fm2gr	29.5	18.3	52.2
			Bt1	70-90	cs	10 YR 6/6	cosc	fm3sbk	37.9	14.1	48.0
			Bt2	90-107	cs	2.5 Y 7/4	cosc	f3sbk	41.6	9.7	48.7
			BC	+ 107		2.5 Y N7/	c	fmgr	45.0	12.5	42.5
AL_6	450	10-15	A	0-10	cs	10 YR 5/3	cosl	f3sbk	16.8	21.0	62.2
			Bt1	10-28	gs	7.5 YR 5/4	c	fm3sbk	48.6	18.5	32.9
			Bt2	28-42	cw	10 YR 7/3	c	f3abk	58.7	25.1	16.2
			BCg	42-60	gs	2.5 Y 6/2	c	f3abk	58.4	28.2	13.4
			Cg	60-95	ci	2.5 Y 6/2	c	m2abk	60.8	25.7	13.5
			Cr	+ 95		2.5 Y 4/6	scl	m2abk	32.6	18.5	48.9
A_{35}	460	15	A1	0-8	ds	10 YR 2/1	sl	fmgr	3.7	33.2	63.1
			A2	8-20	gs	7.5 YR 3/2	sl	fm2cr	28.6	24.1	47.3
			E	20-35	as	7.5 YR 4/6	cl	m2cr	36.9	22.1	41.0
			Btg1	35-55	gs	10 YR 6/6	c	fm2sbk	58.6	19.7	21.7
			Btg2	55-70	gs	10 YR 5/6	sc	fm2sbk	38.9	13.5	47.6
			Crg	+ 70		10 YR 5/6	c	fmgr	53.3	19.3	27.4
A_{36}	360	8	A1	0-20	as	7.5 YR 3/2	sl	f2sbk	16.4	25.3	58.3
			A2	20-30	gs	7.5 YR 3/4	scl	f2sbk	26.3	22.9	50.8
			E	30-40	aw	7.5 YR 4/6	scl	m2sbk	29.8	21.6	48.6
			Bt1	40-80	ds	5 YR 4/6	c	m2sbk	52.7	21.7	25.6
			Btg2	80-100	gs	5 YR 6/8	c	m2sbk	59.0	18.0	23.0
			Btg3	100-150	as	5 YR 4/6	c	f1sbk	55.6	22.3	22.1
			BCg	+ 150		Altered sandstone rocks					
AR_{34}	430	5-7	A	0-13	ds	10 YR 4/4	cl	mc1cr	34.5	28.5	37.0
			E	13-27	gs	5 YR 4/6	c	fmc1cr	45.9	23.5	30.6
			Btg1	27-50	ds	10 YR 5/6 2.5 YR 4/8	c	fm1sbk	52.8	29.0	18.2
			Btg2	50-115	gs	10 YR 5/6 2.5 YR 4/8	c	fm1sbk	48.1	28.3	23.6
			Crg	+ 115		10 YR 5/6 2.5 YR 4/8	cl	m1abk	36.5	21.0	42.5

Table 19: Continued.

Profile symbols	Elevation m	Slope %	Horizon	Depth cm	Boundary	Munsell color (moist)	Texture	Structure	Clay %	Silt %	Sand %
AR_{40}	600	3	A	0-7	as	7.5 YR 3/2	l	fm2cr	25.8	43.5	30.7
			E	7-23	as	7.5 YR 4/4	cl	f2cr-gr	34.4	40.3	25.3
			AB	23-42	ds	5 YR 5/8	c	m2sbk	62.1	23.6	14.3
			Btg1	42-60	gs	5 YR 5/8	c	f2sbk	67.8	22.0	10.2
			Btg2	60-93	ds	2.5 Y 5/4	c	fm2sbk	61.5	24.1	14.4
			Btg3	93-130	aw	5 YR 5/8	c	fm2sbk	63.8	27.0	9.2
			Crg	+ 130		Schistous rocks					
BT_{18}	640	10	A	0-6	cs	10 YR 4/4	l-scl	fmgrms	22.9	28.8	48.3
			E	6-18	cs	10 YR 5/4	scl	fmgrms	25.6	18.0	56.4
			EB	18-34	cs	10 YR 4/3	cl	vffgrms	27.2	33.2	39.6
			BE	34-66	cs	10 YR 5/4	cl	vffgrms	28.7	34.4	36.9
			Btg1	66-96	cs	7.5 YR 4/4	cl	vfgrms	37.1	40.3	22.6
			Btg2	96-110	cs	2.5 YR 5/2	c	vfgrms	42.0	34.1	23.9
			Cr	+ 110		2.5 YR 5/2	c	vfgr	52.2	30.5	17.3
K_{31}	1550	0	A	0-20	ds	10 YR 3/3	cl	vff1cr	29.1	45.4	25.5
			AB	20-42	gs	10 YR 3/3	sicl	vff1cr	34.2	51.5	14.3
			Bt	42-82	as	10 YR 5/4	sicl	fm2sbk	39.8	46.7	13.5
			Cr	+ 82		Altered mixed quartzitic sandstone rocks					
Mo_{37}	1300	25	A	0-5	as	10 YR 5/1	sl	vffgr	17.7	24.4	57.9
			AB	5-27	as	10 YR 4/3	cl	f2pr	36.1	33.2	30.7
			Bt	27-57	ds	10 YR 4/3	cl	m2pr	31.4	26.8	41.8
			BC	57-80	ds	10 YR 4/3	scl	vf1pl	20.8	27.1	52.1
			Cr	+ 80	-	10 YR 4/3	l	f1pl	24.1	31.7	44.2
						5 YR 6/4					
Mo_{38}	1290	3	A	0-16	ds	10 YR 3/3	cl	f2cr	28.5	43.9	27.6
			E	16-36	as	10 YR 6/4	cl	f2cr	31.9	42.5	25.6
			Btg1	36-60	ds	2.5 Y 5/6	c	fm3pr	58.4	33.0	8.6
			Btg2	60-92	ds	2.5 Y 5/6	c	f2pr	52.5	38.9	8.6
						10 YR 5/1					
			BCg	92-120	ds	2.5 Y 5/6	sic	f2sbk	43.9	41.6	14.5
			Cr	+ 120	-						

Table 20: Chemical properties of examined Ultisols. CEC = cation exchange capacity, PBS = percent base saturation.

Profile symbols	Horizon	Depth cm	pH H_2O	pH KCl	Total $CaCO_3$ %	C %	N %	C/N	Available P_2O_5 mg/Kg	CEC meq/100g	Ca meq/100g	Mg meq/100g	K meq/100g	Na meq/100g	PBS %
AL_1	A	0-12	5.7	4.2	nd ø	4.60	0.38	12.1	28.0	47.5	2.5	0.9	1.0	7.3	24.6
	E	12-30	5.7	4.2	nd	2.34	0.23	10.2	8.0	58.1	0.5	0.6	0.5	6.9	14.6
	EB	30-44	6.0	4.2	nd	1.00	0.14	7.1	3.0	47.5	1.0	1.6	0.3	7.1	21.1
	Bt1	44-65	5.8	4.3	nd	0.80	0.10	8.0	10.0	45.6	0.5	0.9	0.3	7.0	19.1
	Bt2	65-90	6.1	4.2	nd	0.50	0.08	6.3	5.0	42.4	0.5	0.7	0.3	7.7	21.7
	Cr	+ 90	--	--	nd	--	--	--	--	--	--	--	--	--	--
AL_5	A	0-20	5.6	4.1	nd	7.40	0.48	15.4	60.0	60.6	5.3	3.4	0.8	0.3	16.2
	E	20-45	5.7	4.1	nd	3.34	0.29	11.5	63.0	49.0	1.5	1.1	0.2	1.6	9.0
	EB	45-70	5.8	4.5	nd	1.40	0.15	9.3	13.0	41.2	1.0	0.8	0.1	1.1	7.3
	Bt1	70-90	5.5	4.3	nd	0.48	0.09	5.3	30.0	39.0	1.3	1.1	0.1	1.9	11.3
	Bt2	90-107	5.4	4.2	nd	0.33	0.08	4.1	15.0	37.9	1.0	0.9	0.1	0.9	7.7
	BC	+ 107	5.3	4.0	nd	0.22	0.08	2.8	5.0	36.5	1.0	0.8	0.1	0.9	7.7
AL_6	A	0-10	5.3	4.0	nd	2.30	0.12	19.2	38.0	37.2	2.0	1.9	0.1	0.3	11.6
	Bt1	10-28	5.4	4.2	nd	1.50	0.10	15.0	15.0	42.4	4.5	3.8	1.3	0.4	23.6
	Bt2	28-42	5.3	4.0	nd	0.75	0.09	8.3	8.0	48.4	3.8	0.4	0.2	1.7	12.6
	BCg	42-60	5.4	4.1	nd	0.56	0.10	5.6	5.0	49.2	1.3	2.4	0.1	0.4	8.5
	Cg	60-95	5.2	4.0	nd	0.35	0.07	5.0	8.0	50.9	0.0	1.3	0.1	0.3	3.3
	Cr	+ 95	5.1	4.1	nd	0.24	0.05	4.6	8.0	36.2	0.3	0.7	0.1	0.3	3.9
A_{35}	A1	0-8	5.7	4.9	nd	2.72	0.07	38.9	190.0	36.8	8.5	2.6	0.6	0.1	32.1
	A2	8-20	6.0	4.8	nd	0.60	0.06	10.0	55.0	22.7	2.5	0.7	0.3	0.1	15.9
	E	20-35	6.0	4.6	nd	0.22	0.05	4.4	33.8	24.1	2.8	0.9	0.3	0.1	17.0
	Btg1	35-55	5.9	4.0	nd	0.60	0.07	8.6	23.8	34.6	5.5	3.3	0.4	0.1	26.9
	Btg2	55-70	5.2	3.7	nd	0.27	0.08	3.4	25.0	36.6	1.8	1.7	0.4	0.1	10.9
	Crg	+ 70	5.0	3.6	nd	0.27	0.07	3.9	17.5	32.6	1	1.3	0.4	0.1	8.6
A_{36}	A1	0-20	6.1	5.2	nd	3.14	0.16	19.6	58.2	34.7	6.8	2.9	0.5	0.1	29.7
	A2	20-30	6.0	4.5	nd	0.49	0.10	4.9	15.0	28.7	4.5	3.0	0.3	0.1	27.5
	E	30-40	5.8	4.2	nd	0.22	0.07	3.1	12.5	29.9	4.3	3.3	0.3	0.2	27.1
	Bt1	40-80	5.4	4.6	nd	0.38	0.07	5.4	11.3	36.2	4.5	4.6	0.3	0.2	26.5
	Btg2	80-100	5.3	3.6	nd	0.43	0.09	4.8	20.0	37.8	4.5	5.3	0.3	0.3	27.5
	Btg3	100-150	5.3	3.6	nd	0.27	0.09	3.0	15.0	32.7	3.3	5.3	0.3	0.5	28.7
	BCg	+ 150													
AR_{34}	A	0-13	5.6	4.4	nd	2.10	0.13	16.2	35.0	55.1	5.0	5.2	0.4	0.5	20.1
	E	13-27	5.5	4.1	nd	0.96	0.08	12.0	23.8	49.6	3.5	6.0	0.3	0.3	20.4
	Btg1	27-50	5.6	3.9	nd	0.60	0.09	6.7	16.3	50.5	3.0	6.4	0.3	0.6	20.4
	Btg2	50-115	5.5	3.8	nd	0.30	0.08	3.8	5.0	55.2	2.0	6.1	0.3	0.3	15.8
	Crg	+ 115	5.5	3.8	nd	0.24	0.08	3.0	17.5	50.7	1.5	6.0	0.3	0.3	16.0

ø : not done .

Table 20: Continued.

Profile symbols	Horizon	Depth cm	pH H_2O	pH KCl	Total $CaCO_3$ %	C %	N %	C/N	Available P_2O_5 mg/Kg	CEC meq/100g	Ca meq/100g	Mg meq/100g	K meq/100g	Na meq/100g	PBS %
AR_{40}	A	0-7	5.7	5.0	nd	6.40	0.24	26.7	106.3	30.9	7.5	4.8	0.4	0.5	42.7
	E	7-23	5.3	4.9	nd	1.52	0.08	19.0	47.5	23.9	3.3	0.8	0.2	0.4	19.7
	AB	23-42	5.1	3.6	nd	4.39	0.10	43.9	32.5	25.1	3.0	4.9	0.2	0.5	34.3
	Btg1	42-60	5.1	3.5	nd	0.61	0.09	6.8	33.8	25.6	0.5	3.1	0.1	0.6	16.8
	Btg2	60-93	5.1	3.4	nd	0.50	0.06	8.3	43.8	28.2	0.3	2.4	0.1	0.6	12.1
	Btg3	93-130	5.2	4.3	nd	0.39	0.04	9.8	42.5	29.7	0.3	2.1	0.3	1.2	13.1
	Crg	+ 130						Schistous rocks							
BT_{18}	A	0-6	5.5	4.4	nd	4.25	0.22	19.3	7.3	37.9	13.5	7.3	0.7	0.4	57.8
	E	6-18	5.4	4.0	nd	2.00	0.08	25.0	1.8	33.0	6.0	4.4	0.1	1.1	35.2
	EB	18-34	5.3	4.0	nd	2.25	0.14	16.1	1.5	29.1	5.3	4.1	0.1	0.7	35.1
	BE	34-66	5.5	4.3	nd	1.75	0.13	13.5	1.7	29.7	4.3	3.8	0.1	0.9	30.6
	Btg1	66-96	5.1	4.0	nd	1.70	0.14	12.1	4.0	29.3	1.5	2.8	0.1	1.0	18.4
	Btg2	96-110	5.2	3.9	nd	1.00	0.11	9.1	4.5	32.4	2.3	4.0	0.1	0.4	21.0
	Cr	+ 110	5.6	4.4	nd	0.50	0.10	5.0	5.0	26.7	7.0	7.7	0.1	1.6	26.7
K_{31}	A	0-20	5.5	4.1	nd	2.80	0.24	11.7	57.5	40.5	4.3	2.4	0.3	0.4	18.3
	AB	20-42	5.7	4.1	nd	1.60	0.15	10.7	41.3	50.3	2.3	1.9	0.2	0.5	9.7
	Bt	42-82	6.1	4.2	nd	0.80	0.11	7.3	31.3	42.5	1.0	1.7	0.1	0.4	7.5
	Cr	+ 82						Altered mixed quartzitic sandstone rocks							
Mo_{37}	A	0-5	6.20	5.00	nd	1.76	0.10	17.6	153.8	33.4	8.0	4.5	0.6	0.1	39.5
	AB	5-27	5.50	3.80	nd	1.10	0.07	15.7	423.8	37.0	8.0	3.6	0.6	0.1	33.2
	Bt	27-57	5.70	3.90	nd	0.22	0.06	3.7	862.5	36.8	9.3	3.5	0.5	0.1	36.4
	BC	57-80	5.90	4.10	nd	0.22	0.05	4.4	2241.3	28.0	8.3	2.9	0.5	0.1	42.1
	Cr	+ 80	6.30	4.60	nd	0.28	0.07	4.0	2482.5	26.6	8.8	3.1	0.4	0.1	46.6
Mo_{38}	A	0-16	5.8	4.4	nd	2.28	0.12	19.0	60.0	27.6	5.3	1.0	1.4	0.7	30.4
	E	16-36	5.8	3.4	nd	0.89	0.12	7.4	38.8	20.7	3.3	0.8	0.3	0.4	23.2
	Btg1	36-60	5.5	4.0	nd	0.45	0.11	4.1	22.5	31.2	3.5	1.6	0.3	0.7	19.6
	Btg2	60-92	5.5	3.6	nd	0.33	0.10	3.3	27.5	30.1	5.5	1.6	0.3	0.8	27.2
	BCg	92-120	8.1	7.2	nd	0.39	0.10	3.9	697.5	28.4	19.0	1.5	0.3	0.6	75.4
	Cr	+ 120	-	-	-	-	-								

the dominance of Al and H on the colloidal soil complex. For these soils the pH does not vary with vegetation type; however, a relatively small decrease of pH with depth is common in most (Table 20).

Because these Ultisols occurred on relatively stable, older landscape segments with deeper weathering, redder colors, and 1:1 clays, the age of soils (weathering time) might be considered in the explanation of base depletion and acidity.

■ Exchangeable cations.

These Ultisols had relatively low exchangeable bases compared to Alfisols and Mollisols developed on calcareous material, particularly Ca and Mg. Among Ultisols, higher values of Ca and Mg were related to soils from mixed schistous sandstone (Aïn Rami-Amlay and Bab Taza toposequences) relative to those from sandstone or mixed quartzitic sandstone (AL1, AL5, AL6 and K31).

The values of K were quite low for all Ultisols but do not seem to cause any nutritional problem for plants. Most of the Ultisol profiles had some decrease of exchangeable bases with soil depth. In some profiles, basic cations increase in Bt horizons.

Some differences related to vegetation type were observed for soils from mixed schistous sandstone material. Under pine plantations (BT18), the values for all exchangeable bases were higher compared to the levels found under cork oak forest (AR40). Similarly, soils under cedar forest, which developed from mixed quartzitic sandstone material, had high amounts of Ca and Mg. Soils from the Jbel Alam toposequence under cork oak forest had relatively high concentrations of K and Na (Table 20).

- Sum of exchangeable bases, cation exchange capacity, and percent base saturation.

Ultisols from mixed schistous sandstone parent material had the highest base saturation, followed by sandstone material, while mixed quartzitic sandstone material had the lowest. Differences related to vegetation type were found for mixed schistous parent material. Ultisols from pine plantations (BT18) had higher base saturation than the sites under cork oak vegetation.

Percent base saturation and pH values showed a positive trend. The highest CEC values were found in Ultisols at highest altitudes (Jbel Alam and Ketama toposequences). An exception from lower altitudes was AR34 from mixed schistous sandstone material, which had CEC values over 50 meq/100g of soil. Cation exchange capacity increased in the lower part of Bt horizons. This is explained by the high quantities of clay present at these depths due to illuviation or alteration (Table 20).

■ Organic matter, carbon, nitrogen, and available phosphorus.

Ultisols had relatively high levels of organic matter and dark colors through the A and E horizons, although organic matter decreased rapidly below the A horizon. These concentrations of organic matter have a favorable effect on soil structure, aeration, and water retention, and contribute to soil fertility through decomposition and mineralization.

The decrease of organic matter and nitrogen with soil depth was regular in the Haploxerults and Hapludults (AL1, AL5, AL6, K31, and AR34) and discontinuous in the Albaquults (A35, BT18, and AR40) and the Aquic subgroup of Haploxerult (A36). Mo37 and Mo38 showed a regular decrease with depth with little increase in Cr horizons. Therefore, the concentration or illuviation of organic substances and nitrogen at depth, particularly in the Bt horizon, correlates with hydromorphic characteristics caused by a perched water table. Available phosphorus levels were highest in A horizons and then showed some increase in lower subsoil horizons, except for profile K31 located at higher altitude under cedar forest. However, these values represent a low fertility level of P_2O_5. The Haplohumult (Mo37) had the highest values of phosphorus and hence the best fertility levels. For this soil, the highest values were observed in lower subsoil horizons. In acid soils with pH below 6, phosphorus was probably fixed by hydrous oxides on non-exchangeable sites. Higher elevation sites had C/N ratios below 15 that are favorable for nitrogen mineralization (AL1, AL5, and K31). Other profiles at lower altitudes with C/N ratios over 22 in surface horizons suggest lower net N mineralization (Table 20).

C/ Potential land use.

Ultisols have a good potential for agricultural production. Historically, Ultisols have been favored for agricultural development. These are deep soils with high water storage capacity and usually have the potential to produce good crops for the first few years, until the nutrient reserve in the biocycled organic matter is released and taken up by the plants or leached from the profile. Around Aïn Rami forest, most of the lower elevation is used for agriculture and with increases of human population most of Ultisols now under forest will be cleared and cropped. This may have no detrimental effect if it is limited to lower flat landscapes. However, if clearing and cropping extend into steeper areas, erosion would cause loss of the A horizon and exposure of the clayey B horizon. Such truncated soils restrict water infiltration and plant growth, and may eventually be abandoned. Ultisols have relatively low fertility and low base status. The use of fertilizer and other modern agricultural practices is necessary when cropping these soils. However, to protect the steeper areas from erosion, timber production should be considered as a valuable use of such Ultisols. Even the cutting of native forest with establishment of new conifer plantations might lead to progressive decrease in soil fertility.

II.4. CONCLUSION.

The aim of this study was to provide information about the distribution and nature of forested soils in the Western Rif Mountains. Soil profiles and soil profile descriptions are of interest to all people who are involved in land use. The success of both rural and urban development is highly dependent upon planning that recognizes the proper use of soil resource information.

In the forests around Chefchaouen, local climate, soil substrate, altitude, vegetation types, and topographic position were the principal features that control soil development and distribution. The main soil orders (soil taxonomy) encountered were Entisols and Inceptisols (on all parent materials), Mollisols and Alfisols (on calcareous and dolomitic parent material), and Ultisols (on acidic parent material). The main soil classes (C.P.C.S.), which are not equivalent to the soil orders of soil taxonomy system were "les sols peu evolués" (less developed soils), "les sols calcimagnesiques" (soils derived from limestone), "les sols brunifiés" (brown soils), "les sols à sesquioxydes" (soils with sesquioxides), and "les sols hydromorphes" (hydromorphic soils). Younger soils, including Entisols, Inceptisols, and some Mollisols, occurred mainly on ridge crests and steep slopes. Soils with developed Bt horizons (Alfisols, Ultisols, and some Mollisols) occupied more stable sites including flat benches and depressions.

Soil physical and chemical properties varied among the five soil orders. Within the same soil order, soil properties varied according to the parent material, vegetation type, and slope position. The texture ranged from granular and coarse sand loam to clay. The main structures were granular, crumb, and subangular to angular blocky. The pH varied from 5 on acidic parent material to 8.5 on calcareous and dolomitic parent material. Also, these properties showed some variation with soil depth, for example, most of the nutrient elements showed a decrease with soil depth.

The soils under forest showed good to moderate nutrient levels. The ranges in fertility variables were: 0.06-9.9 percent carbon, 0.03-0.76 percent nitrogen, 1.5-

240 mg/kg available phosphorus, 6-61 meq/100g cation exchange capacity, and < 10 to 92 percent base saturation. High base levels of some of the parent materials and active nutrient cycling were the main factors in maintaining soil fertility.

Because most of the area has steep slopes and V-shaped topography, soil erosion is probably the most destructive process that acts to reduce productivity. Topsoils and A horizons generally contain the most nutrients and best structure for plant growth, thus any materials eroded from the upper part of the soil profile should have a detrimental effect upon crop yields and plant growth. Because of the high erosion potential, the most suitable use of the soil in the area is retention as woodland with limited pasture.

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CHAPTER III

SOIL GENESIS

ABSTRACT.

Soil genesis of forest stands around Chefchaouen was investigated to better understand soil processes and soil landscape relations.

The study area included the forests of Jbel Alam, Talassamtane, Madissouka, Chefchaouen, Khezana, Bab Taza, and Ketama. The dominant forest species were Quercus suber (oak), Abies marocana (fir), Pinus pinaster var. moghrebiana and Pinus radiata (pine), and Cedrus atlantica (cedar). The study area was subdivided into four broad geological groups comprised of colluvium-residuum deposits derived from calcareous and dolomitic materials, sandstone, mixed schistous sandstone and mixed quartzitic sandstone deposits.

Forty soil profiles were described by genetic horizons within altitudinal gradients (toposequences), according to vegetation type and lithological substrata. Most of the soils were shallow, unstable and were limited in their productive capabilities. The principal soil classes in the area were Entisols, Inceptisols, Mollisols, Alfisols, and Ultisols. The main internal soil developing processes were weathering, decalcification, melanization,

mineralization, humification, rubifaction, leaching, lessivage, gleization, and erosion. Melanization imparted dark color to upper horizons. Rubifaction was most distinct at lower elevations particularly around Chefchaouen where Ultisols were more prevalent and where high temperatures and stable landscape positions combined to develop deeply leached soils with reddish and yellowish colors according to the degree of hydration of iron oxides.

Clay minerals were mostly inherited from parent materials. Kaolinite, illite, chlorite, interlayer clays, quartz, and feldspars were common to all toposequences, whereas smectite and paligorskite clay minerals and dolomite were specific to calcareous and dolomitic parent material.

III.1. INTRODUCTION.

The forests around Chefchaouen are of particular interest to the local population as a source of income or for grazing; to forest and soil conservation services as a source of wood and as a resource to be protected; and to scientists as a significant locale for research.

The geological and geomorphological complexity of the terrain, the contrasting types of climate, and the diversity of vegetation are important factors that interest natural scientists.

If these areas are to be used successfully it is essential for the manager to have a good understanding of the natural forest ecosystems. The geology, geomorphology, climatology, and vegetation of the areas have been relatively well studied (Griffon, 1965; Maurer, 1968; Michard, 1976; El Gharbaoui, 1981; Ben Abib, 1982). However, there has been little study of the soils. All the major factors of soil formation, i.e., climate, parent material, relief, time, and organisms, vary widely within the highland forests around Chefchaouen, with differing influences on soil characteristics. Most of the soils were previously classified as Mediterranean red soils or brown forest soils (Giordano, 1965; EL Gharbaoui, 1981; Ben Abid, 1982).

Soil genesis is defined as that phase of soil science (sometimes referred to as pedology when combined with soil classification activity) that deals with factors and processes of soil formation (Buol et al., 1980).

Jenny (1941) identified a soil function as the quantitative solution of the relationship:

$$S = f\ (T, Cl, O, R, P, \ldots)$$

where the soil and its properties (S) are functions of time (T), climate (Cl), organisms (O), relief (R), and parent material (P) (Bouma et al., 1969; Jenny, 1941).

In this study, soils from different forest types and different parent materials along altitudinal gradients (toposequences) were described and characterized and the relationship of their properties to their classification and pedogenic processes are discussed. The aim was to help forest managers and users in understanding the soil component of forest ecosystem and its relationships with other components.

III.2. **MATERIALS AND METHODS.**

The study sites were selected to represent six forest stands that extend along a geographical band from Jbel Alam near Holly Moulay Abdessalam (20 km northwest of Chefchaouen) to Ketama (about 60 km east of Chefchaouen), (see paragraph II.2 and Figure 5, chapter II).

III.2.1. **Field study.**

Forty profiles were sampled by genetic horizons from eight representative toposequences. A total of 168 soil samples were collected from soil horizons and analysed for selected physical, chemical, and mineralogical soil properties. Also, specimens of plants around the pits were collected and dried for identification. The sites and toposequences were selected to represent different forest types and different parent materials (see paragraph II.2.1, chapter II). The geographical distribution of the toposequences is shown in Figure 5, chapter II.

III.2.2. **Laboratory analyses.**

The standard techniques of Forest Research Division soil laboratory (Sefrioui et al. 1971) were used (paragraph II.2.3, chapter II).

The determination of clay types was done in collaboration with Agronomic Research Institute and the Mining Ministry (Rabat, Morocco). Soil samples were treated with H_2O_2 (organic matter destruction) and with sodium hexameta-phosphate (particle dispersion). Clays were then saturated with calcium. Selected samples were treated with sodium dithionate to remove oxide coatings. The mineralogical study was performed by X-ray diffraction (XRD) on clay mounted slides. X-ray diffraction patterns were obtained from oriented aggregates (air dried, glycerol solvated, or heated to 500°C for 2h.). We studied selected colloidal clays. These are minerals of Te:Oc (tetrahedral to octahedral) = 2:1 mineral groups, i.e., illite (I), vermiculite (V), montmorillonite (M), and their interlayers; minerals of Te:Oc = 1:1 mineral groups, i.e., kaolinite and chlorite; and Quartz, feldspars, and palygorskite.

III.2.3. Representative toposequences.

Eight toposequences were selected to represent a range of soil profiles found under dominant forest types and from the major geological substrates in the area (Table 21).

Table 21: Frequency with which different soil orders occur in the toposequences. Toposequences have names of the localities in which they occor. Profile names are the initial letters of the corresponding locations.

	Soil orders				
Toposequence	Entisols	Inceptisols	Mollisols	Alfisols	Ultisols
Jbel Alam		AL2,AL3,AL4			AL1,AL5,AL6
Khezana		Kh13,Kh14,Kh15			
Madissouka	M12	M9,M10	M7,M8,M10,M11		
Talassamtane			TL25,TL27,TL27'	T122,TL23,TL26,TL28	
Taznote			T19,T20,T21,T24		
Ain Rami-Amlay		AR33,AR41,AR42			A35,A36,AR34,AR40
Bab Taza	BT17	BT16			BT18
Ketama		K29,K30			K31
Number of profiles Percent of total	2 (5.0 %)	14 (35,0 %)	11 (27.5 %)	4 (10.0 %)	9 (22,5 %)

A toposequence is defined here as a succession of sites on representative slope positions from a crest or plateau to a valley bottom. The toposequences were given names of the localities where they occur, and soil profiles, the initial letters of corresponding locations. The different forest stands encompassed were Quercus suber (cork oak), Abies marocana (fir), Pinus pinaster var moghrebiana (natral pine), Pinus pinaster var moghrebiana and Pinus radiata (pine plantations), Quercus pyrenaïca (deciduous oak), and Cedrus atlantica (cedar). Among the complex mixture of geological formations, four broad groups of colluvium-residuum deposits were chosen as the most representative parent materials, i.e., calcareous and dolomitic material, sandstone, mixed schistous sandstone, and mixed quartzitic sandstone. Three toposequences developed from calcareous and dolomitic materials were occupied by pine (Madissouka), fir (Talassamtane), and mixed oak-pine stands (Taznote). Two toposequences developed from sandstone were under cork oak forest (Jbel Alam) or deciduous oak forest (Khezana). Two other toposequences were representative of cork oak or pine plantations over mixed schistous sandstone deposits (Aïn Rami-Amalay and Bab Taza, respectively). One toposequence was selected as representative of cedar forest over mixed quartzitic sandstone deposits (Ketama). The distribution of toposequences is shown on Figure 5, chapter II.

In all toposequences five major land elements could be distinguished:

- The crests (T) and upper slopes (U): mainly convex or in the form of a flat bench.

- The mid slopes (M): convex, concave or in the form of a flat bench.

- The lower slopes (L): mainly concave with local convex parts.

- The valley bottoms (V): concave or flat with local microrelief according to the mode of deposition.

This study was concerned with the parts of the landscape which were forested (natural forest or plantations) or local prairie vegetation types in forest openings. Cleared forest areas and cropped fields were not included. Rock outcrops and areas with very shallow soils over bedrock mainly occurred in the upper part of the landscapes, but not necessarily in the highest positions.

Rock ledges were frequent below the crest or plateau level and sometimes on the lower slopes, causing localized changes in the general topographic pattern. Soils of such outcrop areas are of limited value and did not merit much attention in this study. All the toposequences are covered with forest vegetation, have a dense dendritic drainage system, and the soils are relatively stable. On the other hand, pediments found in the lower part of the landscape at the accumulation level (superior glacis) are most prone to the impact of human activities and were not included in this study.

III.3. **RESULTS AND DISCUSSION.**

III.3.1. **Geological-ecological relationships of toposequences.**

The toposequences were selected to represent different parent materials and different forest vegetation types corresponding with climatic differences. Altitude was shown to be a good indicator of climatic conditions. Between altitudes of 350 and 700 m, the soil profiles have a subhumid climate with warm to temperate winters. Altitudes between 700 and 1,200 m have a humid climate with temperate to cool winters. Above 1,200 m, the climate is perhumid with cool to cold winters. A geological-ecological matrix of the toposequences is shown in Table 22.

III.3.2. **Characterization of toposequences.**

III.3.2.1. **Sandstone deposit toposequences.**

The Jbel Alam toposequence and the Khezana toposequence are both situated in the geological formation

Table 22: Geological-ecological matrix of the toposequences.

	Geology			
Ecological Zone	Sandstone deposit	Calcareous and dolometic deposit	Mixed schistous sandstone deposit	Mixed quartzitic sandstone deposit
Subhumid			Ain Rami toposequence AR34, AR33, AR40, A36, A35 T-W Wt ## cork oak - Pine plantations.	
Subhumid-humid	Jbel Alam toposequence AL1, AL2, AL3, AL4, AL5, AL6, F-T Wt ## cork oak		Amlay forest AR41 - AR42 T-W Wt ## cork oak Bab Taza toposequence BT17, BT16, BT18 T - Wt ## Pine plantations.	
Humid	Khezana toposequence Kh13, Kh14, Kh15 F-T Wt ## cork oak-deciduous oak			
Perhumid		Madissouka toposequence M7, M8, M9 M10, M10', M11, M12 F-C Wt ## Natural Pine Talassamtane toposequence TL23 TL22, TL28, TL25, TL27, TL27', TL26 C - Wt ## Fir forest Taznote toposequence T24, T19, T20, T21 C-Wt Pine + oak##		Ketama toposequence K31, K29, K30 C - Wt ## Cedar

Ecological features for localities where the toposequences were selected are given with initials. C: Cold, F: Cool, T: Temperate, W: Warm, Wt: Winter.

known as the Numidian sheet, which is mainly of Oligocene age. Jbel Alam (Alam mountain) extends over an area (7 km x 1 km) oriented SE-NW with crests reaching 1,228 m of altitude. Comparatively, Jbel Khezana (Khezana mountain) stretches over a large area (20 km x 4 km) in the SE-NW direction with higher crests at 1,700 m. The major forms of the relief are crests, cliffs, slopes, and nearly level accumulation benches below the slopes (accumulation terraces or glacis). These benches include many localized positions with convex or concave microrelief. Flat froms of the Numidian sheet (perched plateaus) occurring between 700 and 1,200 m (south aspect) and between 500-1,100 m (north aspect), were the basic sites of accumulation for detrital materials from summits or cliffs during the Superior Villafranchian (Inferior Pleistocene time) (Maurer, 1968). These deposits, mainly angular sandstone fragments in a sandy matrix, constituted the parent material of all members of the two toposequences. In terms of pedogenesis, the strong chemical alteration that dominated throughout the Pliocene-Inferior Villafranchian period under a tropical climate was no longer present. During the Pleistocene epoch, the physical alteration of superficial deposits dominated. The result of this alteration was the redistribution of finer materials mostly by humid solifluction processes.

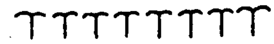
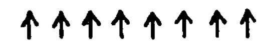
At present, most of the area is covered with forest. This vegetation cover is effective in controlling erosion in the dissected, sloping topography. In both toposequences, soils with varying degrees of hydromorphic characteristics occur locally, particularly on lower slopes near the valley bottom or at any elevation where grassy concave benches are present. The grasses or ferns are considered good indicators of a shallow water table or hydromorphic characteristics (profiles AL2, AL3, AL6, and Kh13). Weakly developed profiles occur on the upper slopes (Kh15) or, at steep slope positions where soils are shallow. Skeletal soils are more prevalent in the Jbel Alam toposequence. Schematic representations of these toposequences with different soil profiles are shown on Figures 6 and 7. The main soil orders of these toposequences are Inceptisols and Ultisols. The physical and chemical properties of these soils are summarized in Tables 23 and 24 for Jbel Alam and 25 and 26 for Khezana. Detailed interpretation of soil properties is reported in chapter II.

III.3.2.2. Calcareous and dolomitic deposit toposequences.

The previous forms of the relief that extended along the Numidian sheet were different from those related to the Calcareous Dorsal (Mesozoic age). The slopes were

<u>Chart 2</u>: Legend chart for diagrams on figures 6 to 13.

Vegetation

	Grassy vegetation .
	Fern vegetation .
	Other herbaceous plants (thistle...).
	Evergreen oak trees .
	Cork oak trees .
	Pine trees .
	Pine plantations .
	Cedar trees .
	Fir trees .

Soil

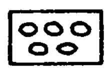
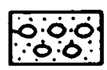
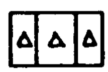
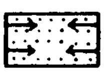
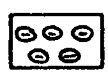
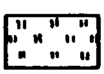
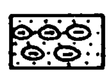
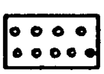
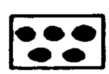
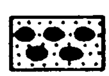
	Organic horizons.		Sandstone materials .
	Surface horizons with granular structure .		Altered sandstones .
	Surface horizons with crumb & angular structure .		Calcareous & dolomitic materials .
	Illuviation prevalent . (Argillic horizon)		Altered calcareous & dolometic materials .
	Alteration prevalent . (Cambic horizon)		Mixed schistous sandstone materials .
	Hydromorphic features . (Mottles, stains,...)		Altered mixed schist-sandstone materials .
	Calcic horizons .		Mixed quartzitic sandstone materials .
	Sandy dolomitic deposit .		Altered quartzitic sandstone materials .

Figure 6: Jbel Alam toposequence soils.
Subhumid to humid climate.
Sandstone deposit.

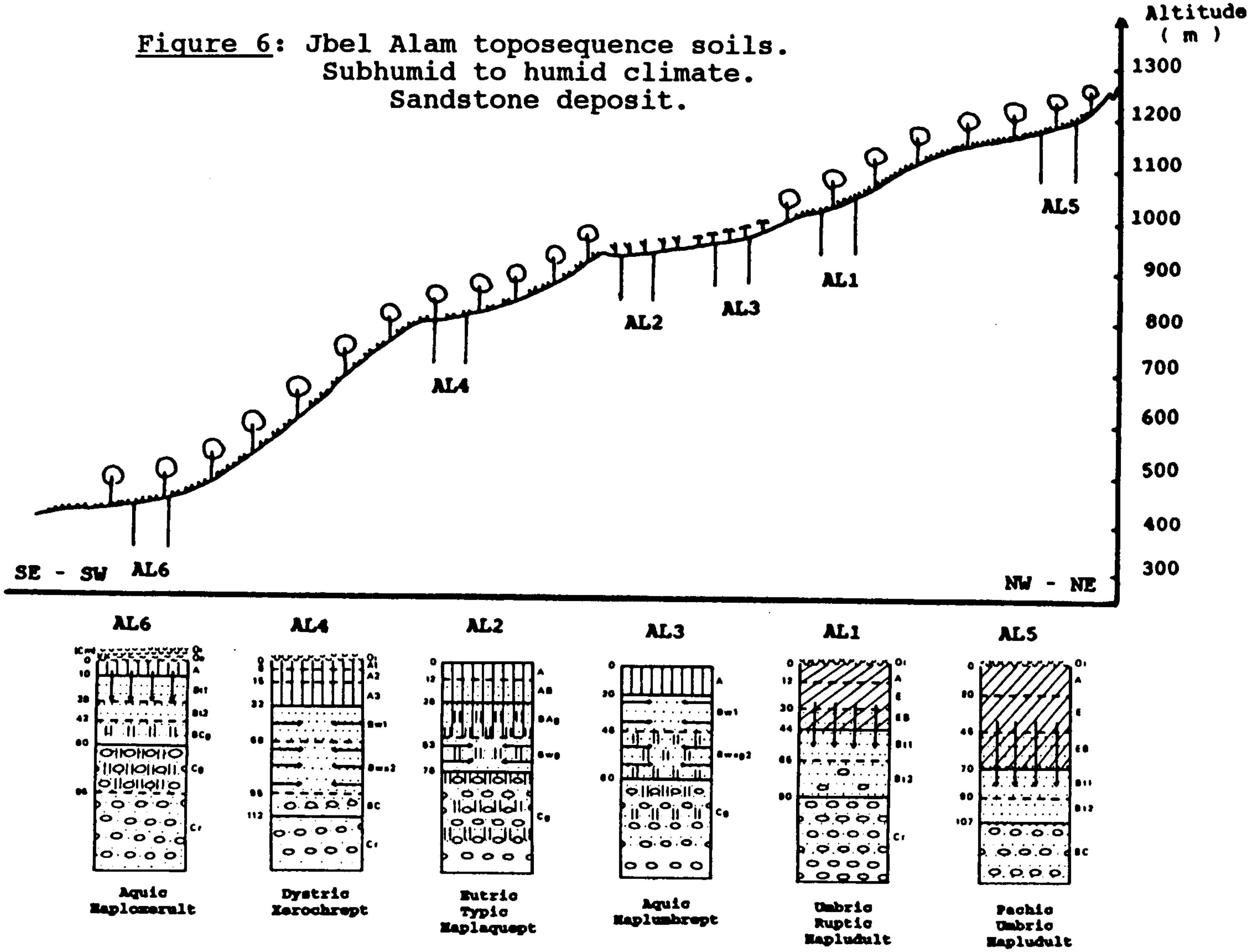


Table 23: Morphological and physical properties of Jbel Alam toposequence profiles. (See abbreviation chart for soil description, page 47, chapter II).

Profile symbols	Elevation m	Slope %	Horizon	Depth cm	Boundary	Munsell color (moist)	Texture	Structure	Clay %	Silt %	Sand %
AL_1	1030	2	A	0-12	gs	7.5 YR 3/2	gsl	f1gr	11.3	30.1	58.6
			E	12-30	cs	7.5 YR 3/2	gscl	f1sbk	20.2	26.6	53.2
			EB	30-44	cs	7.5 YR 3/4	gscl	m1sbk	29.5	22.0	48.5
			Bt1	44-65	gs	7.5 YR 4/4	gsc	m2sbk	35.1	16.9	48.0
			Bt2	65-90	cw	7.5 YR 5/6	gscl	m2sbk	33.0	15.9	51.1
			Cr	+ 90		7.5 YR 5/6	gscl	mgrms	--	--	--
AL_2	960	12-15	A	0-12	cs	10 YR 4/2	c	f1sbk	41.8	25.3	32.9
			AB	12-28	cs	2.5 Y 5/2	c	m2sbk	42.9	27.0	30.1
			BAg	28-53	ds	7.5 YR 5/6	c	fmgr	48.3	26.8	24.9
			Bwg	53-78	cw	7.5 YR 5/6	scl	fmgr	28.2	9.8	62.0
			Cg	+ 78		7.5 YR 5/6	gc	fmgr	56.3	23.8	19.9
AL_3	970	20	A	0-20	cw	10 YR 3/2	scl	f2sbk	28.6	26.8	44.6
			Bw1	20-46	cs	10 YR 6/3	cl	f3sbk	38.4	17.2	44.4
			Bwxg2	46-80	ds	7.5 YR 5/6	c	c1sbk	48.4	22.7	28.9
			Cg	+ 80		7.5 YR 5/6	c	c1sbk	61.2	26.9	11.9
AL_4	820	12-15	A1	0-6	as	10 YR 3/1	cosl	m2gr	10.8	15.2	74.0
			A2	6-15	cs	10 YR 5/2	coscl	f2sbk	29.2	13.9	56.9
			A3	15-32	cs	10 YR 4/3	coscl	f2sbk	23.1	11.4	65.5
			Bw1	32-58	gd	10 YR 3/2	coscl	fm3sbk	30.2	9.9	59.9
			Bwx2	58-95	cw	2.5 Y 5/2	coscl	m2sbk	33.4	8.7	57.9
			BC	+ 95	cw	2.5 Y 5/2	c	fmgr	56.3	22.6	21.1
AL_5	1190	2-3	A	0-20	ds	10 YR 3/2	cosl	m2gr	13.5	23.2	63.3
			E	20-45	gs	10 YR 3/3	cosl	f2gr	15.4	25.0	59.6
			EB	45-70	cs	10 YR 4/3	coscl	fm2gr	29.5	18.3	52.2
			Bt1	70-90	cs	10 YR 6/6	cosc	fm3sbk	37.9	14.1	48.0
			Bt2	90-107	cs	2.5 Y 7/4	cosc	f3sbk	41.6	9.7	48.7
			BC	+ 107		2.5 Y N7/	c	fmgr	45.0	12.5	42.5
AL_6	450	10-15	A	0-10	cs	10 YR 5/3	cosl	f3sbk	16.8	21.0	62.2
			Bt1	10-28	gs	7.5 YR 5/4	c	fm3sbk	48.6	18.5	32.9
			Bt2	28-42	cw	10 YR 7/3	c	f3abk	58.7	25.1	16.2
			BCg	42-60	gs	2.5 Y 6/2	c	f3abk	58.4	28.2	13.4
			Cg	60-95	ci	2.5 Y 6/2	c	m2abk	60.8	25.7	13.5
			Cr	+ 95		2.5 Y 4/6	scl	m2abk	32.6	18.5	48.9

Table 24: Chemical properties of Jbel Alam toposequence profiles. CEC = cation exchange capacity, PBS = percent base saturation.

Profile symbols	Horizon	Depth cm	pH H_2O	pH KCl	Total $CaCO_3$ %	C %	N %	C/N	Available P_2O_5 mg/Kg	CEC meq/100g	Ca meq/100g	Mg meq/100g	K meq/100g	Na meq/100g	PBS %
AL_1	A	0-12	5.7	4.2	nd Ø	4.60	0.38	12.1	28.0	47.5	2.5	0.9	1.0	7.3	24.6
	E	12-30	5.7	4.2	nd	2.34	0.23	10.2	8.0	58.1	0.5	0.6	0.5	6.9	14.6
	EB	30-44	6.0	4.2	nd	1.00	0.14	7.1	3.0	47.5	1.0	1.6	0.3	7.1	21.1
	Bt1	44-65	5.8	4.3	nd	0.80	0.10	8.0	10.0	45.6	0.5	0.9	0.3	7.0	19.1
	Bt2	65-90	6.1	4.2	nd	0.50	0.08	6.3	5.0	42.4	0.5	0.7	0.3	7.7	21.7
	Cr	+ 90	--	--	nd	--	--	--	--	--	--	--	--	--	--
AL_2	A	0-12	6.6	5.1	nd	2.00	0.24	8.3	3.0	67.1	16.5	8.7	0.5	9.5	52.5
	AB	12-28	6.9	5.7	nd	1.20	0.18	6.7	20.0	63.4	16.0	8.6	0.6	8.2	52.7
	BAg	28-53	7.0	5.3	nd	0.60	0.14	4.3	113.0	51.5	14.3	8.2	0.5	8.2	60.6
	Bwg	53-78	6.0	3.8	nd	0.40	0.07	5.7	5.0	36.3	0.3	1.3	0.3	7.8	26.7
	Cg	+ 78	7.3	6.1	nd	0.40	0.12	3.3	180.0	51.2	16.8	9.6	0.6	8.5	69.3
AL_3	A	0-20	6.5	5.0	nd	3.20	0.30	10.7	28.0	60.4	11.0	4.8	1.3	0.8	29.6
	Bw1	20-46	5.8	4.1	nd	0.80	0.18	4.4	85.0	52.3	6.0	4.2	0.6	1.3	23.1
	Bwxg2	46-80	5.7	4.0	nd	0.40	0.15	2.7	18.0	48.8	8.8	5.4	0.4	1.1	32.2
	Cg	+ 80	5.6	3.9	nd	0.40	0.12	3.3	8.0	49.3	11.0	7.0	0.5	0.8	39.1
AL_4	A1	0-6	5.2	4.3	nd	6.00	0.31	19.4	15	47.9	4.3	3.8	0.8	1.1	20.9
	A2	6-15	5.0	4.1	nd	1.60	0.12	13.3	5	38.6	1.0	2.8	0.3	1.5	14.5
	A3	15-32	5.8	4.4	nd	1.75	0.12	14.6	8	34.5	1.3	3.1	0.3	1.2	17.1
	Bw1	32-58	5.5	4.3	nd	1.30	0.14	9.3	10	41.1	0.5	1.9	0.4	0.7	8.5
	Bwx2	58-95	5.6	4.6	nd	0.75	0.10	7.5	10	48.8	0.3	1.2	0.3	1.3	6.4
	BC	+ 95	6.7	5.8	nd	0.40	0.13	3.1	163	58.1	17.5	8.5	0.5	2.0	49.1
AL_5	A	0-20	5.6	4.1	nd	7.40	0.48	15.4	60	60.6	5.3	3.4	0.8	0.3	16.2
	E	20-45	5.7	4.1	nd	3.34	0.29	11.5	63	49.0	1.5	1.1	0.2	1.6	9.0
	EB	45-70	5.8	4.5	nd	1.40	0.15	9.3	13	41.2	1.0	0.8	0.1	1.1	7.3
	Bt1	70-90	5.5	4.3	nd	0.48	0.09	5.3	30	39.0	1.3	1.1	0.1	1.9	11.3
	Bt2	90-107	5.4	4.2	nd	0.33	0.08	4.1	15	37.9	1.0	0.9	0.1	0.9	7.7
	BC	+ 107	5.3	4.0	nd	0.22	0.08	2.8	5	36.5	1.0	0.8	0.1	0.9	7.7
AL_6	A	0-10	5.3	4.0	nd	2.30	0.12	19.2	38	37.2	2.0	1.9	0.1	0.3	11.6
	Bt1	10-28	5.4	4.2	nd	1.50	0.10	15.0	15	42.4	4.5	3.8	1.3	0.4	23.6
	Bt2	28-42	5.3	4.0	nd	0.75	0.09	8.3	8	48.4	3.8	0.4	0.2	1.7	12.6
	BCg	42-60	5.4	4.1	nd	0.56	0.10	5.6	5	49.2	1.3	2.4	0.1	0.4	8.5
	Cg	60-95	5.2	4.0	nd	0.35	0.07	5.0	8	50.9	0.0	1.3	0.1	0.3	3.3
	Cr	+ 95	5.1	4.1	nd	0.23	0.05	4.6	8	36.2	0.3	0.7	0.1	0.3	3.9

Ø nd : not done .

Figure 7: Khezana toposequence soils.
Humid climate.
Sandstone deposit.

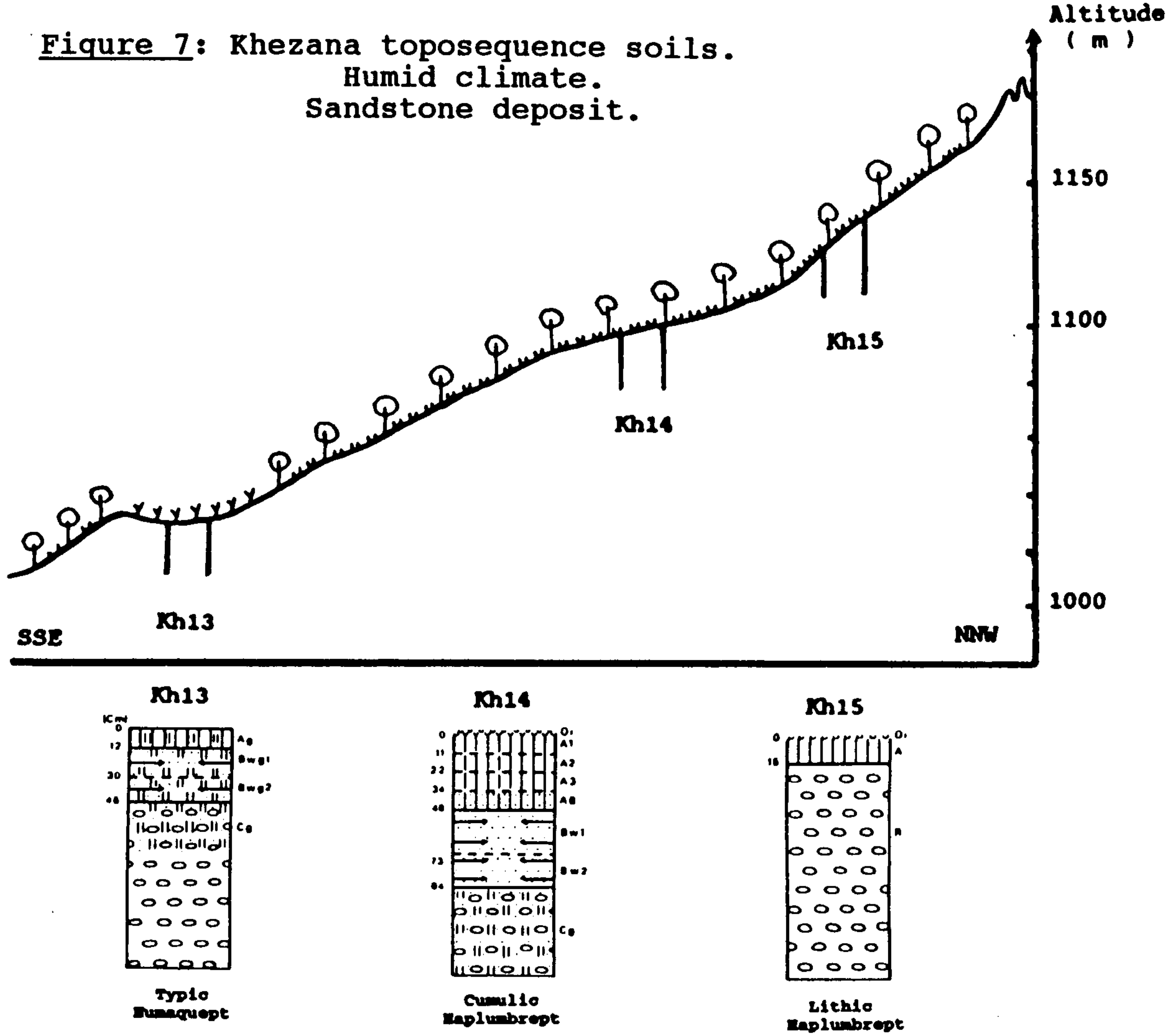


Table 25: Morphological and physical properties of Khezana toposequence profiles. (See abbreviation chart for soil description, page 47, chapter II).

Profile symbols	Elevation m	Slope %	Horizon	Depth cm	Boundary	Munsell color (moist)	Texture	Structure	Clay %	Silt %	Sand %
Kh_{13}	1030	1	Ag	0-12	ds	5 YR 5/6	cl	f1cr	34.1	45.3	20.6
			Bwg1	12-30	ds	5 YR 5/6	l	f1cr	15.8	33.0	51.2
			Bwg2	30-45	ds	10 YR 3/2	cl	f1cr	34.9	35.3	29.8
			Cg	+ 45	-	10 YR 3/2	cl-c	f1cr	39.6	33.0	27.4
Kh_{14}	1100	10	A1	0-11	as	10 YR 3/3	coscl	m1cr	24.6	16.7	58.7
			A2	11-22	ds	10 YR 3/2	cosl	m1cr	9.2	19.9	70.9
			A3	22-34	ds	10 YR 3/3	sl	m1cr	9.9	20.7	69.4
			AB	34-46	ds	10 YR 3/2	coscl	vffgr	20.5	25.9	53.6
			Bw1	46-73	ds	10 YR 3/2	l	vfgr	21.7	34.1	44.2
			Bw2	73-94	ds	10 YR 3/3	cosl	fgr	17.8	28.1	54.1
			Cr	+ 94		10 YR 3/3	l	fmgr	20.6	31.9	47.5
Kh_{15}	1140	45	A	0-15	as	10 YR 3/2	coscl	m2cr	20.0	16.5	63.5
			R	+ 15	Hard sandstone rocks						

Table 26: Chemical properties of Khezana toposequence profiles. CEC = cation exchange capacity, PBS = percent base saturation.

Profile symbols	Horizon	Depth cm	pH H_2O	pH KCl	Total $CaCO_3$ %	C %	N %	C/N	Available P_2O_5 mg/Kg	CEC meq/100g	Ca meq/100g	Mg meq/100g	K meq/100g	Na meq/100g	PBS %
Kh_{13}	Ag	0-12	5.8	4.9	nd #	5.00	0.39	12.8	47.5	36.9	9.8	6.7	0.3	1.9	50.7
	Bwg1	12-30	5.7	4.3	nd	3.00	0.17	17.7	27.5	38.9	6.5	4.9	0.2	1.6	33.9
	Bwg2	30-45	5.9	4.3	nd	2.00	0.32	6.3	52.5	33.8	3.3	4.0	0.2	1.1	25.4
	Cg	+ 45	5.9	4.3	nd	1.50	0.16	9.4	30.0	31.2	5.3	4.7	0.2	0.6	34.6
Kh_{14}	A1	0-11	5.4	4.0	nd	3.00	0.20	15.0	45.0	30.2	6.3	3.2	0.8	0.6	36.1
	A2	11-22	5.5	4.1	nd	3.00	0.21	14.3	40.0	32.8	6.8	3.6	1.0	0.5	36.3
	A3	22-34	5.4	4.0	nd	2.50	0.17	14.7	35.0	32.1	4.3	3.0	0.8	1.0	28.4
	AB	34-46	5.4	4.0	nd	2.70	0.21	12.9	32.5	33.3	3.8	2.6	0.6	0.6	22.8
	Bw1	46-73	5.2	4.0	nd	4.20	0.30	14.0	30.0	39.4	5.3	2.5	0.5	1.0	23.6
	Bw2	73-94	5.5	4.2	nd	2.60	0.24	10.8	42.5	34.9	3.5	1.6	0.3	0.7	17.5
	Cr	+ 94	5.7	4.3	nd	2.50	0.22	11.4	62.5	33.4	2.0	1.1	0.2	1.0	12.9
Kh_{15}	A	0-15	5.5	4.1	nd	2.90	0.20	14.5	42.0	29.9	6.1	3.2	0.8	0.5	35.5
	R	+ 15			Hard sandstone rocks										

nd : not done .

mainly short and accumulation terraces were very few. Maurer (1968) discussed the existence of two accumulation terraces on the south slope of the Calcareous Dorsal. They formed from schistous sandstone materials that accumulated along the front of the lower part of the Calcareous Dorsal.

The toposequences considered here are the Madissouka, Talassamtane, and Taznote toposequences. All three are situated between Jbel Lakraa (2,159 m) to the west and Jbel Taloussisse (2,005 m) to the east. The main feature distinguishing this landscape from the previous one is the lack of accumulation terraces derived from calcareous materials. The soil parent material consists of angular calcareous and dolomitic rocks in a matrix of finer calcareous materials, which may be cemented, or powdery dolomitic materials. These materials are scree from the cliffs that made the crests of the Calcareous Dorsal. The deposit thickness was not great enough to form accumulation terraces. The general forms of accumulation along the slopes are relatively complex and nested in each other. Many geologists have had difficulty determining the age of these forms. The most plausible age given by Maurer (1968) was mid-Quaternary.

Between altitudes of 1,000 and 1,400 m, two types of deposits were recognized, both related to the Soltanian age (late Pleistocene). The oldest and most important deposit is weakly cemented. The more recent deposit is reddish and consists of calcareous angular boulders in a clayey or sandy matrix associated with solifluction in a humid climate. Between 1,400 and 1,600 m, the structures and forms are related to a periglacial climate. Above 1,600 m, nivation forms are prominent with the youngest above 2,000 m. In contrast to the Pliocene tropical alteration mentioned for the sandstone toposequences, the dissolution of calcareous-dolomitic materials during that time led to formation of some sinkholes (dolines) or other karst forms in the area. Common features of these toposequences are the calcareous and dolomitic parent material and the perhumid climate. The differences were mainly the elevations of the profiles and the type of vegetation (pine, fir, and mixed pine-oak stands). The principal factors that caused differences among soils along the toposequences were the microrelief and mesorelief. The younger soils (T21, M10′, and M12) were near the crests, on upper slopes, and on steep slopes. Profiles on flat benches and depressions showed more advanced degrees of evolution. This might be explained by greater stability of the flat benches relative to the steep slopes. With more advanced weathering and soil formation, the profiles are relatively more clayey than most profiles of other toposequences. This relationship is particularly well expressed in the Talassamtane toposequence between 1,640 and 1,770 m. These toposequences and their soil profiles are represented in Figures 8, 9, and 10. The main soil orders of these toposequences are Entisols, Inceptisols, and Mollisols for Madissouka; Mollisols and Alfisols for Talassamtane; and Mollisols for Taznote. Their morphological, physical, and chemical properties are shown in Tables 27 and 28 for Madissouka, 29 and 30 for Talassamtane, and 31 and 32 for Taznote. Detailed interpretation of soil properties is reported in chapter II.

III.3.2.3. **Mixed schistous sandstone deposit toposequences.**

These deposits, though similar in their forms and structures to the sandstone Numidian sheet, are considered parts of the calcareous chain and the only real terraces in contact with the lower part of the Calcareous Dorsal (Raynal et al., 1964; Maurer et al., 1968). The two toposequences are located on terraces as described below:

- One terrace dominates the area of Aïn Rami forest (south west of Chefchaouen, mainly between 500 and 800 m).
- The other terrace is north of Bab Taza on Koudiat Achato, mainly between 500 and 1,200 m.

Figure 8: Madissouka toposequence soils.
Perhumid climate.
Calcareous and dolomitic deposit.

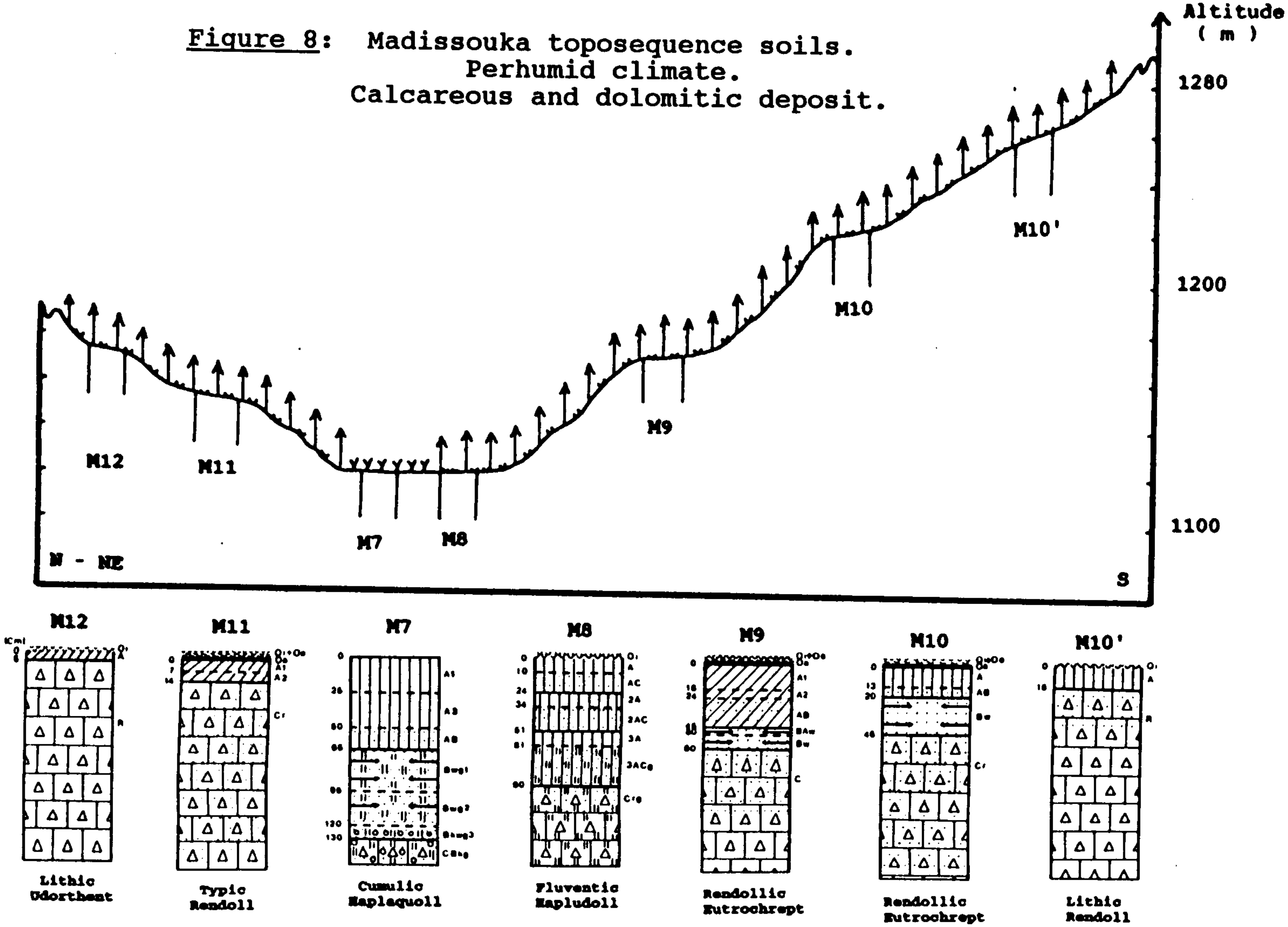


Table 27: Morphological and physical properties of Madissouka toposequence profiles. (See abreviation chart for soil description, page 47, chapter II).

Profile symbols	Elevation m	Slope %	Horizon	Depth cm	Boundary	Munsell color (moist)	Texture	Structure	Clay %	Silt %	Sand %
M_7	1120	10-15	A1	0-25	as	10 YR 3/1	sil	m2cr	7.8	53.1	39.1
			A2	25-50	ds	10 YR 3/1	sl	m2cr	6.3	44.0	49.7
			AB	50-65	ds	10 YR 3/1	l	m2cr	17.7	43.0	39.3
			Bwg1	65-95	ds	10 YR 3/1	l	m1cr	26.8	35.8	37.4
			Bwg2	95-120	gs	10 YR 3/2	l	fmgr	26.1	47.2	26.7
			Bkwg3	120-130	gs	10 YR 4/1	sicl	fmgr	30.7	59.7	9.6
			CBkg	130-150	gs	10 YR 4/1	sil	fmgr	23.8	60.7	15.5
			Ckg	+ 150		10 YR 4/1	cl	fmgr	29.3	50.8	19.9
M_8	1120	5	A	0-10	as	10 YR 3/2	sil	m1cr	15.1	51.8	33.1
			AC	10-24	as	10 YR 2/2	cosl	m1cr	1.8	31.3	66.9
			2A	24-34	ds	10 YR 3/2	cosl	m1cr	6.3	33.0	60.7
			2AC	34-51	cs	10 YR 3/2	cosl	m1cr	7.5	40.6	51.9
			3A	51-61	as	10 YR 2/1	cosl	m1sbk	4.4	29.7	65.9
			3ACg	+ 61		10 YR 3/2	sl	m1cr	3.7	47.0	49.3
M_9	1170	2	A1	0-18	gs	10 YR 3/2	cosl	fgr	10.4	23.9	65.7
			A2	18-24	gs	10 YR 3/3	lcos	vfgr	5.9	10.0	84.1
			AB	24-45	gi	10 YR 4/4	fs	vfgr	4.1	6.6	89.3
			BAw	45-50	gi	10 YR 5/4	lfs	vfmgr	7.7	15.4	76.9
			Bw	50-60	gi	10 YR 6/4	sil	mgr	6.3	67.8	25.9
			C	+ 60		10 YR 7/4	sil	cgr	13.3	65.4	21.3
M_{10}	1220	5	A	0-13	cs	10 YR 3/2	sl	f1cr-sbk	3.8	34.4	61.8
			AB	13-20	cs	10 YR 3/3	l-sl	f1cr-sbk	7.1	41.4	51.5
			Bw	20-46	gs	10 YR 6/4	si-sil	vfgr	12.3	81.1	6.6
			Cr	+ 46		10 YR 6/4	sil		8.3	68.6	23.1
$M_{10'}$	1260	40	A	0-15	as	10 YR 2/2	sl	fm2cr	5.2	34.9	59.9
			R	+ 15		Calcareous rocks					
M_{11}	1150	5	A1	0-7	cs	10 YR 3/2	lfs	vfgr	3.5	11.6	84.9
			A2	7-14	cs	10 YR 3/3	lfs	vfgr	3.4	15.2	81.4
			Cr	+ 14		10 YR 6/4	lfs	vfgr	0.0	17.1	82.9
M_{12}	1170	5	A	0-5	as	10 YR 3/3	lfs	vfgr	4.0	14.8	81.2
			R	+ 5		Calcareous and dolomitic rocks					

Table 28: Chemical properties of Madissouka toposequence profiles. CEC = cation exchange capacity, PBS = percent base saturation.

Profile symbols	Horizon	Depth cm	pH H_2O	pH KCl	Total $CaCO_3$ %	C %	N %	C/N	Available P_2O_5 mg/Kg	CEC meq/100g	Ca meq/100g	Mg meq/100g	K meq/100g	Na meq/100g	PBS %
M_7	A1	0-25	7.5	7.3	52.7	1.89	0.25	7.8	112.5	28.5	19.5	2.9	0.3	0.1	80.0
	A2	25-50	7.9	7.3	45.4	1.29	0.24	5.4	180.0	26.7	17.3	6.8	0.2	0.1	91.4
	AB	50-65	8.0	7.3	45.8	1.29	0.24	5.4	110.0	29.9	19.0	7.2	0.1	0.9	91.0
	Bwg1	65-95	8.0	7.3	47.0	1.80	0.22	8.2	100.0	25.9	17.8	5.9	0.2	0.1	92.7
	Bwg2	95-120	8.0	7.4	53.1	1.62	0.15	10.8	105.0	24.8	15.8	5.9	0.2	0.1	88.7
	Bkwg3	120-130	8.0	7.4	62.4	0.63	0.11	5.7	92.5	21.6	12.5	5.2	0.1	0.1	82.9
	CBkg	130-150	8.1	7.5	67.0	1.02	0.08	12.8	82.5	19.0	12.3	4.1	0.1	0.0	86.8
	Ckg	+ 150	8.2	7.5	69.5	0.63	0.06	10.5	80.0	17.9	11.8	3.9	0.1	0.0	88.3
M_8	A	0-10	7.8	7.2	68.7	3.90	0.31	12.6	130.0	28.8	17.3	8.4	0.1	0.1	89.9
	AC	10-24	7.9	7.2	69.5	1.74	0.24	7.3	120.0	28.4	19.0	8.0	0.1	0.1	95.8
	2A	24-34	8.0	7.2	62.1	4.68	0.34	13.8	100.0	37.9	21.8	10.0	0.1	0.1	84.4
	2AC	34-51	8.1	7.4	65.4	2.82	0.24	11.8	110.0	26.7	17.8	6.8	0.1	1.0	96.3
	3A	51-61	8.0	7.2	56.7	5.04	0.38	13.3	102.5	36.1	20.3	9.2	0.1	0.7	83.9
	3ACg	+ 61	7.8	7.2	55.4	1.44	0.22	6.6	87.5	29.6	17.0	8.8	0.1	0.1	87.8
M_9	A1	0-18	7.7	7.2	68.4	2.22	0.16	13.9	122.5	15.2	7.5	3.8	0.2	0.0	75.7
	A2	18-24	7.7	7.2	80.3	1.14	0.08	14.3	95.0	8.4	5.0	2.3	0.1	0.0	88.1
	AB	24-45	8.0	7.7	85.1	0.24	0.03	8.0	80.0	5.3	3.0	1.7	0.1	0.0	90.6
	BAw	45-50	8.0	7.6	83.0	0.24	0.03	8.0	82.5	7.9	4.0	2.4	0.1	0.0	82.3
	Bw	50-60	8.1	7.5	76.5	0.36	0.05	7.2	95.0	10.2	5.3	3.3	0.4	0.2	90.2
	C	+ 60	8.3	7.7	83.6	0.36	0.03	12.0	65.0	9.4	4.5	2.7	0.1	0.3	80.9
M_{10}	A	0-13	7.5	7.2	58.8	2.34	0.15	15.6	265.0	14.5	8.0	3.3	0.2	0.0	79.3
	AB	13-20	7.6	7.4	80.2	1.26	0.08	15.8	100.0	10.1	5.3	2.5	0.1	0.0	78.2
	Bw	20-46	8.1	7.9	85.4	0.24	0.06	4.0	87.5	8.6	4.3	2.7	0.1	0.0	82.6
	Cr	+ 46	8.4	8.3	85.9	0.06	0.03	2.0	75.0	7.7	3.5	2.4	0.0	0.9	88.3
$M_{10'}$	A	0-15	7.4	7.2	60.1	2.40	0.12	20.0	251.0	22.1	10.2	5.3	0.2	0.0	71.0
	R	+ 15			Calcareous rocks										
M_{11}	A1	0-7	7.8	7.3	83.8	2.48	0.19	27.6	82.5	8.9	5.0	2.2	0.1	0.0	82.0
	A2	7-14	7.8	7.3	85.9	1.34	0.23	5.8	92.5	7.7	4.3	2.2	0.1	0.3	89.6
	Cr	+ 14	8.2	7.3	85.8	0.41	0.03	13.7	117.5	7.2	3.5	2.1	0.0	0.0	77.8
M_{12}	A	0-5	7.7	7.3	80.2	2.73	0.15	18.2	101.1	9.6	5.3	2.1	0.1	0.0	78.1
	R	+ 5			Calcareous and dolomitic rocks										

Figure 9: Talassamtane toposequence soils.
Perhumid climate.
Calcareous and dolomitic deposit.

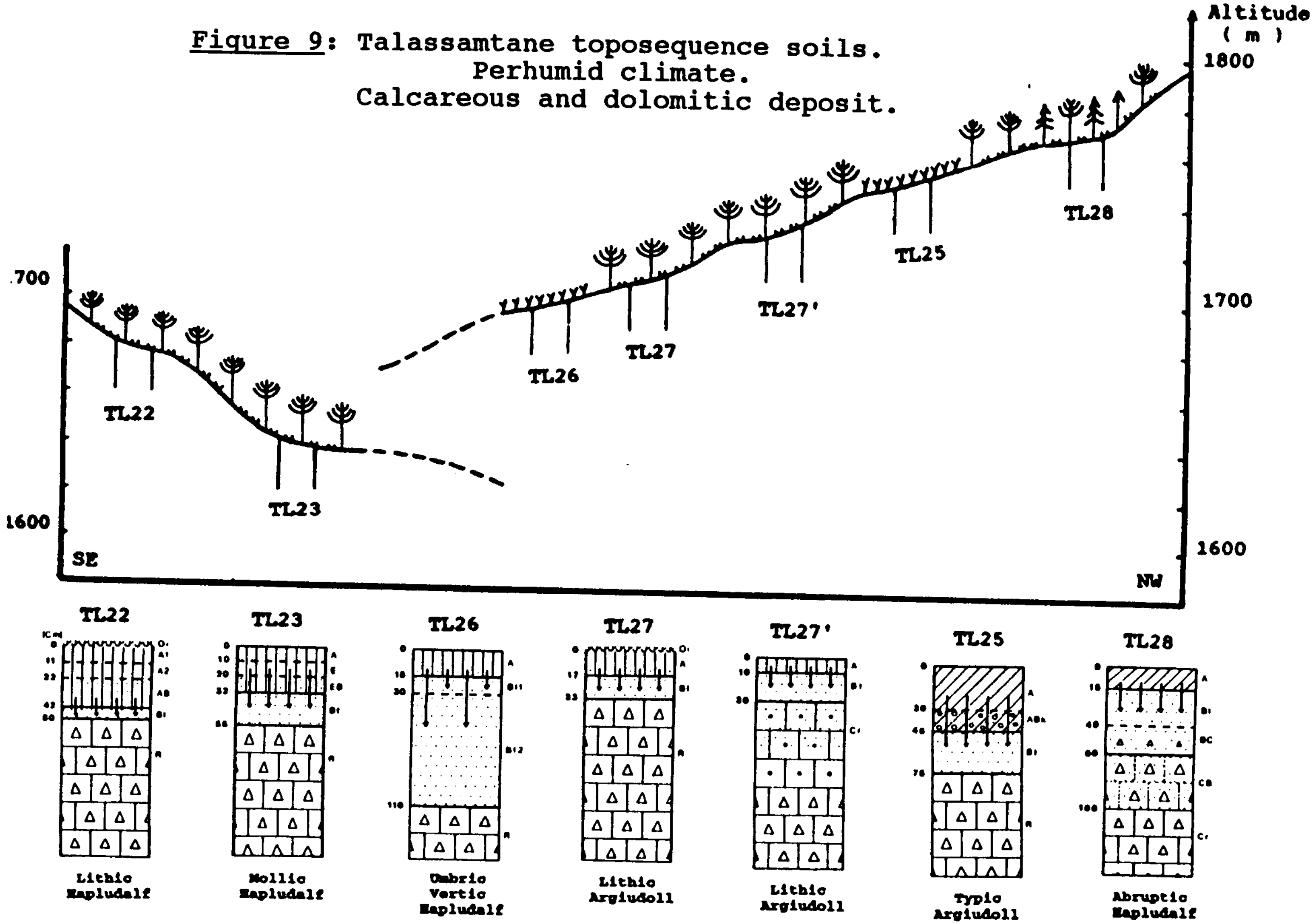


Table 29: Morphological and physical properties of Talassamtane toposequence profiles. (See abbreviation chart for soil description, page 47, chapter II).

Profile symbols	Elevation m	Slope %	Horizon	Depth cm	Boundary	Munsell color (moist)	Texture	Structure	Clay %	Silt %	Sand %
TL_{22}	1680	10	A1	0-11	ds	10 YR 4/3	cosl	f1cr	10.8	31.8	57.4
			A2	11-22	ds	10 YR 4/3	l	fm1cr	17.9	42.0	40.1
			AB	22-42	aw	10 YR 4/3	l	m1cr	34.6	39.4	26.0
			Bt	42-50	as	10 YR 4/3	c	m1cr	42.2	37.7	20.1
			R	+ 50		Calcareous rocks					
TL_{23}	1640	5-10	A	0-10	ds	10 YR 3/2	cosl	fm2cr	4.3	28.7	67.0
			E	10-20	gs	10 YR 4/4	l	fm1cr	26.2	30.7	43.1
			EB	20-32	ds	10 YR 4/6	c	f1cr	42.1	34.5	23.4
			Bt	32-55	as	10 YR 5/4	c	vc1pr	43.1	36.0	20.9
			R	+ 55		Calcareous rocks					
TL_{25}	1750	10	A	0-30	as	10 YR 3/2	sil	fmgr	9.7	62.9	27.4
			ABk	30-45	as	10 YR 3/2	sil	fmgr	17.8	54.2	28.0
			Bt	45-75	as	10 YR 4/3	c	m1sbk	48.0	33.5	18.5
			R	+ 75		Calcareous rocks					
TL_{26}	1700	15	A	0-18	as	10 YR 3/1	l-cl	vffm1cr	26.3	37.2	36.5
			Bt1	18-30	gs	5 YR 4/3	c	vffgr	50.4	39.5	10.1
			Bt2	30-110	as	5 YR 4/3	c	vffgr	52.6	40.9	6.5
			R	+ 110		Calcareous rocks					
TL_{27}	1710	15	A	0-17	as	10 YR 3/2	cl	fm1cr	28.1	37.4	34.5
			Bt	17-33	as	5 YR 4/3	sic	fm1sbk	45.2	41.5	13.3
			R	+ 33		Calcareous rocks					
$TL_{27'}$	1730	5-10	A	0-10	as	10 YR 3/2	cl	fm2cr	10.2	63.0	26.8
			Bt	10-30	as	10 YR 3/2	c	f1sbk	48.0	33.7	18.3
			Cr	+ 30		Altered calcareous and dolomitic rocks					
TL_{28}	1770	2	A	0-15	ds	10 YR 3/3	l	vffmgr	20.3	41.8	37.9
			Bt	15-40	aw	7.5 YR 3/4	c	vfgrms	59.5	26.1	14.4
			BC	40-60	cw	10 YR 4/3	sil	fmgrms	12.0	57.5	30.5
			CB	60-100	ds	10 YR 5/3	sil	fmgr	0.0	63.3	36.7
			Cr	+ 100		10 YR 5/2	sil	fmgrms	0.0	50.4	49.6

Table 30: Chemical properties of Talassamtane toposequence profiles. CEC = cation exchange capacity, PBS = percent base saturation.

Profile symbols	Horizon	Depth cm	pH		Total $CaCO_3$	C	N	C/N	Available P_2O_5 mg/Kg	CEC	Ca	Mg	K	Na	PBS %
			H_2O	KCl	%					meq/100g					
TL_{22}	A1	0-11	6.5	5.9	nd ∅	7.00	0.41	17.1	120.4	57.2	27.3	3.5	1.1	0.4	56.4
	A2	11-22	6.3	5.2	nd	2.80	0.16	17.5	48.2	61.3	16.0	2.0	0.5	0.3	30.7
	AB	22-42	6.5	5.2	nd	1.40	0.11	12.7	24.1	35.4	14.3	1.6	0.6	0.3	47.5
	Bt	42-50	6.5	5.4	nd	1.20	0.11	10.9	20.6	25.5	18.0	1.5	0.6	0.1	79.2
	R	+ 50						Calcareous rocks							
TL_{23}	A	0-10	6.2	5.5	nd	8.40	0.47	17.9	75.0	58.5	25.0	4.7	1.2	0.1	53.0
	E	10-20	6.2	5.5	nd	2.80	0.17	16.5	55.0	57.5	20.0	3.5	0.6	0.2	42.3
	EB	20-32	6.3	5.3	nd	1.40	0.10	14.0	103.8	49.9	19.8	4.2	0.6	0.2	49.7
	Bt	32-55	6.7	6.0	nd	0.80	0.09	8.9	243.8	38.5	22.3	8.2	0.6	0.2	81.3
	R	+ 55						Calcareous rocks							
TL_{25}	A	0-30	7.6	7.1	62.1	3.84	0.40	9.6	108.8	21.3	11.0	4.8	0.5	2.4	87.8
	ABk	30-45	7.5	7.1	51.7	2.88	0.27	10.7	85.0	18.4	10.0	5.1	0.3	0.4	85.9
	Bt	45-75	7.9	7.0	07.5	2.13	0.20	10.7	28.8	24.2	12.5	7.4	0.6	0.3	86.0
	R	+ 75						Calcareous rocks							
TL_{26}	A	0-18	7.8	7.0	19.2	6.72	0.76	8.8	87.5	29.5	18.0	5.3	0.5	0.2	81.4
	Bt1	18-30	8.1	7.2	21.7	0.69	0.11	6.3	21.3	21.3	13.5	3.5	0.6	0.2	83.6
	Bt2	30-110	8.2	7.5	24.4	0.30	0.05	6.0	15.0	20.0	11.0	4.3	0.7	0.3	81.5
	R	+ 110						Calcareous rocks							
TL_{27}	A	0-17	7.1	6.6	08.3	9.90	0.71	13.9	235.0	39.6	20.8	8.3	1.3	0.5	78.0
	Bt	17-33	7.6	6.9	17.5	1.83	0.18	10.2	83.8	23.3	16.8	3.6	1.2	0.8	96.1
	Cr	+ 33						Calcareous rocks							
$TL_{27'}$	A	0-10	7.6	7.1	60.0	3.43	0.40	8.9	95.5	37.1	13.3	10.1	0.5	2.4	70.9
	Bt	10-30	7.5	7.0	49.7	2.34	0.20	11.7	26.0	45.1	19.4	12.0	0.6	0.3	71.6
	Cr	+ 30						Altered calcareous and dolomitic rocks							
TL_{28}	A	0-15	7.7	7.2	50.8	3.20	0.13	24.6	115.0	29.0	13.8	7.1	0.8	0.3	75.9
	Bt	15-40	7.9	6.8	13.3	1.92	0.39	4.9	41.3	23.1	12.3	7.8	0.6	0.3	90.9
	BC	40-60	8.0	7.5	67.1	0.54	0.13	4.2	31.3	12.8	7.3	3.3	0.1	0.3	85.9
	CB	60-100	8.3	7.7	70.8	0.30	0.05	6.0	40.0	8.3	5.0	2.1	0.1	0.2	89.2
	Cr	+ 100	8.5	8.0	75.0	0.21	0.02	10.5	25.0	6.1	3.3	2.0	0.1	0.2	91.8

∅ nd : not done .

Figure 10: Taznote toposequence soils.
Perhumid climate.
Calcareous and dolomitic deposit.

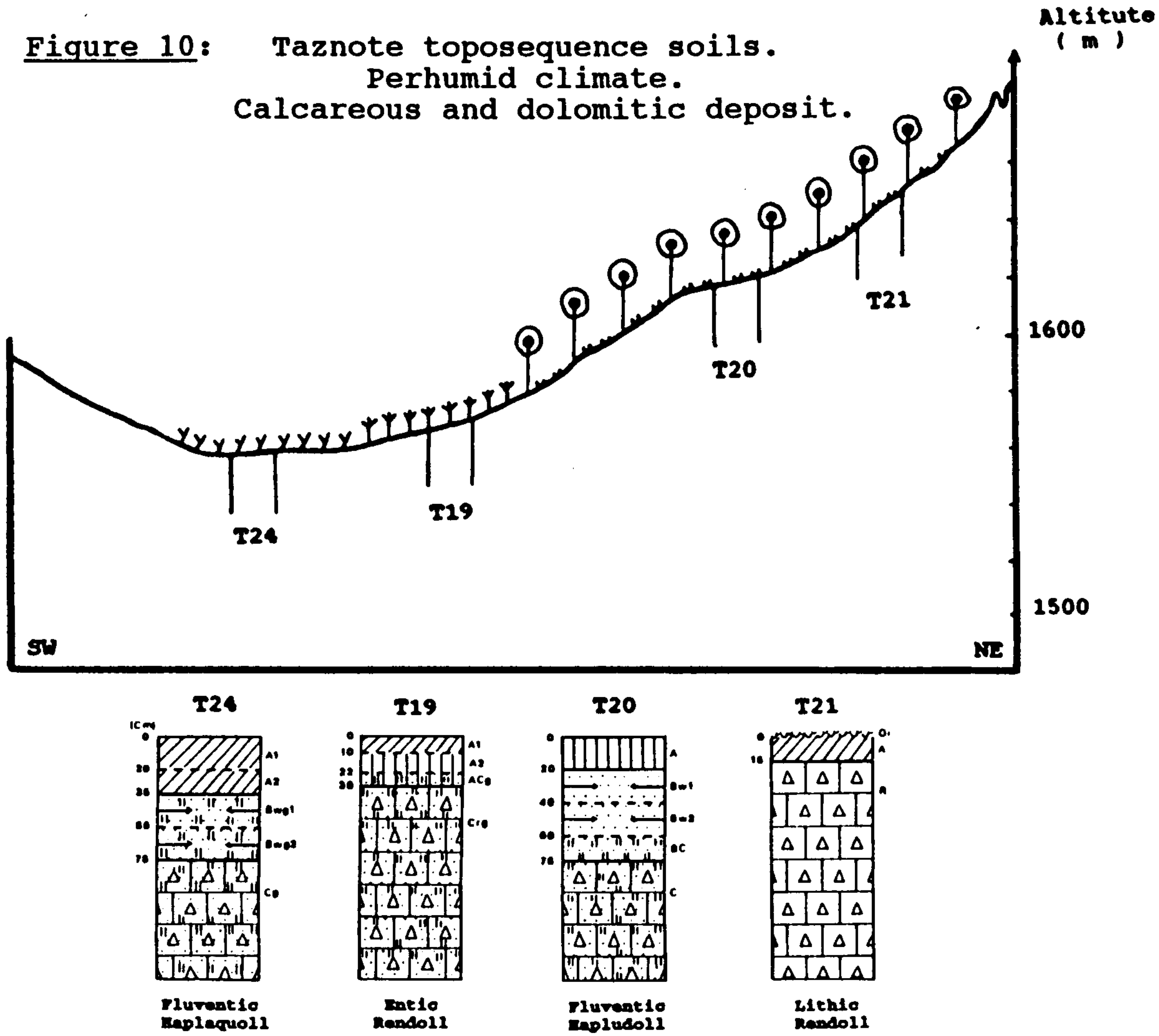


Table 31: Morphological and physical properties of Taznote toposequence profiles. (See abbreviation chart for soil description, page 47, chapter II).

Profile symbols	Elevation m	Slope %	Horizon	Depth cm	Boundary	Munsell color (moist)	Texture	Structure	Clay %	Silt %	Sand %
T_{19}	1570	12-15	A1	0-10	gs	10 YR 3/3	l	mgrms	13.5	40.3	46.2
			A2	10-22	gs	10 YR 4/4	sl	m1-2cr	14.1	32.0	53.9
			ACg	22-30	gs	5 Y 5/4	sl-l	mgr	13.2	36.3	50.5
			Crg	+ 30		5 Y 6/4	l	mgr	16.0	34.1	49.9
T_{20}	1620	10	A	0-20	as	10 YR 3/2	cl	mscpr	30.7	26.6	42.7
			Bw1	20-40	gs	5 Y 5/2	cl	msvcpr	39.1	17.9	43.0
			Bw2	40-60	gs	5 Y 5/2	cl	vffgrms	34.7	34.6	30.7
			BC	60-75	gs	5 Y 5/3	cl	fmgrms	29.5	26.9	43.6
			C	+ 75		5 Y 5/1	cl	fmgrms	38.5	25.8	35.7
T_{21}	1650	50	A	0-15	as	10 YR 3/2	cl	fgrms	32.7	45.3	22.0
			R	+ 15		Calcareous rocks					
T_{24}	1560	0	A1	0-20	ds	10 YR 3/2	sl-l	vfgr	13.5	35.2	51.3
			A2	20-35	gs	10 YR 3/3	cl	vfgr	39.8	37.5	32.7
			Bwg1	35-55	gs	2.5 Y 5/6	c	vfgr	50.1	38.7	11.2
			Bwg2	55-75	gs	2.5 Y 5/6	c	vfgrms	47.4	42.2	10.4
			Cg	+ 75		2.5 Y N6/	c	vfgrms	42.6	39.4	18.2

Table 32: Chemical properties of Taznote toposequence profiles. CEC = cation exchange capacity, PBS = percent base saturation.

Profile symbols	Horizon	Depth cm	pH		Total $CaCO_3$	C	N	C/N	Available P_2O_5 mg/Kg	CEC	Ca	Mg	K	Na	PBS %
			H_2O	KCl	%					meq/100g					
T_{19}	A1	0-10	7.8	7.2	22.1	2.46	0.12	20.5	185.0	20.2	14.5	1.4	0.5	1.0	86.1
	A2	10-22	8.0	7.3	24.2	0.72	0.08	9.0	26.3	19.0	14.0	1.7	0.3	0.9	88.9
	ACg	22-30	8.0	7.3	21.7	0.30	0.05	6.0	35.0	19.4	13.5	1.6	0.2	0.8	84.0
	Crg	+ 30	8.1	7.3	25.9	0.24	0.04	6.0	21.3	18.4	13.0	1.9	0.2	1.0	87.5
T_{20}	A	0-20	6.7	6.0	00.0	3.06	0.09	34.0	100.0	34.7	15.3	2.5	1.4	0.3	56.2
	Bw1	20-40	7.5	6.8	01.3	0.72	0.07	10.3	150.0	23.3	12.5	2.3	1.0	1.2	78.5
	Bw2	40-60	7.9	7.0	02.9	0.30	0.07	4.3	87.5	20.1	11.9	3.1	0.8	1.0	83.6
	BC	60-75	7.9	7.0	05.0	0.60	0.07	8.6	28.8	18.0	11.0	3.1	1.0	0.6	87.2
	C	+ 75	8.0	7.0	04.2	0.84	0.06	14.0	22.5	19.2	9.5	5.5	0.8	0.4	84.4
T_{21}	A	0-15	6.6	6.1	nd Ø	5.00	0.41	12.2	676.3	53.5	25.0	7.3	1.9	0.2	64.3
	R	+ 15							Calcareous rocks						
T_{24}	A1	0-20	7.6	6.9	15.4	5.46	0.40	13.7	92.5	39.9	17.0	9.8	0.5	4.4	79.4
	A2	20-35	7.4	6.7	06.3	2.13	0.21	10.1	185.0	41.8	17.5	10.7	0.7	4.4	79.7
	Bwg1	35-55	7.5	6.8	03.8	1.17	0.12	9.8	47.5	36.6	17.0	10.1	0.7	4.4	88.0
	Bwg2	55-75	7.8	7.0	06.7	1.08	0.12	9.0	86.3	31.4	11.8	9.1	0.6	4.4	82.5
	Cg	+ 75	7.7	7.0	03.9	1.62	0.19	8.5	68.8	37.7	16.0	11.3	0.6	4.4	85.7

Ø nd = not determined

These terraces are underlain by resistant sandstone superimposed over soft schistous material. The steeper slopes are related to harder rock and undulating forms to the soft material. The parent material is somewhat similar to that previously described for the Jbel Alam and Khezana toposequences, particularly the angular rock material embedded in a sandy gray matrix on higher slopes and sandy or finer reddish matrix on lower parts.

When the accumulation terraces meet alluvial terraces of the valley bottom, the deposit changes to angular gravels and stones in a reddish matrix. By analogy with Jbel Alam and Khezana, the upper part is related to Superior Villafranchian and the lower part with soft material to Regregian age (early Pleistocene). Here also, less developed soils occur on the upper slopes, crests, and the steeper slopes at any altitude (profiles BT16 and BT17). Flat or concave slope positions are more stable and soils are more developed (profiles AR42, AR40, AR33, AR34, A36, A35 and BT18). Because of the lower convcave flat local relief of these toposequences (cumulative lateral drainage from the upper part) and the more clayey material (schist) in some spots, profiles with hydromorphic characteristics are common (profiles AR40, AR42, AR34, A36, A35, and BT18). The vegetation cover of these toposequences is either pine plantations (Bab Taza and parts of Aïn Rami) or cork oak (Aïn Rami and Amlay forests). These toposequences and their profiles are represented on Figures 11 and 12. The main soil orders of these toposequences are Entisols, Inceptisols, and Ultisols. Their morphological, physical, and chemical properties are summarized in Tables 33 and 34 for Aïn Rami-Amlay, and 35 and 36 for Bab Taza. Detailed interpretation of soil properties is reported in chapter II.

III.3.2.4. **Mixed quartzitic sandstone deposit toposequence.**

These deposits are part of the Ketama Unit (Central Rif). The relief is dominated by a sequence of crests and valleys. The toposequence is developed on mixed quartzitic sandstone deposits of Jbel Dehdouh (2,112 m). The crests are underlain by resistant quartzitic sandstone rocks of Albo-aptian (Cretaceous age). Relict landforms (Pontian and Villafranchian) are numerous, particularly between the crests and valley bottoms, i.e., perched plains, wide depressions, and rock knobs. The schistous material that characterizes the Ketama Unit is not as prevalent relative to the most distal east-west limits of Jbel Dehdouh. The structures and forms of the relief are similar to those described previously for calcareous and dolomitic materials. The source of detrital material covering the

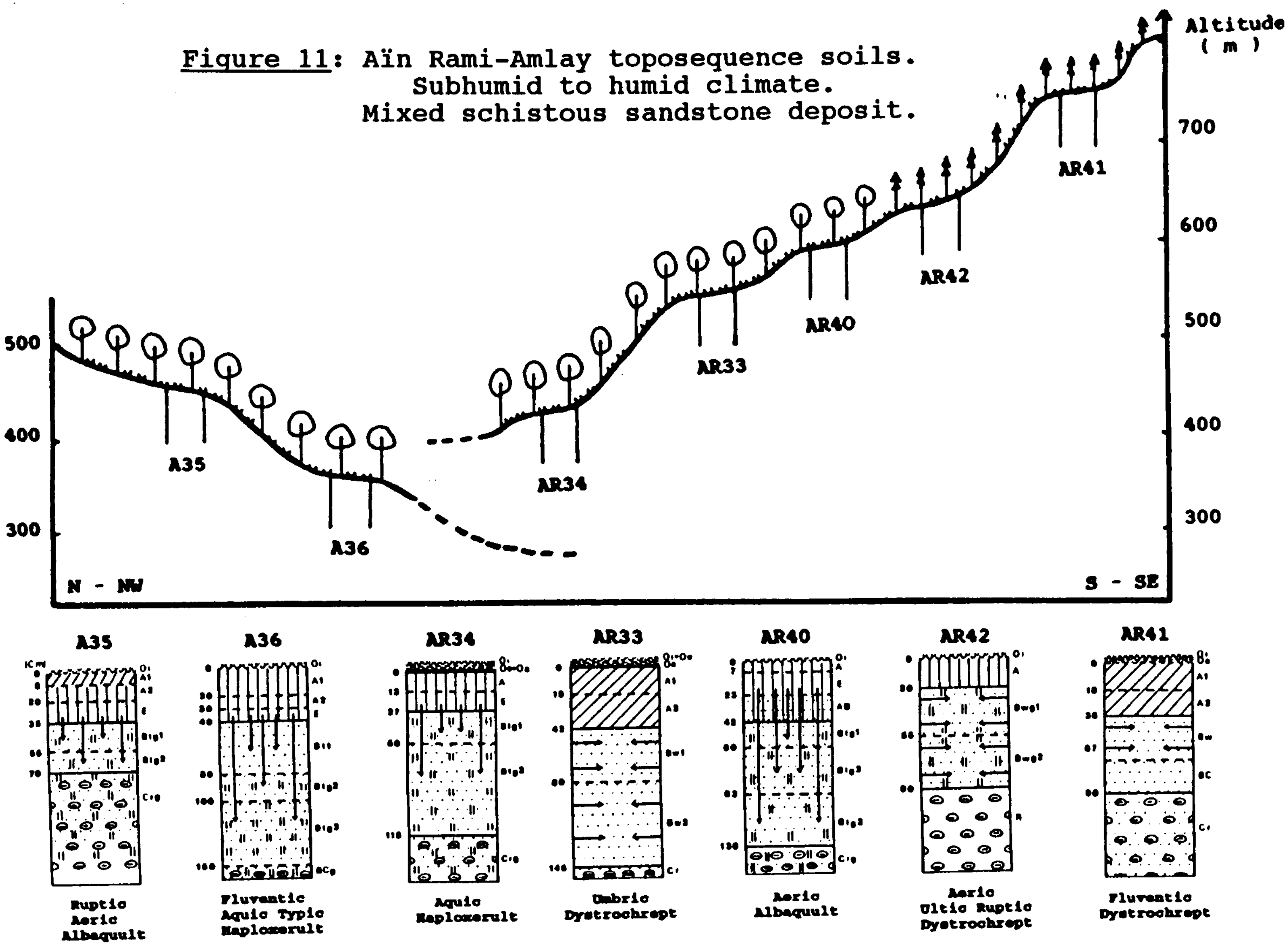


Figure 11: Aïn Rami-Amlay toposequence soils.
Subhumid to humid climate.
Mixed schistous sandstone deposit.

<u>Table 33</u>: Morphological and physical properties of Aïn Rami-Amlay toposequence profiles. (See abbreviation chart for soil description, page 47, chapter II).

Profile symbols	Elevation m	Slope %	Horizon	Depth cm	Boundary	Munsell color (moist)	Texture	Structure	Clay %	Silt %	Sand %
AR_{33}	550	5	A1	0-18	ds	10 YR 3/2	sl	fgr	13.8	15.0	71.2
			A2	18-42	gs	7.5 YR 3/4	sl	fgr	19.1	13.4	67.5
			Bw1	42-80	ds	5 YR 4/6	scl	fgr	27.4	12.3	60.3
			Bw2	80-145	ab	5 YR 5/8	scl	fgr	30.3	14.2	55.5
			Cr	+ 145		Sanstone rocks					
AR_{34}	430	5-7	A	0-13	ds	10 YR 4/4	cl	mc1cr	34.5	28.5	37.0
			E	13-27	gs	5 YR 4/6	c	fmc1cr	45.9	23.5	30.6
			Btg1	27-50	ds	10 YR 5/6 2.5 YR 4/8	c	fm1sbk	52.8	29.0	18.2
			Btg2	50-115	gs	10 YR 5/6 2.5 YR 4/8	c	fm1sbk	48.1	28.3	23.6
			Crg	+ 115		10 YR 5/6 2.5 YR 4/8	cl	m1abk	36.5	21.0	42.5
AR_{40}	600	3	A	0-7	as	7.5 YR 3/2	l	fm2cr	25.8	43.5	30.7
			E	7-23	as	7.5 YR 4/4	cl	f2cr-gr	34.4	40.3	25.3
			AB	23-42	ds	5 YR 5/8	c	m2sbk	62.1	23.6	14.3
			Btg1	42-60	gs	5 YR 5/8	c	f2sbk	67.8	22.0	10.2
			Btg2	60-93	ds	2.5 YR 5/4	c	fm2sbk	61.5	24.1	14.4
			Btg3	93-130	aw	5 YR 5/8	c	fm2sbk	63.8	27.0	9.2
			Crg	+ 130		Schistous rocks					
AR_{41}	750	0-1	A1	0-18	ds	10 YR 4/3	sl	fgr	15.1	23.7	61.2
			A2	18-36	ds	10 YR 4/3	sl	fgrms	16.4	20.0	63.6
			Bw	36-67	ds	5 YR 3/3	sl	fgr	17.7	19.6	62.7
			BC	67-90	as	10 YR 4/3	scl	fgr	25.8	16.3	57.9
			Cr	+ 90		Sandstone rocks					
AR_{42}	640	3	A	0-20	as	10 YR 4/3	cl	fm2cr	34.6	33.6	31.8
			Bwg1	20-53	ds	5 YR 5/8	c	m2sbk	55.1	14.5	30.4
			Bwg2	53-90	gs	variegated *	c	m2sbk	64.1	18.2	17.7
			R	+ 90		Schistous rocks					
A_{35}	460	15	A1	0-8	ds	10 YR 2/1	sl	fmgr	3.7	33.2	63.1
			A2	8-20	gs	7.5 YR 3/2	sl	fm2cr	28.6	24.1	47.3
			E	20-35	as	7.5 YR 4/6	cl	m2cr	36.9	22.1	41.0
			Btg1	35-55	gs	10 YR 6/6	c	fm2sbk	58.6	19.7	21.7
			Btg2	55-70	gs	10 YR 5/6	sc	fm2sbk	38.9	13.5	47.6
			Crg	+ 70		10 YR 5/6	c	fmgr	53.3	19.3	27.4
A_{36}	360	8	A1	0-20	as	7.5 YR 3/2	sl	f2sbk	16.4	25.3	58.3
			A2	20-30	gs	7.5 YR 3/4	scl	f2sbk	26.3	22.9	50.8
			E	30-40	aw	7.5 YR 4/6	scl	m2sbk	29.8	21.6	48.6
			Bt1	40-80	ds	5 YR 4/6	c	m2sbk	52.7	21.7	25.6
			Btg2	80-100	gs	5 YR 6/8	c	m2sbk	59.0	18.0	23.0
			Btg3	100-150	as	5 YR 4/6	c	f1sbk	55.6	22.3	22.1
			BCg	+ 150		Altered sandstone rocks					

* : 5 YR 5/8, 2.5 Y 6/4 & 5 Y 7/1 .

<u>Table 34</u>: Chemical properties of Aïn Rami-Amlay toposequence profiles. CEC = cation exchange capacity, PBS = percent base saturation.

Profile symbols	Horizon	Depth cm	pH H_2O	pH KCl	Total $CaCO_3$ %	C %	N %	C/N	Available P_2O_5 mg/Kg	CEC meq/100g	Ca meq/100g	Mg meq/100g	K meq/100g	Na meq/100g	PBS %
AR_{33}	A1	0-18	5.6	4.3	nd *	2.40	0.11	21.8	70.0	26.1	1.0	1.1	0.1	0.2	9.2
	A2	18-42	5.6	4.5	nd	1.40	0.08	17.5	65.0	24.6	0.0	0.6	0.0	0.1	2.8
	Bw1	42-80	5.4	4.3	nd	0.50	0.04	12.5	57.5	22.6	0.3	0.7	0.1	0.1	5.3
	Bw2	80-145	5.4	4.1	nd	0.34	0.04	8.5	37.5	31.1	0.0	0.4	0.1	0.1	1.9
	Cr	+ 145						Sandstone rocks							
AR_{34}	A	0-13	5.6	4.4	nd	2.10	0.13	16.2	35.0	55.1	5.0	5.2	0.4	0.5	20.1
	E	13-27	5.5	4.1	nd	0.96	0.08	12.0	23.8	49.6	3.5	6.0	0.3	0.3	20.4
	Btg1	27-50	5.6	3.9	nd	0.60	0.09	6.7	16.3	50.5	3.0	6.4	0.3	0.6	20.4
	Btg2	50-115	5.5	3.8	nd	0.30	0.08	3.8	5.0	55.2	2.0	6.1	0.3	0.3	15.8
	Crg	+ 115	5.5	3.8	nd	0.24	0.08	3.0	17.5	50.7	1.5	6.0	0.3	0.3	16.0
AR_{40}	A	0-7	5.7	5.0	nd	6.40	0.24	26.7	106.3	30.9	7.5	4.8	0.4	0.5	42.7
	E	7-23	5.3	4.9	nd	1.52	0.08	19.0	47.5	23.9	3.3	0.8	0.2	0.4	19.7
	AB	23-42	5.1	3.6	nd	4.39	0.10	43.9	32.5	25.1	3.0	4.9	0.2	0.5	34.3
	Btg1	42-60	5.1	3.5	nd	0.61	0.09	6.8	33.8	25.6	0.5	3.1	0.1	0.6	16.8
	Btg2	60-93	5.1	3.4	nd	0.50	0.06	8.3	43.8	28.2	0.3	2.4	0.1	0.6	12.1
	Btg3	93-130	5.2	4.3	nd	0.39	0.04	9.8	42.5	29.7	0.3	2.1	0.3	1.2	13.1
	Crg	+ 130						Schistous rocks							
AR_{41}	A1	0-18	5.2	4.0	nd	2.59	0.11	23.6	44.5	19.3	1.3	0.8	0.1	0.4	13.5
	A2	18-36	5.1	4.0	nd	1.38	0.13	10.6	23.7	18.2	0.3	0.3	0.1	0.3	5.5
	Bw	36-67	5.1	4.0	nd	1.43	0.14	10.2	24.6	15.2	0.5	0.3	0.0	0.5	8.6
	BC	67-90	5.1	3.8	nd	0.66	0.07	9.4	11.4	16.4	0.5	0.4	0.0	0.7	9.8
	Cr	+ 90						Sandstone rocks							
AR_{42}	A	0-20	6.0	4.6	nd	4.52	0.12	37.7	77.7	27.2	7.5	3.6	0.3	0.7	44.5
	Bwg1	20-53	5.0	3.5	nd	0.50	0.07	7.1	8.6	28.0	4.0	3.3	0.3	0.4	28.6
	Bwg2	53-90	5.0	3.4	nd	0.39	0.06	6.5	6.7	36.8	1.3	2.4	0.1	0.3	11.1
	R	+ 90						Schistous rocks							
A_{35}	A1	0-8	5.7	4.9	nd	2.72	0.07	38.9	190.0	36.8	8.5	2.6	0.6	0.1	32.1
	A2	8-20	6.0	4.8	nd	0.60	0.06	10.0	55.0	22.7	2.5	0.7	0.3	0.1	15.9
	E	20-35	6.0	4.6	nd	0.22	0.05	4.4	33.8	24.1	2.8	0.9	0.3	0.1	17.0
	Btg1	35-55	5.9	4.0	nd	0.60	0.07	8.6	23.8	34.6	5.5	3.3	0.4	0.1	26.9
	Btg2	55-70	5.2	3.7	nd	0.27	0.08	3.4	25.0	36.6	1.8	1.7	0.4	0.1	10.9
	Crg	+ 70	5.0	3.6	nd	0.27	0.07	3.9	17.5	32.6	1.0	1.3	0.4	0.1	8.6
A_{36}	A1	0-20	6.1	5.2	nd	3.14	0.16	19.6	58.2	34.7	6.8	2.9	0.5	0.1	29.7
	A2	20-30	6.0	4.5	nd	0.49	0.10	4.9	15.0	28.7	4.5	3.0	0.3	0.1	27.5
	E	30-40	5.8	4.2	nd	0.22	0.07	3.1	12.5	29.9	4.3	3.3	0.3	0.2	27.1
	Bt1	40-80	5.4	4.6	nd	0.38	0.07	5.4	11.3	36.2	4.5	4.6	0.3	0.2	26.5
	Btg2	80-100	5.3	3.6	nd	0.43	0.09	4.8	20.0	37.8	4.5	5.3	0.3	0.3	27.5
	Btg3	100-150	5.3	3.6	nd	0.27	0.09	3.0	15.0	32.7	3.3	5.3	0.3	0.5	28.7
	BCg	+ 150						Altered sandstone rocks							

* nd : not done .

Figure 12: Bab Taza toposequence soils.
Subhumid to humid climate.
Mixed schistous sandstone deposit.

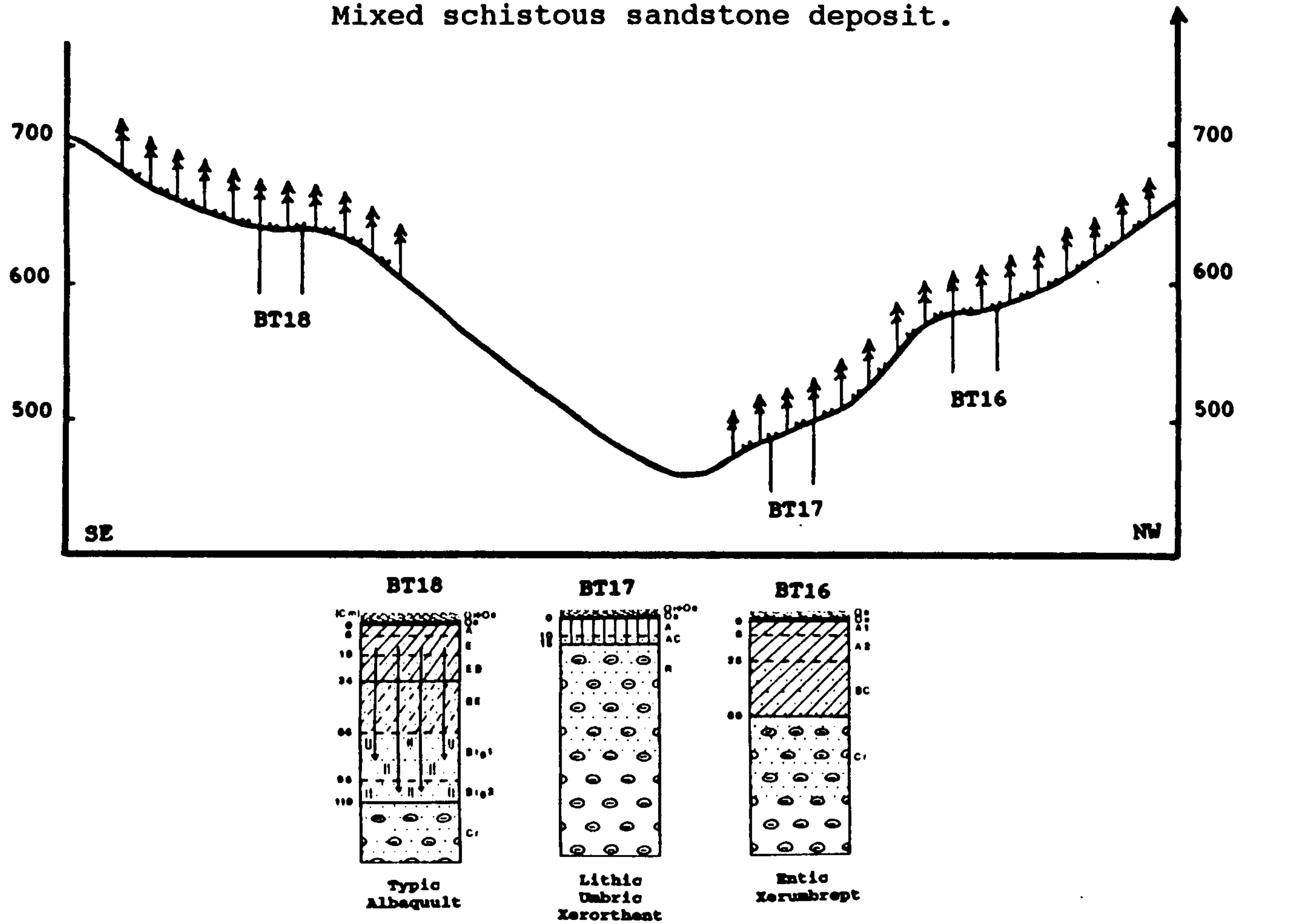


Table 35: Morphological and physical properties of Bab Taza toposequence profiles. (See abbreviation chart for soil description, page 47, chapter II).

Profile symbols	Elevation m	Slope %	Horizon	Depth cm	Boundary	Munsell color (moist)	Texture	Structure	Clay %	Silt %	Sand %
BT_{16}	580	3	A1	0-8	cs	10 YR 3/2	lfs	vfgr	6.0	14.4	79.6
			A2	8-25	aw	7.5 YR 3/2	lfs	vfgr	5.2	18.9	75.9
			BC	25-60	cs	5 YR 5/8	fsl	vfgrms	10.3	19.0	70.7
			Cr	+ 60		10 YR 6/6	sc-cl	vfgrms	38.4	15.3	46.3
BT_{17}	500	15	A	0-10	cs	10 YR 2/2	lfs-fsl	vfgrms	3.7	24.3	72.0
			AC	10-15	as	7.5 YR 4/4	lfs	vffgr	4.6	13.7	81.7
			R	+ 15		5 YR 5/8	scl	fgrms	29.6	12.4	58.0
BT_{18}	640	10	A	0-6	cs	10 YR 4/4	l-scl	fmgrms	22.9	28.8	48.3
			E	6-18	cs	10 YR 5/4	scl	fmgrms	25.6	18.0	56.4
			EB	18-34	cs	10 YR 4/3	cl	vffgrms	27.2	33.2	39.6
			BE	34-66	cs	10 YR 5/4	cl	vffgrms	28.7	34.4	36.9
			Btg1	66-96	cs	7.5 YR 4/4	cl	vfgrms	37.1	40.3	22.6
			Btg2	96-110	cs	2.5 YR 5/2	c	vfgrms	42.0	34.1	23.9
			Cr	+ 110		2.5 YR 5/2	c	vfgr	52.2	30.5	17.3

Table 36: Chemical properties of Bab Taza toposequence profiles. CEC = cation exchange capacity, PBS = percent base saturation.

Profile symbols	Horizon	Depth cm	pH		Total $CaCO_3$	C	N	C/N	Available P_2O_5 mg/Kg	CEC	Ca	Mg	K	Na	PBS %
			H_2O	KCl	%					meq/100g					
BT_{16}	A1	0-8	5.9	5.1	nd *	3.00	0.09	33.3	88.5	22.2	5.3	1.8	0.1	0.6	35.1
	A2	8-25	5.7	4.5	nd	2.50	0.07	35.7	122.5	21.8	3.8	1.4	0.1	0.5	26.6
	BC	25-60	5.9	4.5	nd	0.50	0.03	16.7	25.0	17.2	2.3	1.3	0.0	0.4	23.3
	Cr	+ 60	4.9	3.9	nd	0.80	0.05	16.0	27.5	39.5	2.5	2.2	0.0	0.7	13.7
BT_{17}	A	0-10	6.1	4.9	nd	3.00	0.14	21.4	17.5	26.6	8.0	2.1	0.1	0.2	39.1
	AC	10-15	5.8	4.6	nd	1.20	0.08	15.0	12.5	16.0	3.6	3.5	0.0	0.2	45.6
	R	+ 15	5.4	4.2	nd	0.25	0.04	6.3	20.0	16.4	2.3	1.4	0.0	0.9	28.0
BT_{18}	A	0-6	5.5	4.4	nd	4.25	0.22	19.3	7.3	37.9	13.5	7.3	0.7	0.4	57.8
	E	6-18	5.4	4.0	nd	2.00	0.08	25.0	1.8	33.0	6.0	4.4	0.1	1.1	35.2
	EB	18-34	5.3	4.0	nd	2.25	0.14	16.1	1.5	29.1	5.3	4.1	0.1	0.7	35.1
	BE	34-66	5.5	4.3	nd	1.75	0.13	13.5	1.7	29.7	4.3	3.8	0.1	0.9	30.6
	Btg1	66-96	5.1	4.0	nd	1.70	0.14	12.1	4.0	29.3	1.5	2.8	0.1	1.0	18.4
	Btg2	96-110	5.2	3.9	nd	1.00	0.11	9.1	4.5	32.4	2.3	4.0	0.1	0.4	21.0
	Cr	+ 110	5.6	4.4	nd	0.50	0.10	5.0	5.0	26.7	7.0	7.7	0.1	1.6	26.7

* nd = not done

slopes was cliffs and crests of resistant quartzitic sandstone. Nivation niches are prevalent above 1,600 m. Below this level, periglacial accumulations produced a shallow detrital cover on slopes. Most of these forms are related to post-Villafranchian ages, particularly Pleistocene ages (Günz, Riss, and Würm), and consist mainly of angular rocks embedded in a finer gray matrix. The younger soils are near the crest (K30) or on steep slopes (K29). The soils developed on the flat plain (Issaghene) show more developed characteristics (K31). This toposequence and its related profiles are represented on Figure 13. The main soil orders of this toposequence are Inceptisols and Ultisols. Their morphological, physical, and chemical properties are shown in Tables 37 and 38. Detailed interpretation of soil properties is reported in chapter II.

III.3.3. **Internal soil forming processes.**

Soil formation has been defined as a complex or sequence of events including both complicated reactions and comparatively simple rearrangements of matter, that affected the soil in which they operated. Numerous events might take place simultaneously or in sequence, to mutually reinforce or counter each other (Simonson, 1959).

Figure 13: Ketama toposequence soils.
Perhumid climate.
Mixed quartzitic sandstone deposit.

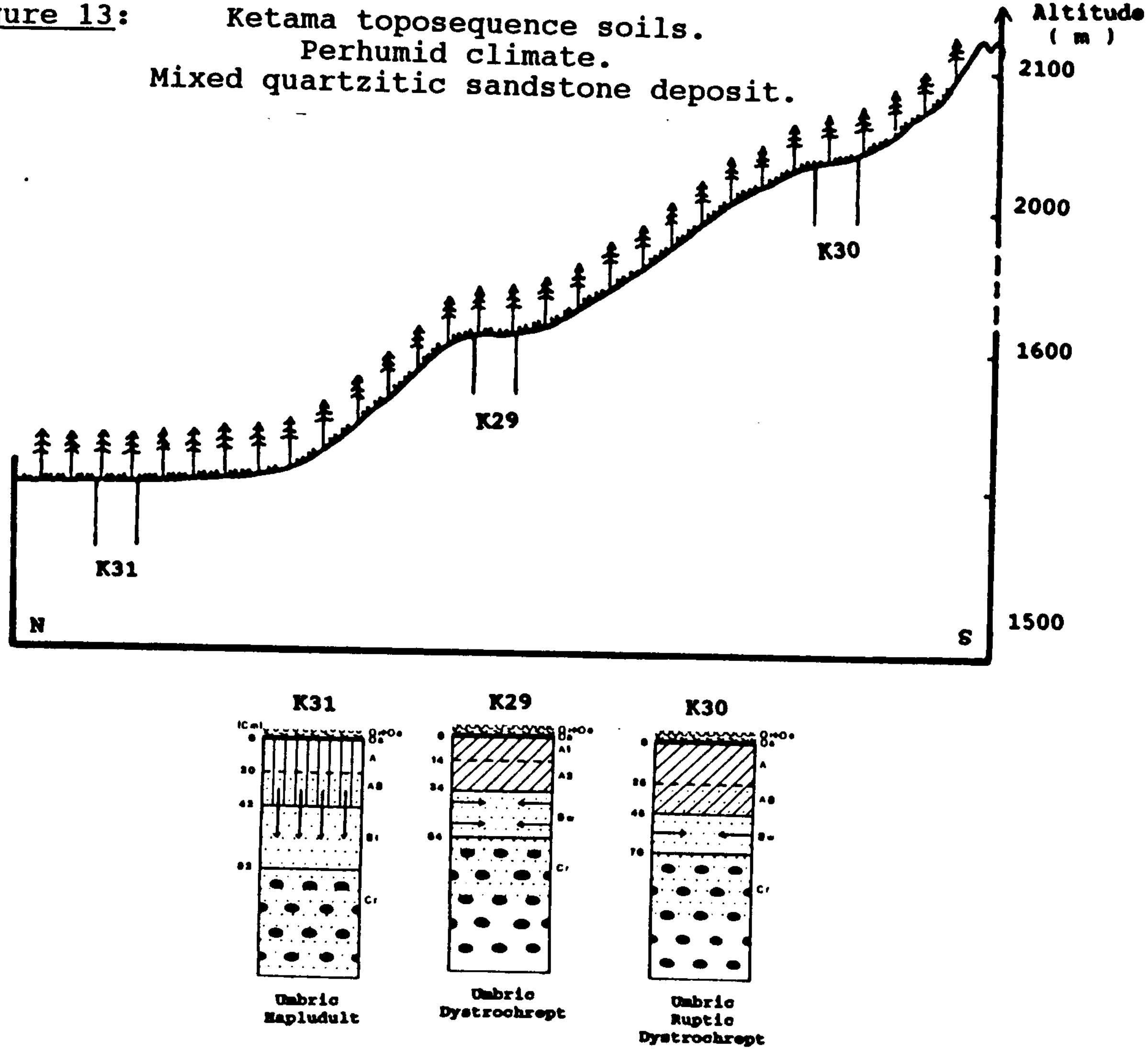


Table 37: Morphological and physical properties of Ketama toposequence profiles. (See abbreviation chart for soil description, page 47, chapter II).

Profile symbols	Elevation m	Slope %	Horizon	Depth cm	Boundary	Munsell color (moist)	Texture	Structure	Clay %	Silt %	Sand %
K_{29}	1610	5-10	A1	0-14	gs	10 YR 3/3	l	fgr	21.8	38.9	39.3
			A2	14-34	gs	7.5 YR 4/4	l	vffgr	26.2	44.8	29.0
			Bw	34-64	ds	10 YR 5/6	sicl	vfgr	38.1	44.0	17.9
			Cr	+ 64	Altered mixed quartzitic sandstone rocks						
K_{30}	2030	15	A	0-25	ds	10 YR 3/3	l	fgr	24.9	32.9	42.2
			AB	25-45	gs	7.5 YR 4/4	l-cl	fgr	26.7	31.8	41.5
			Bw	45-70	ds	10 YR 5/6	cl	fgr	29.5	32.9	37.6
			Cr	+ 70	Altered mixed quartzitic sandstone rocks						
K_{31}	1550	0	A	0-20	ds	10 YR 3/3	cl	vfflcr	29.1	45.4	25.5
			AB	20-42	gs	10 YR 3/3	sicl	vfflcr	34.2	51.5	14.3
			Bt	42-82	as	10 YR 5/4	sicl	fm2sbk	39.8	46.7	13.5
			Cr	+ 82	Altered mixed quartzitic sandstone rocks						

Table 38: Chemical properties of Ketama toposequence profiles. CEC = cation exchange capacity, PBS = percent base saturation.

Profile symbols	Horizon	Depth cm	pH		Total $CaCO_3$	C	N	C/N	Available P_2O_5 mg/Kg	CEC	Ca	Mg	K	Na	PBS %
			H_2O	KCl		%				meq/100g					
K_{29}	A1	0-14	5.4	4.6	nd #	5.00	0.24	20.8	75.0	59.3	7.0	2.6	0.3	0.2	17.0
	A2	14-34	5.3	4.1	nd	3.80	0.24	15.8	77.5	25.9	2.3	1.3	0.3	0.3	16.2
	Bw	34-64	5.4	3.9	nd	1.20	0.09	13.3	43.8	36.6	0.8	0.6	0.1	0.3	4.9
	Cr	+ 64			Altered mixed quartzitic sandstone rock										
K_{30}	A	0-25	5.4	4.3	nd	3.00	0.18	16.7	97.5	48.9	0.8	0.7	0.8	0.4	5.5
	AB	25-45	5.4	4.3	nd	2.40	0.16	15.0	123.8	42.6	0.5	0.3	0.5	0.3	3.8
	Bw	45-70	5.2	4.0	nd	0.40	0.08	5.0	36.3	27.7	0.5	1.0	0.3	0.3	7.6
	Cr	+ 70			Altered mixed quartzitic sandstone rocks										
K_{31}	A	0-20	3.5	4.1	nd	2.80	0.24	11.7	57.5	40.5	4.3	2.4	0.3	0.4	18.3
	AB	20-42	5.7	4.1	nd	1.60	0.15	10.7	41.3	50.3	2.3	1.9	0.2	0.5	9.7
	Bt	42-82	6.1	4.2	nd	0.80	0.11	7.3	31.3	42.5	1.0	1.7	0.1	0.4	7.5
	Cr	+ 82			Altered mixed quartzitic sandstone rocks										

nd = not done .

The most fundamental pedogenic processes are considered to be horizonation and haploidization (Buol et al., 1980). Horizonation is defined as processes and conditions by which initial materials are differentiated into soil profiles with many horizons. Haploidization is defined as processes and conditions by which horizons were mixed or disturbed. Because many processes act together to form any one soil profile, it is difficult to discuss soil formation as a function of specific processes. Soil formation was viewed by Simonson (1959) as the combined effect of additions to the ground surface, transformations within the soil, vertical transfers (up or down) within the soil, and removals from the soil. Also certain soil properties show a fairly consistent relationship to the degree of development of soil.

III.3.3.1. **Entisols.**

Entisols are soils without significant genetic development. Evidence of mineral synthesis and alteration is minimal, but some changes relative to the parent material have surely occurred. In this study, Entisols occurred mainly near the crests and on steep slopes, where hard bedrock inhibits soil development, independent of type of parent material, and mostly on southeast facing slopes. In the Mediterranean type of climate this slope aspect is driest and warmest. These conditions also might limit soil development. Only two Entisols were included in the toposequences (5 % of the soil profiles). They were mostly associated with rock outcrops, bare slopes, and clearings and cultivation on steep slopes. These Entisols are either Lithic Umbric Xerorthents (BT17) or Lithic Udorthents (M12). The most important pedogenic processes acting on these soils are initial rock alteration and brunification or melanization of a thin surface horizon. This process is defined as a darkening of the soil by addition of organic matter and is probably the dominant process in Mollisol formation. The major characteristics of the relatively thin A horizons are dark to very dark colors, sandy clay loam to very fine sand textures and granular to crumb structure, sometimes with abundant rock fragments.

The Entisols satisfied some criteria for a mollic epipedon, particularly color and percent organic matter. Because of their lower percent base saturation (less than 50 percent) and thin epipedons, they were excluded from Mollisols.

The evolution of Entisols might be predicted according to their occurrence. Entisol developed on calcareous and dolomitic parent material showed a higher percent base saturation (M12). A probable development would be:

Entisol (Lithic Udorthent) ──> **Mollisol** ──> **Alfisol**
└──> **Alfisol**

On sandstony parent material (BT17) the sequence would be:

Entisol ——> Inceptisol ——> Ultisol

III.3.3.2. **Inceptisols.**

This order has been described by many authors as soils that have not developed features diagnostic for other orders but have some features in addition to the ochric epipedon and albic horizon permitted in Entisols (Buol et al., 1980; Wilding et al., 1983). All Inceptisols in this study have features that indicate pedogenic immaturity, irrespective of parent rocks. In many cases the direction of soil development was evident and one could predict that certain Inceptisols would ultimately become Ultisols (acidic parent material), or Alfisols or Mollisols (calcareous and dolomitic parent material). Inceptisols developed on steep slopes (AL2, AL3, AL4, Kh14, Kh15, and K30) are subject to destruction if erosion becomes more severe. The clearing of forest stands for agricultural purposes is a common cause of erosion in the area. The mineralogy of Inceptisols (next section) reflects their relative immaturity. Weatherable minerals are always present unless the parent material per se is composed of minerals of an advanced weathering stage. Most of the soils had kaolinite as a component of parent material reflecting chemical weathering under a tropical type of climate during the Pliocene and Inferior Villafranchian eras, particularly of sandstony parent material.

Inceptisols are the most common order in the area (35 % of the studied profiles) and like Entisols they are located on steep slopes.

From a pedogenic point of view, as stated by many authors, all pedogenic processes might be active to some extent in these soils, but none predominated. The aquept suborders were characterized by gleization features that produced mottled colors in the soil matrix. They were commonly located in concave parts of landscapes. The lessivage process and thus the formation of argillic horizons was retarded because of the presence of excess water most of the time in these soils. In most of the Inceptisols both primary and secondary clay minerals were present. The umbrept suborders showed more darkening (melanization process) of the surface horizons than the surrounding ochrepts. The darkening process is different among different parent materials and soil textures . Soils derived from sandstone parent rocks with finer textures lacked the darkening of deep soil horizons. Conversely, soils from calcareous parent material with coarser textures had dark colors deeper in the profiles. Environmental factors that influence the melanization process are the nature of parent material, altitude, water and temperature soil regimes, soil pH, and related biological activities affecting the decomposition and humification of organic residue. Rubifaction is described by many soil scientists as the release of iron from primary minerals, the dispersion of iron particles and their progressive oxidation or hydration, giving rise to reddish, brown or yellowish color to soils. At lower altitudes, where climatic conditions are much warmer and parent materials are rich in iron oxides, the process of rubifaction has given the soil a reddish or yellowish color according to the degree of hydration in soils.

The gleization process and the associated color characteristics, particularly gray colors are dominant in the sites where water table fluctuates (aquic subgroup and aquic suborder).

III.3.3.3. **Mollisols.**

The main feature of Mollisols is a deep, dark, relatively fertile topsoil (mollic epipedon). In general, Mollisols occur in grasslands of steppes and prairies. Exceptions include poorly drained aquolls of lowland hardwood forests and some well drained udolls (Brown Forest Soils) (Buol et al., 1980).

In this study, Mollisols were characterized by the existence of a mollic epipedon with more than 1 % organic matter, dark color (value less than 3.5 moist and less than 5.5 dry, and chroma less than 3.5 moist), and base saturation of more than 50 percent. An argillic horizon, which is mandatory criterion for Alfisols and Ultisols, is not required but is permitted for Mollisols. Rendoll suborders have no argillic horizons. Rendolls in our toposequences occurred mainly near the crests or on relatively steep slopes (profiles T21, T19, M11, and M10'). All Mollisols that showed hydromorphic characteristics were situated down slope in depressions, i.e., Aquoll suborders (T24 and M7). Udolls were found on gentle slopes where stable conditions allowed the formation of an argillic horizon (TL25, TL27, and TL27'). The dominant pedogenic process that leads to the formation of a mollic epipedon is darkening or melanization. This process is defined as the darkening of soil by addition, humification, and the rapid incorporation of organic matter in the soil (Wilding et al., 1983). This author described melanization as a combination of several specific processes, i.e.:

- The extension of roots into the soil profile.
- The partial decay of organic materials in the soil proceeding relatively stable dark compounds.
- The reworking of the soil and organic matter by earthworms and other fauna leading to the formation of dark mineral-organic matter complexes and mixtures.
- Eluviation and illuviation of organic colloids along with some mineral colloids forming dark "cutans" on peds.
- The formation of resistant "ligno-protein" residues giving long-lasting black colors to soils.

In our study, all Mollisols were developed on calcareous and dolomitic parent material. The absence of an E horizon (eluvial horizon / argillic horizon sequence) might be explained either by the high degree of darkening, the mixing of the upper part of soil via bioturbation, cryoturbation or, more probably, by erosion and downslope transportation of the topsoil.

III.3.3.4. **Alfisols.**

The main prerequisites for Alfisols are the presence of layer lattice clay and its accumulation in the subsoil in amounts sufficient to produce an argillic horizon (Bt).

Alfisols are distinguished from Ultisols by higher than 35 percent base saturation and a less weathered state. Alfisols occur mostly under forest conditions, either in temperate, tropical, or subtropical regions (Buol et al., 1980). From a historical perspective, Alfisols have been called by a variety of names e.g., Gray Brown Podzolic soils and Gray Wooded soils (Baldwin et al., 1938), Terra Rossa in Mediterranean regions (Verheye and Stoops, 1973), and Planosols for Albaqualf great groups (Kunz and Oaks, 1957).

In this study Alfisols (Udalfs) were most extensive in a perhumid climate under fir forest, and particularly over calcareous and dolomitic parent material (Talassamtane toposequence: TL23, TL26, and TL28) in association with Mollisols. Their presence might be related to many factors such as:

- The high elevations (1,640-1,770 m) and associated climatic features that provide a high soil moisture status with attendant leaching and downward translocation of clay.

- Calcareous and dolomitic parent material and relatively unweathered clay minerals provide these soils with a high cation exchange capacity and high percent base retention.

- Roots of the forest vegetation, which have a major influence on water and air penetration, and provide channels for ion and water transport and translocation (or cycling) of ion species and clay particles.

From a pedogenic point of view, carbonates are incompletely leached from the zone of clay translocation and floculation with calcium and magnesium ions is expected to some extent. Thus the conditions are not totally favorable to relatively free movement of soil solution under the influence of percolating water. The release of iron through braunification acts as a milder flocculating agent that fosters the deposition of clay in the B horizon. Dark colors due to melanization may mask iron accumulation in the upper horizons. The reddish color of highly oxidized iron was not expressed because of the cool temperature and high moisture status of the soils at these elevations. The eluviation and illuviation of clay was weakly shown by the existence of some thin to very thin argillans in the B horizons of these Alfisols. An E horizon was observed only on a profile on a gentle sloping aspect (TL23) where the leaching of carbonates was more favored. In the profile (TL22) on a steep slope, and the other Alfisols facing the southeast (TL26 and TL28), the E horizon was not clearly expressed. This may be explained by the warmer climate and the low moisture regime that characterize the southeast aspect. Also, the darkening with organic matter masks the bleached dry appearance of E horizons (TL23).

III.3.3.5. Ultisols.

Ultisols are characterized by the presence of an argillic horizon, low base status in the lower part of the solum, and a mean annual soil temperature of more than 8°C.

From a historical point of view, the Yellow and Red Earth described by Ramann (1911) and Laterites, Red Earths, and Yellow Earths in Glinka's classification (1914) were the earliest examples with characteristics comparable to Ultisols.

In this study, in contrast to Alfisols, which were preferentially developed from calcareous and dolomitic parent material, Ultisols have primarily formed on sandstony parent material. Most of the Ultisol profiles were under oak forest (AL6, AL1, AL5, A35, A36, AR34, and AR40), except for BT18 under a pine plantation and K31 under cedar forest.

The main features of Ultisols are extensive leaching under a warm climatic regime. McCaleb (1959) discussed processes of formation of Red Yellow Podzolic soils (recognized as Ultisols). In these soils, extensive leaching and warm temperatures lead to a rapid and fairly complete alteration of weatherable minerals into secondary clays and oxides, and low base saturation deep in the profile. Lessivage leads to the formation of albic and argillic horizons with thin argillans. Like associated Alfisols, unclear albic horizons were present. Lack of a sufficient A horizon to account for the massive build up of clay in the argillic horizon induced some authors (Simonson, 1949) to discount lessivage in Ultisols and place more emphasis on clay formation in situ in the B horizon.

In most of the Ultisols of this study, clay formation as a result of in situ weathering was probably significant. Because of their position on slopes some Ultisols (AL6, AR34, and K31) showed little or no evidence of E horizons, however, argillans were evident in B horizons. A possible explanation for this phenomena was either the lateral translocation of clay or the clay formation in situ in the B horizon.

Fragipans were another common feature in these soils. These pans acted as a restrictor for water movement and create a perched water table. Thus most of these Ultisols showed hydromorphic characteristics and were classifed either as Aquults (A35, A36, and BT18) or as Aquic Haploxerults (AL6, A36, and AR34).

Most of Ultisols were developed at stable lower elevation landforms (older) where the warmer climate promotes rapid mineralization of organic matter. The only Ultisols that have an umbric epipedon with relatively high organic matter content were those found at stable landforms of higher elevations (AL1 and AL5) and are Umbric Hapludults.

The color characteristics of the Ultisols resulted from darkening by organic matter, reddish and yellowish colors through intense hydration and oxidation of iron oxides (rubifaction), and gray colors due to restricted drainage (gleization).

III.3.4. **Clay mineralogy.**

For most of the samples, only XRD patterns from air dried, Ca-saturated clay specimens were clear. The samples that were glycerol solvated or heated did not show very clear XRD patterns. These limitations were mainly from the destructive effect of both glycerol and heat on clay mounted slides. Due to the lack of a quantitative system for evaluating amounts of clay minerals we adopted a qualitative or semi-quantitative rating system to compare the proportions of clay minerals from different horizons. The classes used in this system are: i) Strong (S), ii)

Moderate (M), iii) Weak (W), iv) Very weak (VW), and v) Absent (Ab).

The main clay minerals encountered in the area were kaolinite, smectite, chlorite, illite, vermiculite, and their interlayers.

- Smectite (montmorillonite) designated all minerals that swelled to 17.7 Å after glycerol treatment and that shrank to 10 Å after heating. In Moroccan soils it was shown by Schoen (1969) that the reticular distance of montmorillonite in a natural state mostly corresponds to a Ca or Mg adsorption state, that is approximately 15.5 Å.

- Vermiculite was identified as minerals with a reticular distance of 14 Å in the natural state, that did not swell after glycerol treatment but shrank to 10 Å after heating. It is important to note that detection of very small quantities of vermiculite was very difficult when illite, chlorite, smectite were present.

- Chlorite is the clay mineral that has 14 Å reticular distance and did not change after glycerol treatment and heating.

- Illite showed reticular distance of 10 Å and was unchanged after glycerol treatment and heating.

- 2:1 interlayer minerals were all interstratified with Al-hydroxy interlayers of illite, vermiculite, and smectite.

- Kaolinite includes minerals that exhibited a reticular distance of 7 Å and did not swell with glycerol treatment but did undergo dissolution after heating.

III.3.4.1. **Clay minerals of sandstone deposit toposequences.**

These are the Jbel Alam and Khezana toposequences with dominantly crest and valley relief. The parent material is mainly sandstone detrital material of Superior Villafranchian age and the soils are Entisols, Inceptisols, and Ultisols.

The diffraction patterns of clay from different genetic horizons showed that the principal clays and clay size minerals in these soils were kaolinite, chlorite, illite, and 2:1 interlayers.

A summary of clay mineral types and abundance in soils from the sandstone toposequences are shown in Tables 39 and 40.

There was no particular trend in the proportion of different clay minerals with depth or between soils at different elevations. The comparison of different clay types in different profiles (Tables 39 and 40) suggests that quartz (primary resistant mineral) was abundant in sandstone (in both coarse and clay fraction). Most of the profiles had coarse textures (Tables 23 and 25). The

Table 39: Clay and clay size minerals, and abundance in soils from Jbel Alam sandstone deposit toposequence. (S = strong, M = moderate, W = weak, and VW = very weak).

	Clay types						
Profile	Horizon	Kaolinite	Chlorite	Illite	Interlayer	Quartz #	Feldspar #
AL6-	A1	W	M	W	W	M	VW
	Bt1	VW	W	VW	VW	W	VW
	BCg	VW	W	VW	VW	M	VW
AL4	A1	M	W	W	W	W	VW
	Bwx	W	W	VW	VW	M	VW
	BC	M	W	W	W	M	W
AL2	A1	W	W	VW	VW	M	VW
	Bg	W	VW	VW	VW	M	VW
	Cg	W	VW	VW	VW	M	VW
AL3	A1	W	VW	VW	W	M	VW
	Bwxg	W	VW	VW	W	M	VW
	Cg	W	W	VW	W	M	VW
AL1	A1	M	W	W	W	W	VW
	Bt	M	W	W	W	W	VW
AL5	A1	VW	VW	VW	VW	VW	VW
	Bt	W	W	VW	W	W	VW
	BC	M	W	W	W	M	W

#: Clay size minerals .

Table 40: Clay and clay size minerals, and abundance in soils from Khezana sandstone deposit toposequence. (Ab = absent, W = weak, VW = very weak).

	Clay types							
Profile	Horizon	Kaolinite	Chlorite	Illite	Interlayer	Vermiculite	Quartz #	Feldspar #
Kh13	A1g	VW	W	VW	VW	Ab	VW	VW
	Bwg	VW	W	VW	VW	Ab	VW	VW
	Cg	VW	W	VW	VW	Ab	VW	VW
Kh14	Bw	VW	Ab	VW	VW	W	VW	VW

#: Clay size minerals

proportions of kaolinite and chlorite were relatively higher than other clay minerals.

Maurer and Schoen (1964) found that Numidian sandstone material is mostly arkosic and contains more than 25 % feldspar, more than 60 % quartz, and about 15 % mica and illitic cement. In this study, the content of feldspathic clay size minerals was low. This indicates that the feldspar mineral grains are larger than clay-size and have not undergone much physical disintegration.

Entisols and Inceptisols have been subject to pedogenic processes ranging from weakly to moderately intensive. Their mineralogy reflects their relative immaturity. Most Inceptisols (AL2, AL3, AL4, Kh13, and Kh14) showed few detectable changes in clay mineralogy as a result of pedogenesis. Most of the clay size minerals were inherited from parent material, particularly minerals of an advanced weathering stage such as kaolinite. The marked clay increase in the fragipan relative to overlying horizons (AL3 and AL4) may be explained as due to differential destruction rates rather than to translocation. This explanation was also reported by Jha and Cline (1963).

Ultisols are characterized by an advanced weathering stage. Their clays have higher amounts of kaolinite relative to Inceptisols (AL1 and AL5).

For both toposequences, hydromorphic features (mottles) are prevalent (AL6, AL2, and Kh13). The slow formation rates of phyllosilicates has been attributed to wetness (Sanchez and Buol, 1974). Aluminium hydroxy-interlayer clays (peaks between 11 and 12 Å after heating) occurred particularly in subhorizons (Bt of AL6 and Bw of Kh13). Also, minerals with peaks between 13 and 14 Å probably resulted from the liberation of Al from feldspar and mostly from micas under acid weathering with subsequent precipitation in foliar interspaces of vermiculite and smectite. The identity of smectite was not very clear from the X-ray diffraction pattern because of the stretched 2 ϕ scale and the excess of glycerol added to the slides that might have caused the destruction of clay orientation over (X,Y) planes.

Vermiculite occurred only in the Khezana toposequence (Kh14). This indicates that illite (or mica) had been partially altered to vermiculite. An alternate explanation is the alteration of chlorite to vermiculite and intergradient chlorite-vermiculite.

III.3.4.2. Clay minerals of calcareous and dolomitic deposit toposequences.

The toposequences from carbonate materials are Madissouka, Talassamtane, and Taznote. All are formed on the Calcareous Dorsal. The age of the detrital surface cover is probably Medium to Superior Quaternary age (Mid and Late Pleistocene). These deposits are the parent material for the Entisols, Inceptisols, Mollisols, and Alfisols found on these toposequences. The clay diffraction patterns showed that the clays and clay size minerals in these toposequences were chlorite, illite, smectite, vermiculite, 2:1 interlayers, kaolinite, palygorskite, dolomite, quartz, and feldspar. The dominant minerals were chlorite, illite, and their interlayers. Smectite, vermiculite, and their interlayers were minor components or absent. Kaolinite, feldspar, and quartz were present in smaller proportions than in the sandstone toposequences. The clay-sized minerals that most distinguished these toposequences from those on Numidian sandstone were dolomite and palygorskite. Dolomite was prominent particularly in the lower part of the profiles (TL28, M10, M9 and M7). Palygorskite was absent from the Madissouka toposequence and was present in minor amounts in the other toposequences. Detailed identification of the clay minerals and their magnitude in different soil horizons are shown in Tables 41, 42, and 43.

Table 41: Clay and clay size minerals, and abundance in soils from Talassamtane calcareous and dolomitic deposit toposequence. (S = strong, M = moderate, W = weak, VW = very weak, and Ab = absent).

	Clay types										
Profile	Horizon	Kaolinite	Chlorite	Illite	Vermiculite	Smectite	Palygors kite	Interlayer	Dolomite #	Quartz #	Feldspar #
TL23	A1	Ab	Vw	Vw	Ab	Ab	Ab	Ab	Ab	S	Vw
	-Bt	Ab	Vw	Vw	W	Vw	Ab	Vw	Ab	M	Vw
TL25	Bt	Vw	W	Vw	Ab	Vw	Vw	W	Ab	W	Vw
TL26	A1	Vw	Vw	Vw	Ab	Ab	Ab	Ab	Ab	W	Ab
	Bt	W	W	W	Ab	W	Ab	Ab	Ab	M	Ab
TL27	A1	Ab	Vw	Vw	Ab	Ab	Ab	Vw	Vw	Vw	Vw
	Bt	Ab	W	Vw	Ab	Ab	Ab	Vw	Vw	M	Vw
TL28	A1	Ab	Vw	Ab	Ab	Vw	Ab	Vw	Vw	Vw	Ab
	Bt	Ab	Vw	Vw	Ab	Ab	Ab	Vw	Ab	Vw	Ab
	C	Ab	Vw	Vw	Ab	Ab	Ab	Vw	S	Vw	Ab

: Clay size minerals.

Table 42: Clay and clay size minerals, and abundance in soils from Madissouka calcareous and dolomitic deposit toposequence. (M = moderate, W = weak, VW = very weak, and Ab = absent).

	Clay types										
Profile	Horizon	Kaolinite	Chlorite	Illite	Vermiculite	Smectite	Palygors kite	Interlayer	Dolomite #	Quartz #	Feldspar #
M11	A1	Ab	Vw	Vw	Ab	Ab	Ab	Ab	Ab	Vw	Ab
	Cr	Ab	Ab	Ab	Ab	Ab	Ab	Ab	Ab	W	Ab
M10	Bt	Ab	Vw	M	Ab	Ab	Ab	W	M	M	Ab
	Cr	Ab	Ab	Vw	Ab	Ab	Ab	Vw	S	W	Ab
M9	A1	Ab	Ab	Vw	Ab	Ab	Ab	Vw	Vw	W	Ab
	Bt	Ab	Vw	Vw	Ab	Vw	Ab	Vw	W	Vw	Ab
	C	Ab	W	Vw	Ab	Ab	Ab	W	S	W	Ab
M7	A1	Vw	W	W	Ab	Ab	Ab	Vw	Vw	W	Ab
	BWg	Vw	W	Vw	Ab	Ab	Ab	Vw	Vw	W	Ab
	Cg	Vw	W	Vw	Ab	Ab	Ab	Vw	W	W	Ab

: Clay size minerals.

Table 43: Clay and clay size minerals, and abundance in soils from Taznote calcareous and dolomitic deposit toposequence. (S = strong, M = moderate, W = weak, VW = very weak, and Ab = absent).

	Clay types									
Profile	Horizon	Kaolinite	Chlorite	Illite	Vermiculite	Smectite	Palygorskite	Interlayer	Dolomite #	Quartz #	Feldspar #
T19	A1 ACg	Vw Vw	W Vw	W M	Ab Ab	Ab Ab	Vw Vw	Vw W	Ab Ab	Vw M	Ab Ab
T21	A	Ab	Vw	Vw	Ab	Ab	Ab	Vw	Ab	S	Ab
T24	A1 Bwg Cg	Ab Vw Vw	Vw Vw Vw	Vw Vw Vw	Ab Ab Ab	Vw Vw Vw	Ab Ab Ab	Vw Vw Vw	Ab Ab Ab	Vw Vw Vw	Ab Ab Ab
T20	A Bw	Ab Vw	Vw Vw	Ab Ab	Ab Ab	Ab Ab	Ab Ab	Vw Ab	Ab Ab	Vw Vw	Ab Ab

: Clay size minerals .

As reported in other studies (Javis et al., 1959) changes in silicate clay mineralogy in Mollisols (TL27, TL27', M7, M10', M11, T19, T21, and T24) were limited. The associated down slope Alfisols (TL23, TL26, and TL28) were more smectitic than Mollisols and Inceptisols. Smectite may have been formed in situ or selectively translocated to Bt horizons since it is usually concentrated in the fine clay.

III.3.4.3. **Clay minerals of mixed schistous sandstone deposit toposequences.**

These are the Aïn Rami and Bab Taza toposequences, which are similar in relief and geology to the Numidian

Chain sandstone toposequences (Jbel Alam and Khezana). The clay types were also similar and the main soils also are Entisols, Inceptisols, and Ultisols.

The dominant clay-sized minerals were like those of the sandstone toposequences (Numidian Chain), quartz, chlorite, and to a lesser extent, illite, interlayers, kaolinite, and feldspar. No trend was apparent to the type or magnitude of clay minerals with depth or elevation. Chlorite, interlayers, and illite showed some increase with profile depth (BT18 and AR34). Data of the magnitude and type of clay and clay size minerals for genetic horizons and depths are shown in Tables 44 and 45.

Table 44: Clay and clay size minerals, and abundance in soils from Bab Taza mixed schistous sandstone deposit toposequence. (M = moderate, W = weak, and VW = very weak).

Clay types							
Profile	Horizon	Kaolinite	Chlorite	Illite	Interlayer	Quartz #	Feldspar #
BT 18	A	--	VW	VW	VW	VW	--
	EB	--	VW	VW	VW	VW	--
	Btg	VW	M	W	M	VW	VW
	Cr	VW	M	W	M	VW	VW
BT 16	A	VW	VW	VW	VW	VW	VW
	BC	VW	VW	VW	VW	VW	VW

: Clay size minerals .

Table 45: Clay and clay size minerals, and abundance in soils from Aïn Rami mixed schistous sandstone deposit toposequence. (S = strong, M = moderate, W = weak, VW = very weak, and Ab = absent).

Clay types							
Profile	Horizon	Kaolinite	Chlorite	Illite	Interlayer	Quartz #	Feldspar #
AR34	A Btg Cr	Ab Vw Vw	W W W	Ab Ab Ab	Vw Vw W	S M M	Ab Ab Vw
AR33	A1 Bw	Vw Vw	W W	Vw Vw	Ab W	Vw W	Vw Vw

: Clay size minerals .

III.3.4.4. Clay minerals of mixed quartzitic sandstone deposit toposequence.

The Ketama toposequence formed on mixed quartzitic sandstone. The clay minerals that developed in these soils were quite similar to the ones found in soils from sandstone and mixed schistous sandstone deposits. The main clay size minerals were chlorite, illite, interlayers, kaolinite, quartz and feldspar.

The dominant clay-size mineral was quartz, followed in order by chlorite, interlayer (chlorite / illite), illite, kaolinite, and clay-sized feldspar. Again, no special trend was seen in relation to depth of the profile and change in elevation. The slow formation rates of phyllosilicates and the absence of hydroxy-interlayer clays might be explained by the high elevation (1,550-2,100 m) and the resulting high degree of wetness and low temperatures (Ketama toposequence). Data of the magnitude of clay types with depth and elevation are shown in Table 46.

Table 46: Clay and clay size minerals, and abundance in soils from Ketama mixed quartzitic sandstone deposit toposequence. (S = strong, W = weak, VW = very weak, and Ab = absent).

Clay types							
Profile	Horizon	Kaolinite	Chlorite	Illite	Interlayer	Quartz*	Feldspar*
K30	A	Vw	W	Vw	Ab	Vw	Ab
	Bw	Vw	W	Vw	W	W	Vw
K31	A	Vw	W	Vw	Vw	W	Vw
	Bt	W	W	Vw	Vw	S	Vw
K29	A	Vw	Vw	Vw	Vw	S	Ab

* : Clay size minerals .

III.4. CONCLUSION.

Soil pedogenesis in forest stands around Chefchaouen was studied to better understand the relationships between soil processes and the soil landscape. The aim was to develop soil related information that may help forest managers and users in understanding the soil component of forest ecosystem and its relationships with other components. Local climate, parent material, altitude, vegetation types, and topographic position are the principal features that control soil development and distribution in the area. The main soil orders encountered were Entisols, Inceptisols, Mollisols, Alfisols, and Ultisols. Younger soils, including Entisols, Inceptisols, and some Mollisols, occurred mainly on ridge crests and steep slopes. Soils with developed Bt horizons (Alfisols, Ultisols, and some Mollisols) occupied more stable sites including flat benches and depressions.

Parent material has had a profound effect on most of the soil forming factors. Mollisols and Alfisols were associated with calcareous and dolomitic parent material, whereas Ultisols developed preferentially on acidic sandstone parent material. Vegetation type, altitude, slope position, aspect, and local climate were considered as secondary factors in the ordering of soil forming processes.

The main internal soil development processes were melanization, which imparted dark color to upper horizons; rubifaction, which produced reddish, brownish, or yellowish colors; decalcification (removal of calcium carbonate from soil); translocation of clay that produced E (eluvial) horizons and Bt (illuvial clay horizons); and in situ alteration of soil material to form cambic horizons (Bw).

Rubifaction was most distinct at lower elevations, particularly around Chefchaouen where Ultisols are more prevalent and where high temperatures and stable landscape positions combined to develop deeply leached soils with reddish and yellowish colors according to the degree of hydration of iron oxides.

Entisols and Inceptisols that were common in the area are due to a combination of factors that inhibit horizon development. The principal factors are: 1) mass wasting and other forms of erosion, 2) removal of vegetation (with natural or anthropic means) which accelerates erosion, 3) resistance of parent rock to weathering (quartzitic material, hard sandstone and hard limestone), 4) saturation of soil with water (high precipitation, perched water table, or water derived from snow melt), and 5) low temperatures at higher elevation. The mineralogy of Entisols and Inceptisols reflects their relative immaturity. Most of the clay fraction in these soils is inherited from parent material.

The high precipitation, combined with low permeability of clayey schistous parent materials and concave microrelief, promoted the development of hydromorphic features of aquic soils.

Erosion on steeper slopes has had a negative effect on soil development and some surface horizons have been truncated, with probable loss of the E horizon in some Ultisols and Alfisols. Lateral translocation of clay minerals along the slopes was inferred as a source of clay accumulation in some down slope Bt horizons.

Leaching of carbonates, as a prerequisite to the translocation of clays and Bt formation was more manifested on northwest aspect (Talassamtane toposequence). Where carbonates are only partially leached, evidence of clay translocation (e.g., argillans) was not well developed.

The clays detected by XRD patterns are mostly inherited from parent materials. Kaolinite, chlorite, illite, interlayers, quartz, and feldspars were common to all toposequences, whereas smectite, palygorskite, and dolomite are specific to calcareous and dolomitic materials. The tropical type of climate which is appropriate to produce clays by a strong chemical alteration (during the Pliocene-Inferior Villafranchian epoch) did not exist since the parent materials were exposed to pedogenesis. Thus, most soil clays existed in the parent material itself. Locally, the occurrence of vermiculite suggests some partial chemical weathering of micas, illite, or chlorite to vermiculite.

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CHAPTER IV

NITROGEN CYCLING

ABSTRACT.

Nitrogen is an essential plant nutrient. It exists in the atmosphere in the form of the very stable N_2 gas. Nitrogen gas must be biologically or industrially "fixed" before it is available to plants. Most plant N comes from the uptake of $N\text{-}NH_4^+$ and $N\text{-}NO_3^-$ which are made available by microbial mineralization of organic N.

In this study two experiments were done to assess N mineralization in the forest stands around Chefchaouen: the survey experiment and the trenched plot experiment.

In the survey experiment, soils from different forest stands were collected and incubated in the laboratory. The potentially available soil nitrogen N_{min} (7-day anaerobic incubation period), and N_0 (21-week aerobic incubation period) both showed no significant differences among sites, because of the large within site variability. N_{min} ranged from 22 to 87 mg-N kg^{-1} in the mineral surface horizons and from 3 to 31 mg-N kg^{-1} in the subsurface horizons. N_0 ranged from 48 to 143 mg-N kg^{-1} and from 18 to 57 mg-N kg^{-1} in the upper and lower horizons respectively. The rate constant of N mineralization (k) ranged from

0.130 to 0.253 week^{-1} in the surface horizon and decreased significantly with depth.

In the trenched plot experiment, both potentially available N (aerobic and anaerobic) and N mineralization in the field were examined. The principal forest stands used were Pinus radiata, Pinus pinaster, and Quercus suber (cork oak). The values of N_{min} and N_0 were lower than those of the survey experiment. N_{min} ranged from 11 to 46 mg-N kg^{-1} and N_0 from 29 to 54 mg-N kg^{-1}, with a significant decrease with depth for both. In the field the major factors controlling N mineralization were soil moisture, temperature, and substrate quality and quantity. Yearly net N mineralization varied from 6 to 29 kg-N ha^{-1} yr^{-1} in the surface soil, and from 9 to 14 kg-N ha^{-1} yr^{-1} in the subsurface horizon. Yearly net N uptake was highly correlated with net N mineralization and varied from 17 to 25 kg-N ha^{-1} yr^{-1}. In comparison with the values reported elsewhere this amount of N mineralized were considered adequate to supply the needs of forest trees.

IV.1. INTRODUCTION.

The importance of N for agriculture and forest productivity is well documented. Although a small part of plant needs may come from uptake of organic N, most plant N comes from the uptake of $N\text{-}NH_4^+$ and $N\text{-}NO_3^-$, which are made available by microbial mineralization of organic N and subsequent nitrification (Bremner and Kenny, 1965; Stevenson 1987; Willams, 1989).

In Morocco, all studies related to N mineralization and the evaluation of its availability to plants have emphasized agricultural soils (Stitou et al, 1979; Chiang et al., 1983; Soudi et al., 1990a,b). Yet, in forest ecosystems N is most often limiting.

In forest ecosystems biological estimation of available N in soil seems to be more difficult than for annual crops on agricultural soils (Kimmins, 1977). The reasons for these difficulties are: (1) the definition of rooting depth for forests, (2) the difficulty in determining the rates of nutrient recycling and turnover in forests, and (3) the lack of uniform nutrient demand during the life of forest crop.

Many different techniques for determining the rate of N mineralization have been developed (Miller and Keeny, 1982). These techniques can be divided into three groups: 1) experiments under field conditions, 2) pot experiments, and 3) incubation of soil samples under laboratory conditions.

Vitousek et al. (1982) studied N mineralization, NO_3^- production, and NO_3^- mobilization in a wide range of forest ecosystems through a combination of field and laboratory experiments. The highest potential for NH_4^+ production during an 8-week incubation was observed for a New England northern hardwoods soil (over 1,200 mg-N kg^{-1} in forest floor and over 170 mg-N kg^{-1} in mineral soil). Nitrate production showed high values in soils from Indiana maple sites (over 800 mg-N kg^{-1} in forest floor) and for New England northern hardwoods (about 150 mg-N kg^{-1} in mineral soil). The lowest values were found with an Indiana pine site and a Pacific silver fir site in Washington.

Van Praag and Weissen (1973) evaluated aerobic incubation of litter or soil (18°C, 6 weeks) in the laboratory, in situ incubation at the site in polyethylene bags, and in situ incubation in open 500 cm^3 plastic boxes. Under young spruce stands, laboratory and plastic bag in situ incubations gave similar results (0.2 to 3.9 % of total N mineralized). The F2 horizon, where most of the roots were located, released about 1.3 % of its N in 6 weeks. Over the entire year, as estimated from laboratory incubation data, the F2 released 3.5 % of its total N.

Shumway (1978) correlated results of the anaerobic incubation method with diameter growth increase of Douglas-fir from application of urea (224 kg-N ha^{-1}). Ammonium production in 0 to 15-cm soil samples was highly correlated (r = 0.96) to the increased diameter growth, whereas total soil N was poorly correlated.

Geist (1977) correlated soil properties (organic matter and total N) and results of aerobic and anaerobic incubation methods to dry matter yield and N uptake by orchardgrass (Dactylis glomerata L.) using soils from established forest sites and a greenhouse experiment with $(NH_4)_2SO_4$ treatment at various rates. He found that the anaerobic incubation was most effective in estimating organic N availability over a broad range of N fertilization.

Powers et al. (1978) compared in situ and laboratory anaerobic incubation along an elevational transect. Less N was mineralized in situ than in the laboratory in the xeric zone but in the mesic zone nearly twice as much N was mineralized in the field as in the laboratory. More recently, Powers (1990) studied six vegetation types along a 2,000-m altitudinal gradient in northern California. This work showed that N mineralization per unit of total Kjeldahl N (TKN) varied between 5 and 38 g-N kg^{-1}-TKN when moisture was abundant (anaerobic field incubation). However, aerobic field mineralization rates fell to between 2 and 22 g-N kg^{-1}-TKN because of summer drought. In the same study, aerobic rates were greatest at mid-elevations and were reduced by cold temperatures at high elevations and by soil drought at lower elevations.

Forest management may influence soil nitrogen cycling. Edmonds et al. (1989) compared recently clearcut to young (5-years-old) and mature (45-years-old) stands of Pinus radiata in Australian forests. Field concentrations of NH_4^+-N were less than 11.5 mg-N kg^{-1}. The largest N mineralization rates (21 kg-N ha^{-1} (0-20 cm) in 173 days) occurred in the clearcut. Also, very little nitrification occurred in the clearcut (0.6 kg-N ha^{-1} in 173 days).

The need for information concerning N mineralization in forest ecosystems for management purposes and for a better understanding of soil internal N mineralization in such Mediterranean forest types was the reason for this study.

The main objectives were:

- To determine the variability of N-mineralization under different forest stands and for different soil depths.

- To measure indices of potentially available N (static aerobic and anaerobic incubations).

- To compare N mineralization from laboratory and in situ trenching techniques.

- To determine the time variation (month to month, seasonal, and yearly) of N mineralization among pine plantations and cork oak forest in the area around Aïn Rami nursery.

- To quantify the amounts of N mineralized that were used by plants in the field.

IV.2. MATERIALS AND METHODS.

IV.2.1. Site description.

Nineteen representative sites in eight different forest stands were used: Pinus pinaster var. moghrebiana (natural pine), Pinus pinaster and Pinus radiata (pine plantations), Abies pinsapo subsp. marocana (fir), Cedrus atlantica (cedar), Quercus pyrenaïca (deciduous oak), and Quercus rotundifolia (green oak). The principal parent rocks were sandstone, calcareous, schistous sandstone, and quartzitic sandstone. The different locations concerned were Madissouka, Talassamtane, Khezana, Mounzel (north of Bab Taza), Ketama and Aïn Rami forests. Site elevations varied from 600 m (Aïn Rami) to about 1,700 m (Talassamtane). Mean annual temperatures and rainfall ranged from 11.2°C to 15.9°C and from 934 mm to 1,890 mm, respectively. The soils were mainly Inceptisols (all parent materials); Ultisols (sandstone parent material); and Alfisols and Mollisols (calcareous parent materials). The locations of the sites are shown on Figure 14. Details on site characteristics are shown on Table 47.

Selected soil properties of these sites are given in Table 48.

IV.2.2. **Experimental design.**

In this study two experiments were performed: i) a survey of N availability and ii) a trenched plot in situ N mineralization.

- Survey experiment. In this experiment, duplicate sites were selected from each forest stand (natural pine, fir, cork oak, deciduous oak, and cedar, from Madissouka, Talassamtane, Mounzel, Khezana, and Ketama, respectively). Soil samples from each site were collected during July to September 1990, these samples were aerobically and anaerobically incubated in laboratory.

- In situ N mineralization. In this experiment, triplicate sites were chosen from three forest stands around Aïn Rami nursery: two pine plantations (*Pinus radiata*, and *Pinus pinaster* var. *moghrebiana*) and a cork oak stand (*Quercus suber*). Soil samples were collected from each trenched plot site during a one-year period (February through December 1990). Also, soil samples were collected for laboratory incubation assays.

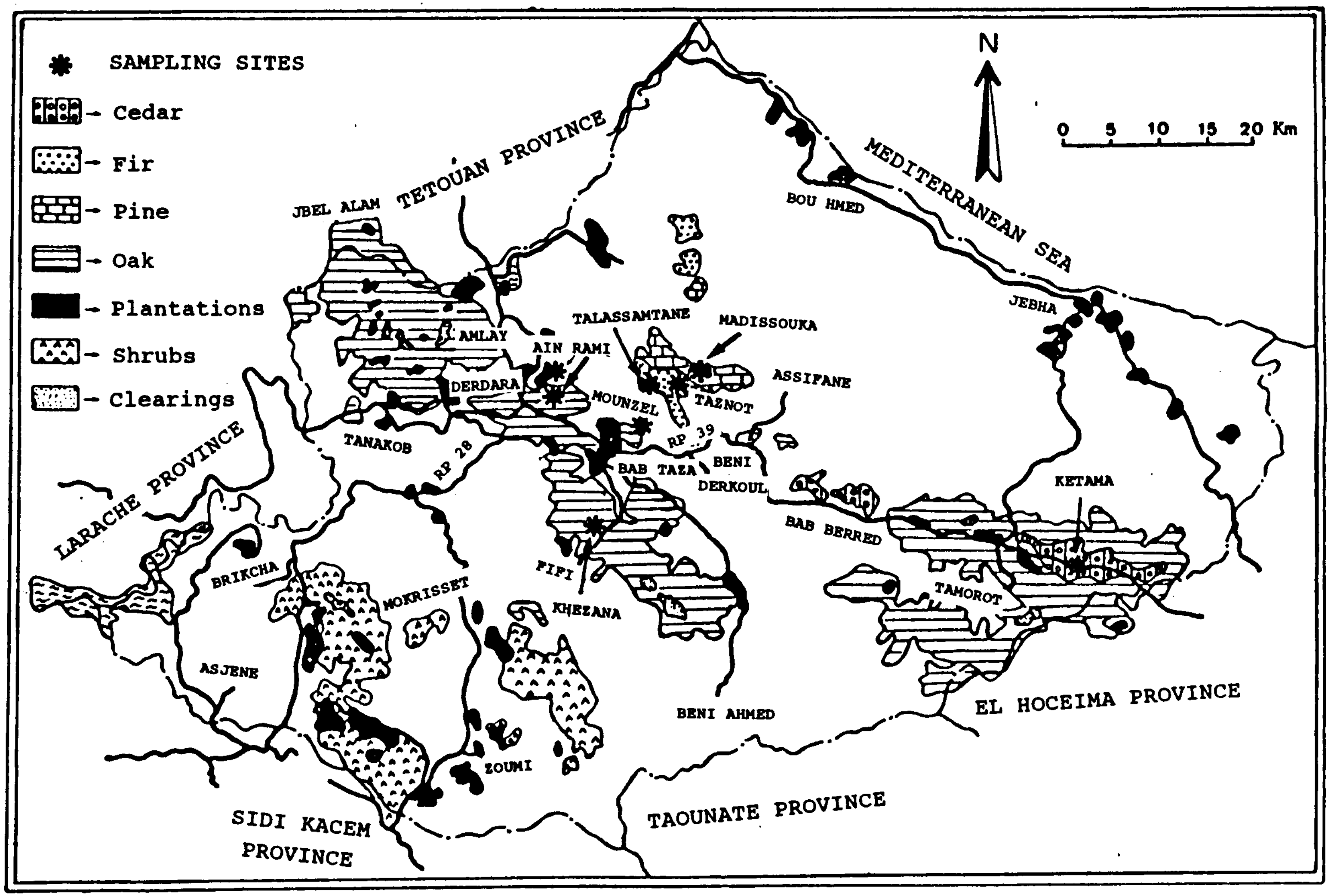


Figure 14: Study site locations.

Table 47: Characteristics of different sites used for laboratory incubations.

Profile		Altitude (m)	Vegetation	Parent material	Climate	Soil depths (cm) # RZ	A	B
Madissouka								
1	M10	1200	*Pinus pinaster*	calcareous	perhumid	0-20	0-20	20-45
2	M9	1170		calcareous	perhumid	0-30	0-45	45-60
Talassamtane								
3	TL23	1640	*Abies marocana*	calcareous	perhumid	0-30	0-30	30-55
4	TL22	1680		calcareous	perhumid	0-30	0-40	40-50
Ketama								
5	K31	1550	*Cedrus atlantica*	quartzitic sandstone	perhumid	0-20	0-40	40-80
6	K29	1620			perhumid	0-20	0-35	35-65
Mounzel								
7	MO37	1300	*Quercus rotundifolia*	schistous sandstone	perhumid	0-30	0-30	30-60
8	MO38	1290			perhumid	0-35	0-35	35-70
Khezana								
9	KH14'	1070	*Quercus pyrenaica*	sandstone	humid	0-35	0-45	45-80
10	KH14	1100		sandstone	humid	0-30	0-40	40-70
Ain Rami								
13	AR42	690	*Pinus pinaster* (plantations)	schistous sandstone	subhumid	0-25	0-25	25-50
14	AR42	700			subhumid	0-30	0-30	30-50
15	AR42	720			subhumid	0-35	0-35	35-50
16	AR41	800	*Pinus radiata* (plantations)	schistous sandstone	subhumid	0-30	0-35	35-70
17	AR41	830			subhumid	0-35	0-35	35-40
18	AR41	880			subhumid	0-40	0-40	40-50
19	AR40	600	*Quercus suber*	schistous sandstone	subhumid	0-20	0-10	10-45
20	AR40	620			subhumid	0-20	0-10	10-50
21	AR40	650			subhumid	0-30	0-20	20-60

RZ : Root zone, A : A horizon, B : B horizon.

Table 48: Selected characteristics of the soil samples used in the laboratory incubation.

Location reference		Depth # reference	pH H_2O	pH KCl	Organic C (%)	TKN † (%)	C/N	Mean bulk density g/cm^3	Mechanical analysis ‡ CS	FS	S	C
Madissouka (Natural pine) *Pinus pinaster*	M10	Rz	7.50	7.30	1.80	0.12	15	-	35.10	21.50	37.90	5.50
		A	7.50	7.30	1.80	0.12	15	-	35.10	21.50	37.90	5.50
		B	8.10	7.90	0.24	0.06	4	-	1.79	4.76	81.07	12.38
	M9	Rz	7.70	7.20	1.68	0.12	14	-	37.25	37.68	16.98	8.09
		A	7.80	7.40	1.20	0.09	13	-	37.22	42.49	13.52	6.77
		B	8.10	7.50	0.30	0.04	8	-	15.45	35.97	41.60	6.98
Talassamtane (Fir) *Abies marocana*	TL23	Rz	6.20	5.40	4.20	0.25	17	-	29.27	15.21	31.32	24.20
		A	6.40	5.40	4.20	0.25	17	-	29.27	15.21	31.32	24.20
		B	6.70	6.00	0.80	0.09	10	-	12.43	8.51	35.99	43.07
	TL22	Rz	6.40	5.60	4.90	0.29	17	-	31.77	16.99	36.90	14.34
		A	6.40	5.40	3.73	0.23	16	-	26.30	14.88	37.73	21.09
		B	6.50	5.40	1.20	0.11	11	-	9.28	10.85	37.70	42.17
Ketama (Cedar) *Cedrus atlantica*	K31	Rz	5.50	4.10	2.80	0.24	12	-	15.86	9.63	45.41	29.10
		A	5.60	4.10	2.20	0.20	11	-	11.01	8.91	48.46	31.62
		B	6.10	4.20	0.80	0.11	7	-	6.84	6.61	46.75	39.80
	K29	Rz	5.40	4.60	5.00	0.24	21	-	21.41	17.86	38.89	21.84
		A	5.30	4.40	4.40	0.24	18	-	18.90	15.22	41.83	24.05
		B	5.40	3.90	1.20	0.09	13	-	7.66	10.20	44.03	38.11
Mounzel (Green oak) *Quercus rotundifolia*	Mo37	Rz	5.90	4.40	1.43	0.09	16	-	30.59	13.73	28.80	26.88
		A	5.90	4.40	1.43	0.09	16	-	30.59	13.73	28.80	26.88
		B	5.70	3.90	0.22	0.06	4	-	28.84	12.95	26.76	31.45
	Mo38	Rz	5.80	3.90	1.59	0.12	13	-	13.03	13.60	43.17	30.20
		A	5.80	3.90	1.59	0.12	13	-	13.03	13.60	43.17	30.20
		B	5.50	4.00	0.45	0.11	4	-	3.43	5.14	32.95	58.48
Khezana (Deciduous oak) *Quercus pyrenaica*	Kh14	Rz	5.40	4.00	2.83	0.19	15	-	51.51	14.82	19.08	14.59
		A	5.40	4.00	2.80	0.20	14	-	48.40	14.75	20.77	16.08
		B	5.20	4.00	4.20	0.30	14	-	27.18	16.99	34.09	21.74
Pinus radiata	AR41	Rz	5.15	4.00	2.09	0.10	21	1.04	23.11	39.33	21.82	15.74
		A	5.15	4.00	1.79	0.11	16	1.04	23.47	39.21	21.14	16.18
		B	5.10	3.80	1.43	0.10	14	1.05	24.22	38.45	19.57	17.76
Pinus pinaster	AR42	Rz	5.90	4.40	3.06	0.15	26	0.91	19.23	12.34	30.38	38.05
		A	5.90	4.40	3.86	0.11	35	0.91	19.23	12.34	30.38	38.05
		B	5.00	3.50	1.85	0.10	19	1.01	22.59	8.27	20.87	48.27
Cork oak *Quercus suber*	AR40	Rz	5.50	4.95	3.96	0.13	31	0.98	12.81	15.17	41.90	30.12
		A	5.60	4.98	5.18	0.15	35	0.98	13.68	15.66	42.70	27.96
		B	5.10	3.55	2.50	0.09	26	0.91	6.66	5.62	22.83	64.89

† TKN : Total Kjeldahl Nitrogen

‡ CS : Coarse sand FS : Fine sand, S : Silt, C : Clay

Rz : Root zone, A : A Horizon, B : B Horizon

IV.2.3. **Soil sampling.**

In both experiments, sites were selected for relative freedom of rocks to facilitate core sampling and to check for spatial variability within each forest stand. At each site, composite soil samples from three core samples were taken from: i) root zone, ii) principal A horizon, and iii) principal B horizon.

The root zone is defined as the portion of the profile where the roots are concentrated. Most of The time root zone coincides with genetic A horizon (Table 47).

The sampling within the root zone and soil genetic A and B horizons was adopted to determine the variability of nitrogen mineralization among sites and over soil depth. Because the forest floor was considered as a site for N immobilization (Keeney, 1980), and it was also a very small layer at most sites, it was excluded from our sampling. In order to minimize soil N transformations during transportation, soil samples were kept refrigerated. In the laboratory, soils were sieved through 2-mm mesh and roots and large fragments were removed from the samples.

IV.2.4. **Anaerobic incubation.**

The anaerobic incubation test proposed by Waring and Bremner (1964) was used. It involved the determination of

NH_4^+-N produced when soil was incubated under waterlogged conditions at 40°C for 7 days.

In this experiment, soil samples were analysed at time zero (t_0) before incubation, and after 7 days. Soil samples weighing 5 g were added to 16 by 150-mm test tubes containing 12.5 ml of distilled water. The soil was added gradually to ensure thorough wetting so that air pockets would not develop in the soil column. The tubes were sealed with plastic lids and incubated for 7 days in the dark at 40°C ± 1°C. (Keeney and Bremner, 1966). Distilled water blanks were included. Following incubation, tubes were shaken vigorously and the contents transferred to the tube of a distillation apparatus, using three rinsings with a total of 12.5 ml of 4N KCl.

IV.2.5. **Static aerobic incubation.**

This method was described by Harmsen (1955) and used in a modified form by Vitousek (1982). It involved the determination of NH_4-N and (NO_3 + NO_2)-N produced when 25 g of soil was incubated aerobically in small glass containers (5 cm diameter) at temperatures ranging from 27°C to 30°C for 21 weeks. Soil moisture was kept at field capacity by monitoring water loss from the cups gravimetrically and adding distilled water weekly as necessary. For aeration purposes, and to minimize water loss during incubation, the cups were covered with plastic film containing small holes. Soil water content at field capacity was determined on soil cores taken from established soil sites (0.5 x 0.5 m). After the sites were fully wetted (after natural rain showers), vegetation was clipped at the ground surface to avoid transpiration and the sites were covered by dark plastic sheet to avoid evaporation. After 36 hours of free drainage, percent water content was determined gravimetrically.

In this experiment, soil samples were analyzed at time zero (t_0) before incubation, and there after at 1, 2, 3, 6, 9, 12, 15, 18, and 21 weeks. Soil samples weighing 10 g were transferred into 250-ml widemonth bottles to which 100 ml of 2M KCl were added. After mechanical shaking for 1 hour, settling for 30 minutes and filtration (Whatman n°2 filter paper), an aliquot (10 ml) of the filtrate was transferred to the tube of distillation apparatus for inorganic N analysis.

The potentially available N (N_0) and the rate constant for N aerobic mineralization (k) were estimated from a first-order kinetic model (Smith et al., 1980).

IV.2.6. **Trenched plots.**

The field experiment consisted of digging three trenched plots (1.2 x 1.2 m) at each site. The trenches were dug only to include the upper 30 to 40 cm of the genetic B horizon. To minimize exchange with the surrounding soil, the inner edge of each trench was lined with two layers of 0.15-mm thick plastic sheet according to Vitousek et al. (1982) and the trenches were then refilled. Plant uptake was prevented by clipping all vegetation at the ground surface in each plot. Repeated clipping prevented the establishment of any vegetation in the plots. At each sampling time 3 soil cores (about 500 g) were taken inside the isolated trenches and outside the trenches for three depths of the soil (root zone, A horizon, and B horizon). The laboratory analysis for this experiment was similar to that conducted for aerobic static incubation. The only difference was that air drying, sieving, shaking, and filtration procedures were performed each time in the field to avoid changes in inorganic N during transportation. The remaining steps were performed in the laboratory on refrigerated filtrates.

IV.2.7. **Chemical analysis.**

Aliquots of soil KCl extracts were distilled with steam until 25 ml of distillate was trapped in 5 ml of boric acid mixed indicator solution (Bremner and Keeney, 1965). Magnesium oxide (MgO) and Devarda alloy were used to separate different forms of exchangeable inorganic N (NH_4^+-N and NO_3^--N). Titration was performed using 0.005 N H_2SO_4. Results were corrected for distilled water blanks and adjusted for oven dry weights.

Total Kjeldahl N (TKN) was determined according to a modified Bremner (1965) technique (Sefrioui et al., 1971).

IV.2.8. **Statistical analysis.**

For both experiments (the survey experiment and the trenched plot experiment) the means and standard deviations were determined and compared for all measured plot variables. Site and depth effects on N mineralized in laboratory (anaerobic and aerobic incubations) and in the field (trenched plots) were tested by one-way ANOVA for rooting zone samples and by two-way factorial ANOVA for A and B horizon samples. Linear regression was used to quantify relationships among N variables.

IV.3. **RESULTS AND DISCUSSION.**

IV.3.1. **Survey experiment.**

IV.3.1.1. **Anaerobic incubation.**

Available N in the root zone as measured by the anaerobic mineralization test (N_{min}) varied over three-fold among the five survey locations (sites) (Table 49). These differences were not statistically significant, however, because of high within site variablitity. The NH_4^+ released by anaerobic incubation represented 2-5 % of the total organic N in the root zone of these soils.

As expected, there were statistically significant differences in N_{min} between A and B horizon soil material at all sites (Table 49). The much lower N_{min} of B horizons relative to A horizons is consistent with the generally lower TKN of the B horizons (Table 48); however, the ratio of N_{min} to TKN also decreased significantly (Table 49). This suggests that not only is there less N in the B horizon, but also that it is less available for microbial mineralization.

Table 49: Within and between location variation of potentially available soil-N indices.

Location reference	N_{min} (mg kg^{-1}) (CV %)			N_{min}/TKN (%) (CV %)		
	Root zone	A horizon	B horizon	Root zone	A horizon	B horizon
Madissouka (Natural pine)	59.6 (30)	45.6 (62)	14.6 (65)	5.0 (30)	4.2 (45)	2.8 (41)
Talassamtane (Fir)	79.8 (62)	87.4 (24)	31.1 (50)	3.8 (59)	3.6 (18)	3.3 (62)
Ketama (Cedar)	44.6 (57)	64.8 (61)	4.6 (64)	2.0 (56)	2.9 (50)	0.5 (76)
Mounzel (Green oak)	23.9 (4)	22.8 (8)	3.0 (53)	2.3 (24)	2.2 (28)	0.4 (86)
Khezana (Deciduous oak)	77.8 (5)	50.3 (22)	4.7 (38)	4.1 (5)	2.5 (22)	0.2 (38)

The decrease of TKN with depth (Table 48) is similar to the trend reported elsewhere (Vitousek, 1982). Also, the spatial variation and magnitude of TKN are somewhat similar. However, both TKN values (Table 48) and N_{min} (Table 49) are 1.5 to 2-fold higher than those reported by Powers (1980). This suggests that site conditions in the Mediterranean forests of the Rif promote not only the production of higher amounts of organic N but possibly reflect a greater proportion of easily mineralized organic N compounds in surface soils.

The same increasing trend of C.V. values (coefficient of variation) for mineralizable soil N with depth (Table 49) was found by Shumway and Atkinson (1978). For this reason they recommended that sampling be confined to the top 0 to 15 cm.

IV.3.1.2. **Aerobic incubation.**

With few exceptions, net N mineralization occurred continually throughout the 21-week aerobic incubation (Figure 15). Over this period, inorganic N production in root zone soils ranged from over 75 mg kg^{-1} at the Mounzel site to almost 200 mg kg^{-1} at the Talassamtane and Khezana sites. In most cases, net N mineralization in A horizon soil was quite similar to that in the root zone and both were generally much greater than B horizon soils.

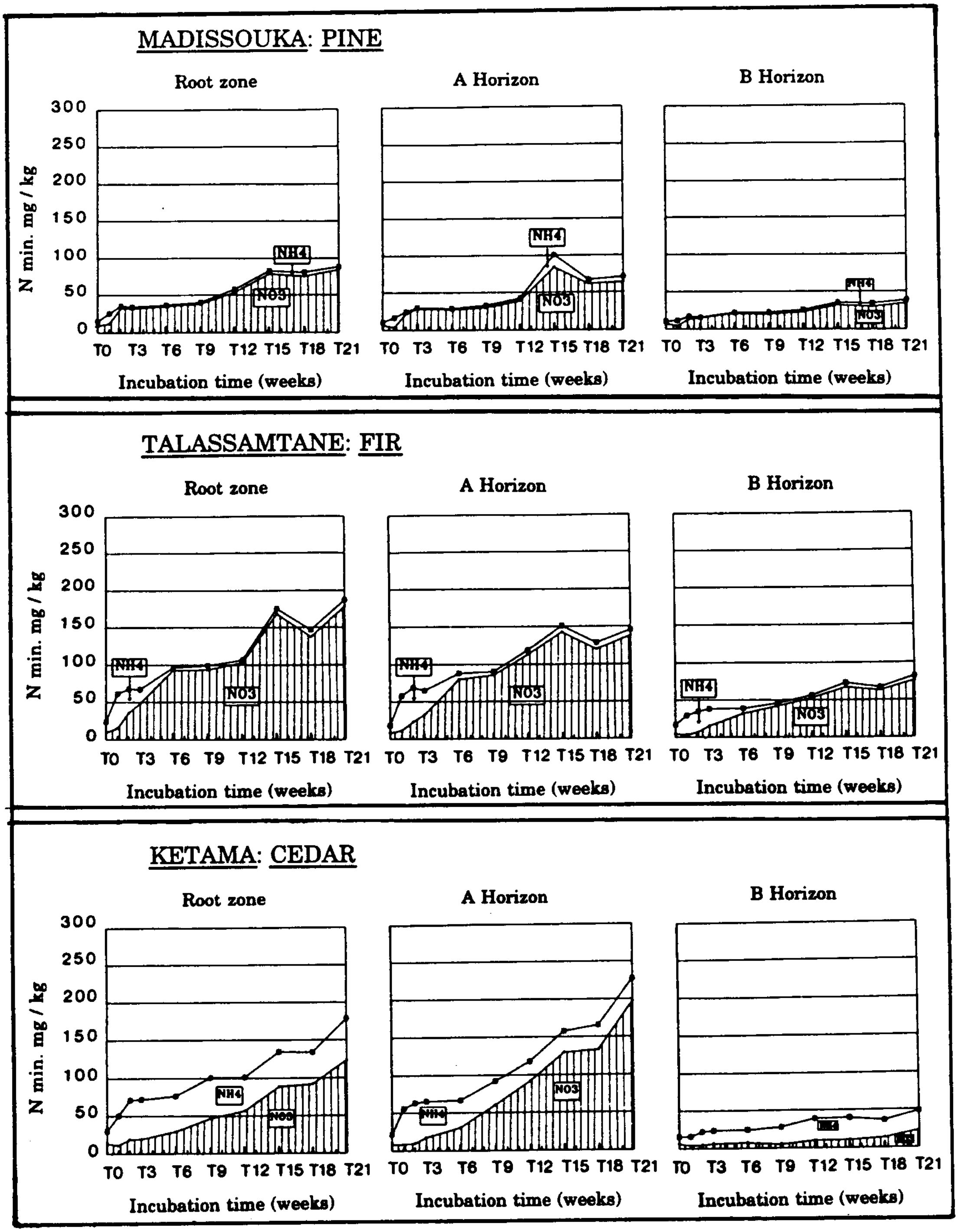


Figure 15: The results of laboratory incubation (static aerobic incubation) of different forest soils and different depths (root zone, A horizon, and B horizon)(survey experiment). Within each graph, the upper line represents the total concentration of extractable mineral nitrogen (ammonium + nitrate nitrogen) at each time, while the lower line (which bounds the shaded area) represents the concentration of nitrate + nitrite nitrogen.

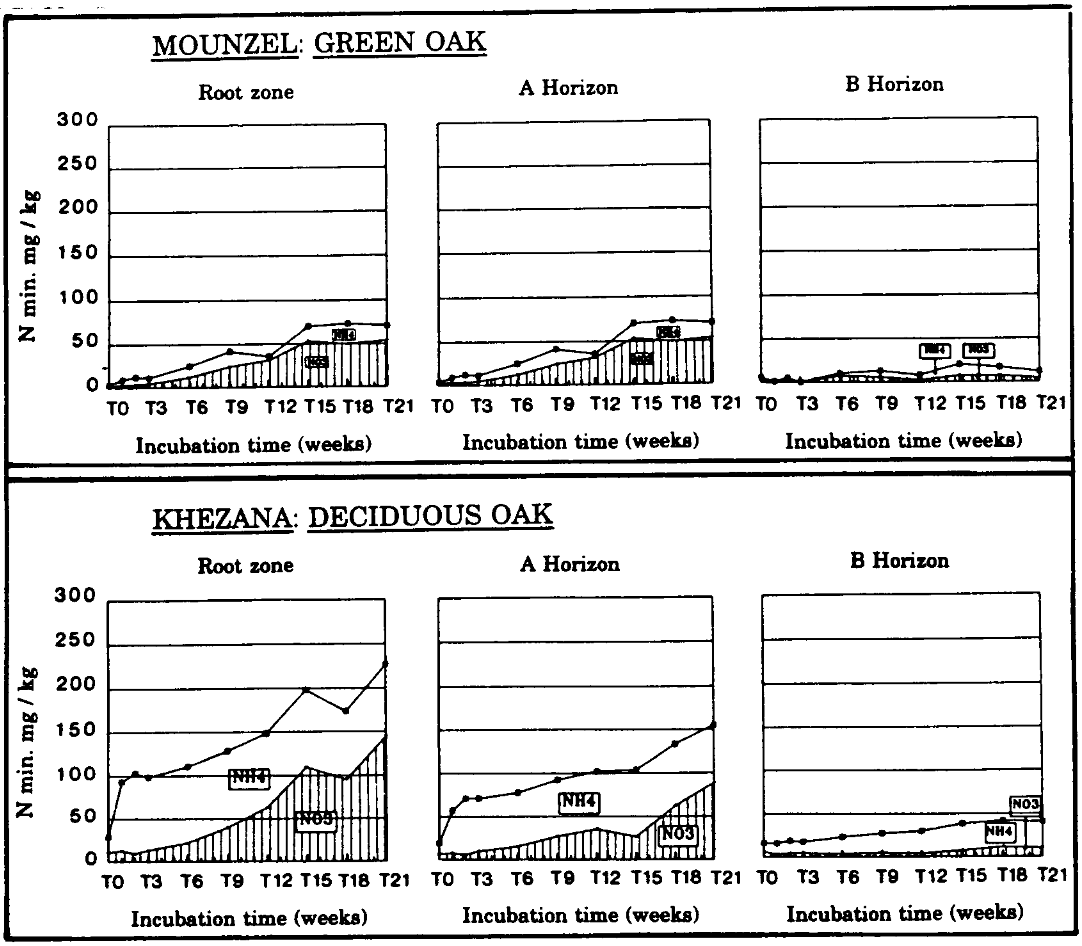


Figure 15: continued.

A/ Lags in nitrification.

Lags in N mineralization or nitrification were defined by Vitousek et al. (1982) as occurring: i) When there was no net production of inorganic N (or NO_3^-) in a horizon, or ii) When the rate of net production of inorganic N (or NO_3^-) accelerate over time. The end of lag period was defined by the same author as occurring: i) When the slope of the net accumulation curve for NO_3^- (the upper bound of the shaded area in Figure 15) equaled or exceeded the slope of the net accumulation curve for total inorganic N (the upper most line on Figure 15), or ii) when the NO_3^- accumulation curve approached a straight line with a positive slope.

At conifer sites, net N mineralization proceeded rapidly with no lags in either the root zone or A horizon; however, nitrification had a one to two-week lag time. In the B horizon, both N mineralization and nitrification were very slow, with a lag of one to two weeks for nitrification. After the initial lag in nitrification at the fir and pine sites, almost all the inorganic N was present as NO_3^-. The proportion of NH_4^+ oxidized per week was much less in the cedar than in the pine or fir soil samples. This was the case for all sampling depths. Consequently, the NH_4^+ pool size remained larger in the cedar soil samples. The cedar B horizon had a much slower rates of net N_{min} and nitrification. The largest NO_3^- pool size was observed for samples from fir sites and the smallest for samples from pine sites for both root zone and A horizon.

At the oak sites, deciduous oak soil samples had higher values for both N mineralization and nitrification in all horizons relative to green oak soil samples. Nitrogen mineralization was rapid in both root zone and A horizon, but nitrification lagged behind N mineralization. In green oak soil samples, both N mineralization and nitrification proceeded slowly. A substantial NH_4^+ pool (the highest of all the sites), accumulated in deciduous oak samples. As a general trend, deciduous oak soil samples showed the largest pools for both NH_4^+ and NO_3^- for all horizons.

B/ Kinetics of mineralization.

Soil N mineralization potential has been defined (Stanford and Smith, 1972) as the fraction of organic N pool that is susceptible to mineralization. Based on data in the literature (Jenny, 1941; Stanford and Smith, 1972) N mineralization reactions often follow approximate first-order kinetics. The assumption of first-order kinetics will be used here as well.

Regression analysis was run on each set of replicates and the results are given as means and CVs (Tables 50 and 51). The fit of the first-order model as expressed by r^2 (Table 50) was quite good, except for two of B horizon soils (Mounzel and Ketama) (Appendix 1). The mineralization potentials (N_0) and the rate constants (k) in the root zone as estimated by the first-order model varied by up to 70 %; however, these differences were not significant among the five survey sites (Table 50). As expected, the higher values of N_0 and k were found in the surface soil (root zone and A horizon) relative to subsurface soil (B horizon). This difference with depth is statistically significant for N_0 but not significant for k. The decrease of N_0 with depth is consistent with the generally lower TKN of the B horizon (Table 48).

The ratio of N_0 to TKN is also variable among sites within the root zone. It decreased significantly with depth only for Mounzel and Khezana samples (green and deciduous oak sites respectively) (Table 51). This suggests that N not only diminishes in the B horizon but also that its availability to microbial mineralization differs according to the nature of organic substrate. This is consistent with the lower k on the Mounzel and Khezana sites.

Table 50: Estimated mineralization potentials (N_0), rate constant (k), and r^2 (coefficient of determination).

	Root zone			A horizon			B horizon		
	Mean N_0 (cv)	Mean k (cv)	Mean r^2 (cv)	Mean N_0 (cv)	Mean k (cv)	Mean r^2 (cv)	Mean N_0 (cv)	Mean k (cv)	Mean r^2 (cv)
	mg Kg^{-1}	($week^{-1}$)	(%)	mg Kg^{-1}	($week^{-1}$)	(%)	mg Kg^{-1}	($week^{-1}$)	(%)
Madissouka (Natural pine)	95 (2)	0.149 (87)	82.42 (4)	48 (7)	0.114 (104)	83.89 (5)	36 (43)	0.104 (102)	85.49 (5)
Talassamtane (Fir)	143 (62)	0.244 (12)	86.14 (3)	136 (71)	0.130 (88)	84.47 (16)	57 (77)	0.129 (55)	85.10 (10)
Ketama (Cedar)	104 (58)	0.221 (4)	88.00 (13)	148 (67)	0.253 (13)	89.83 (2)	45 (6)	0.078 (87)	67.54 (5)
Mounzel (Green oak)	88 (5)	0.147 (76)	90.61 (3)	88 (5)	0.147 (76)	90.61 (3)	18 (35)	0.055 (51)	46.91 (23)
Khezana (Deciduous oak)	126 (47)	0.248 (8)	89.07 (1)	122 (10)	0.216 (21)	74.88 (27)	43 (5)	0.116 (93)	83.71 (8)

Table 51: Estimated N mineralization potentials (N_0), as a fraction of TKN.

	No / TKN		
	Root zone	A horizon	B horizon
	% (cv)	% (cv)	% (cv)
Madissouka (Natural pine)	7.9 (2)	4.6 (13)	8.0 (67)
Talassamtane (Fir)	5.5 (70)	5.6 (66)	6.1 (86)
Ketama (Cedar)	4.3 (58)	6.5 (57)	4.5 (8)
Mounzel (Green oak)	8.5 (15)	8.5 (15)	2.1 (6)
Khezana (Deciduous oak)	6.6 (47)	6.1 (10)	1.4 (5)

IV.3.1.3. Comparison of the two techniques.

The comparison between anaerobic and aerobic incubation results for the root zone revealed higher amounts of N_0 or N_0/TKN (aerobic) relative to N_{min} or N_{min}/TKN (anaerobic). Simple regression correlations among aerobic and anaerobic variables are not all significant ($p \leq 0.05$). N_{min} is significantly correlated with N_0, k, or N_{min}/TKN (Table 52); however, these correlations were not as high as the ones reported elsewhere for N_{min} and N_0 (Gianello and Bremner, 1986).

Table 52: Correlation coefficients for the relationships between the results of aerobic and anaerobic incubation. (N_{min} and N_0 in mg kg^{-1}, k in $week^{-1}$, and N_{min}/TKN and N_0/TKN in percent).

	Aerobic			Anaerobic		
	k	N_0/TKN	N_0	TKN	N_{min}/TKN	N_{min}
N_{min}	0.55*	0.13	0.76*	0.45	0.73*	1
N_{min}/TKN	0.30	0.51*	0.48	-0.22	1	
TKN	0.47	-0.68*	0.28	1		
N_0	0.39	0.49	1			
N_0/TKN	-0.09	1				
k	1					

IV.3.1.4. Discussion.

The survey experiment was used for two purposes: first, to check for the variability of N mineralization among different forest stands and different soil depths, and, second, to determine indices of potentially available soil N for different forest stands. For the root zone, N_{min} ranged between 24 (green oak sites) and 80 mg-N kg^{-1} (fir sites) (Table 49), whereas N_0 ranged from 88 (green oak sites) to 143 mg-N kg^{-1} (fir sites) (Table 50). The higher values of N_0 relative to N_{min} are similar to those reported in other studies (Gianello and Bremner, 1986). Both N_{min} and TKN are higher than those found by Powers (1980). Because of the within site variability, the differences of N_{min} and N_0 between habitat sites are not significant. Similar results were reported in some forest habitats of the Oregon Cascades (McNabb, 1978). These differences were explained as due to changes in gravel content, slope steepness, and litter distribution. In this study, the information on site characteristics (Table 47) was used as a tool to explain the differences between and within sites. The variation of N mineralization indices as shown from incubation results and from statistical analysis was related with ecological features particularly vegetation, parent material, and elevation differences. It is known from the literature (Barbour et al., 1980) that the decomposability of pine leaves is lower than broad leaves. The decomposability of fir and cedar is intermediate. Also, the acidifying effect of needles is greater than oak leaves. The rate constant values (k) are consistent with these findings (Table 50). The effect of elevation was apparent for between site variation. The highest values were obtained for higher altitudes. The higher sites (Talassamtane and Ketama) have more precipitation and consequently more humid soil conditions. Where the parent material is favorable for good water drainage (coarse material) and high pH (calcareous material) N mineralization and particularly nitrification were higher.

From an ecological perspective, net N mineralization had values that varied from site to site for either root zone, A horizon, and B horizon. The parent material and vegetation types are factors that influence N mineralization. The highest values of N_{min} and N_0 were for fir stands on calcareous deposits and the lowest values for green oak samples. The expression of results as a fraction of TKN suggests the variation of organic N quality among different sites. Also, the N mineralization potentials did not follow the same trends as TKN. The consequence was the shifting of the highest values from fir to pine stands for anaerobic data and from fir to pine and green oak for aerobic data (Tables 49 and 51). For A and B horizons other trends were observed. The rate constants (k) are similar to those found in other studies for forest soil (Smith et al., 1980). Highest values were observed for fir (calcareous deposit) and deciduous oak (sandstone deposit) for the root zone. For A and B horizons, the highest figures were observed in cedar and fir sites, respectively (Tables 50 and 51).

The decrease of net N mineralization potentials (both N_{min} and N_0) with depth is general for all sites. This may be explained by the decrease of organic substrate with depth, and the low biological activity in subsoil samples (Table 48).

IV.3.2. **Trenched plots experiment.**

IV.3.2.1. **Anaerobic incubation.**

In this experiment available N in the root zone, as measured by the anaerobic mineralization test (N_{min}), does not show much variation among the three sites (Table 53). All three sites had N_{min} values around 20 mg-N kg^{-1}, which did not exceed 2 % of the total organic N in the root zone of these soils.

Table 53: Variation of anaerobic potentially available soil nitrogen, N_{min}, and N_{min}/TKN (mean values and their CVs).

Stand reference	Root zone		A horizon		B horizon	
	N_{min} (CV %)	N_{min}/TKN (CV %)	N_{min} (CV %)	N_{min}/TKN (CV %)	N_{min} (CV %)	N_{min}/TKN (CV %)
	(mg/kg)	(%)	(mg/kg)	(%)	(mg/kg)	(%)
Pine radiata	17.8 (72)	1.6 (61)	11.5 (76)	1.0 (58)	7.2 (156)	0.6 (143)
Pin pinaster	22.8 (39)	1.7 (64)	30.9 (30)	3.0 (40)	3.7 (14)	0.4 (17)
Cork oak	18.2 (17)	1.5 (34)	45.6 (38)	3.0 (1)	3.4 (2)	0.4 (29)

As expected, the differences between A and B horizon soil material were statistically significant (Table 53). The large decrease of N_{min} from A to B horizon is consistent with the generally lower TKN of the B horizons (Table 48). The ratio of N_{min} to TKN showed also a statistically significant decrease in the B horizons. As mentioned elsewhere (survey experiment), the results suggested that N is less available for microbial mineralization in the B horizon. In the same way, the decrease of TKN with depth (Table 48) is similar to the trends reported elsewhere (Vitousek, 1982). However, both TKN values (Table 48) and N_{min} (Table 53) are lower than those reported in the survey experiment but are somewhat similar to the ones reported by Powers (1980). One possible explanation is that at lower altitudinal sites there is less N input into the system through litterfall. This litterfall N may be quickly mineralized resulting in low soil TKN which is also relatively unavailable for N mineralization.

IV.3.2.2. **Aerobic incubation.**

Net N mineralization as measured by static aerobic incubation occurred continually throughout the 21-week incubation period (Figure 16). During this time, the N produced in the root zone samples ranged from about 50 mg-N kg^{-1} in cork oak and Pinus pinaster sites to over 75 mg-N kg^{-1} in Pinus radiata sites. For these three sites, net N mineralization in the A horizon was quite similar to that in the root zone and both were about two fold or more greater than in B horizon soils.

A/ Lags in nitrification.

The lags in N mineralization and nitrification were used as defined by Vitousek et al. (1980), (See paragraph IV.3.1.2). N mineralization took place rapidly without lags in the radiata pine stand (Figure 16). In the two other stands of relatively lower elevation (Pinus pinaster and cork oak), nitrification lagged behind N mineralization by 2 to 3 weeks for both root zone and A

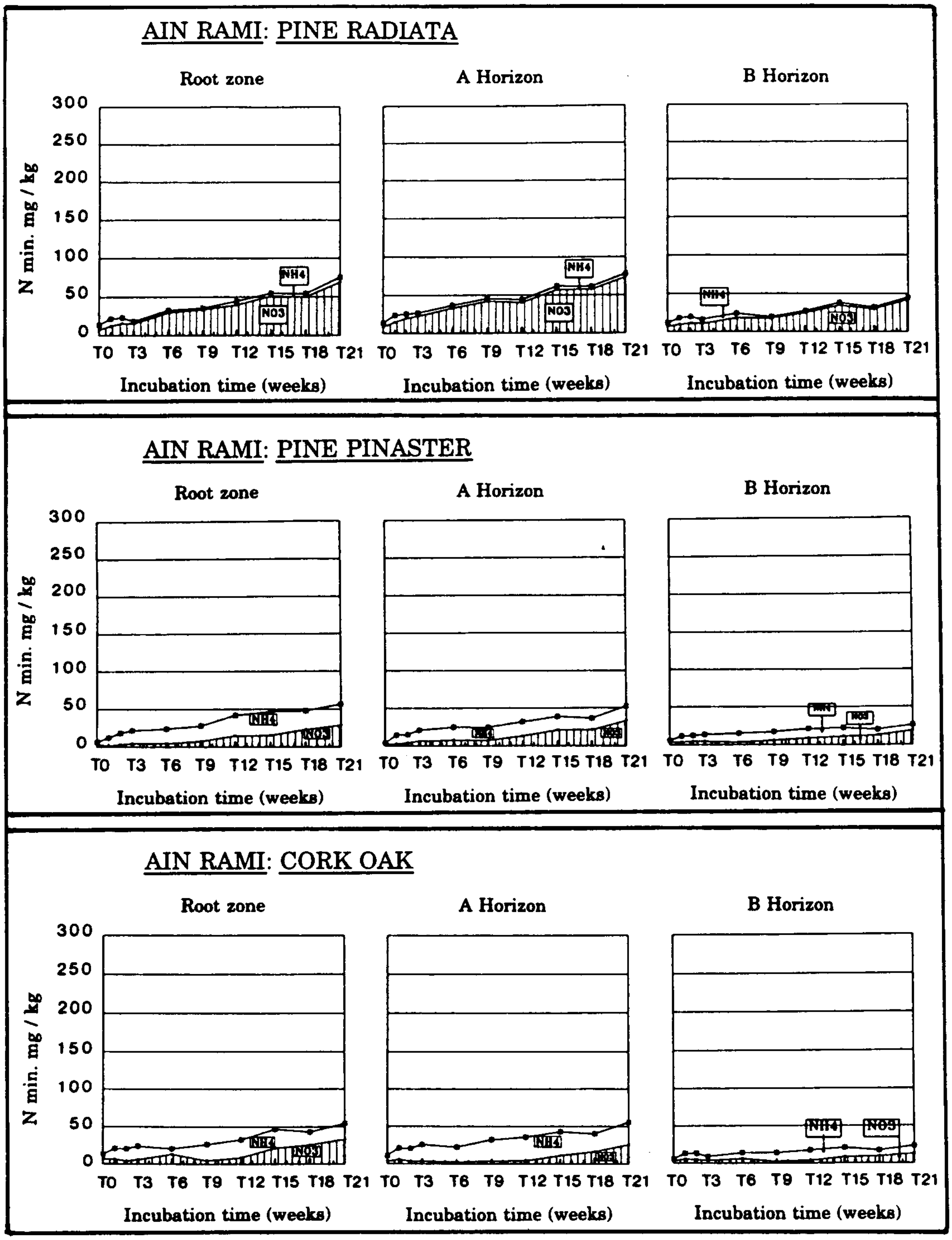


Figure 16: The results of laboratory incubation (static aerobic incubation) of three forest stands and different soil depths around Aïn Rami nursery (trenched plot experiment)(see Figure 15 for definition of values and symbols).

horizon. Once the rate of nitrification equalled the rate of N mineralization, which occurred rapidly in *Pinus radiata* site samples, the proportion of NH_4^+ oxidized per week was much less for *Pinus pinaster* and cork oak stands than for the *Pinus radiata* stand. This was the case for all horizons. The largest NO_3^- pool was found in *Pinus radiata* soil samples for all horizons.

B/ Kinetics of mineralization.

In this study, attempts were made to fit a first-order kinetic model (Jenny, 1941; Stanford et al, 1972) to aerobic N mineralization data. N mineralization potential N_0, as measured from the model, has been defined (Stanford and Smith, 1972) as the fraction of organic N pool that is susceptible to mineralization. The goodness of fit of the model to the data as expressed by r^2 showed higher values for surface horizons (root zone and A horizon) relative to the subsurface B horizon (Appendix 2).

N mineralization potentials (N_0) and the rate constants (k) as estimated from the first-order model are variable among sites and especially within sites. However, the among site variation is not statistically significant ($p \leq 0.05$) for either N_0 and k (Table 54), but was significant for N_0/TKN ratio (Table 55).

Table 54: Estimated values of potentially available nitrogen (N_0), rate constant (k), and maximized r^2 for trenched sites.

Stand reference	Root zone			A horizon			B horizon		
	N_0 (CV %)	k (CV %)	r^2 (CV %)	N_0 (CV %)	k (CV %)	r^2 (CV %)	N_0 (CV %)	k (CV %)	r^2 (CV %)
	mg kg^{-1}	$week^{-1}$	%	mg kg^{-1}	$week^{-1}$	%	mg kg^{-1}	$week^{-1}$	%
Pine radiata	45 (37)	0.188 (8)	86.8 (9)	54 (41)	0.184 (19)	85.6 (5)	27 (79)	0.125 (25)	63.7 (26)
Pine pinaster	45 (87)	0.137 (43)	89.8 (9)	31 (56)	0.161 (22)	80.5 (10)	11 (9)	0.118 (9)	64.4 (29)
Cork oak	29 (62)	0.108 (54)	77.8 (25)	32 (39)	0.160 (24)	81.5 (16)	17 (68)	0.064 (35)	41.5 (77)

Table 55: Estimated values of N_0 as a fraction of TKN for trenched sites.

Stand reference	N_0 / TKN		
	Root zone	A horizon	B horizon
	% (CV)	% (CV)	% (CV)
Pine radiata	4.79 (41)	4.99 (25)	2.51 (57)
Pine pinaster	2.68 (61)	3.03 (65)	1.14 (13)
Cork oak	2.67 (92)	2.15 (29)	1.78 (37)

As expected, N_0 and k decreased significantly with depth. This decrease with depth is consistent with the lower values of TKN at the B horizon (Table 48). The variation of N_0/TKN with depth is also significant ($p \leq 0.05$). The fraction of TKN that is potentially available is relatively very small.

IV.3.2.3. Field experiment: trenched plot.

A/ Temporal variation.

In the field, the major factors controlling N mineralization are soil moisture, temperature, and substrate quality and quantity (Powers, 1990). Trenched plots showed a general trend of NH_4^+ and NO_3^- accumulation over one year (Figure 17), whereas control plots that were not trenched had more or less constant concentrations of NH_4^+ and NO_3^- (Figure 18). The concentrations of inorganic N were quite similar among vegetation types and soil depths in the control plots with NH_4^+ concentrations ranging from < 1 to almost 10 mg-N kg^{-1} and NO_3^- ranging from 1 to almost 6 mg-N kg^{-1}. For trenched plots, there were differences among vegetation types and soil depths; however, these differences were not statistically significant, because of high within site variability.

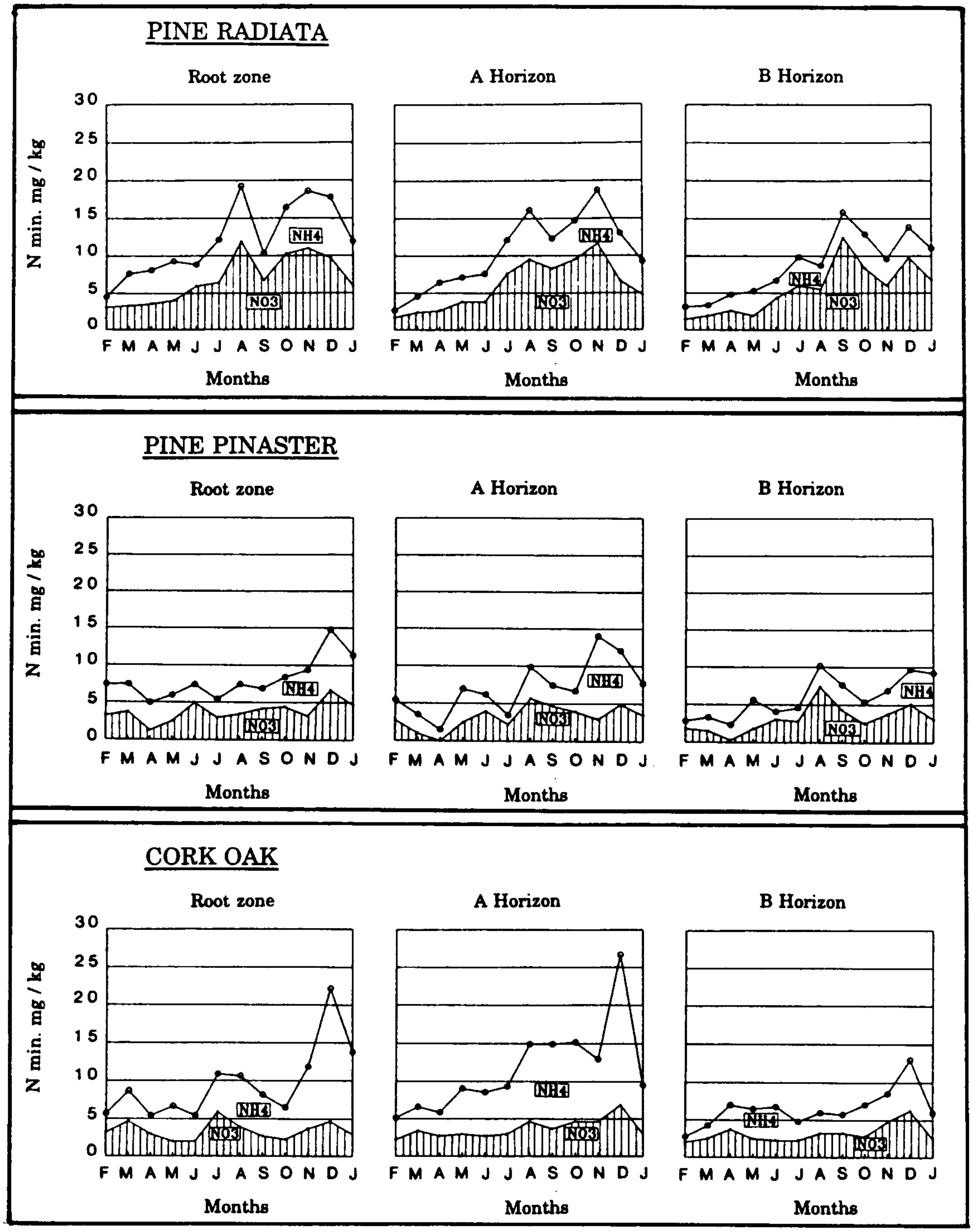


Figure 17: Response of extractable total mineral-N (upper line) and nitrate-N (lower line which bounds the shaded area) to trenching in Aïn Rami forest stands. Values reported are the means of triplicate figures.

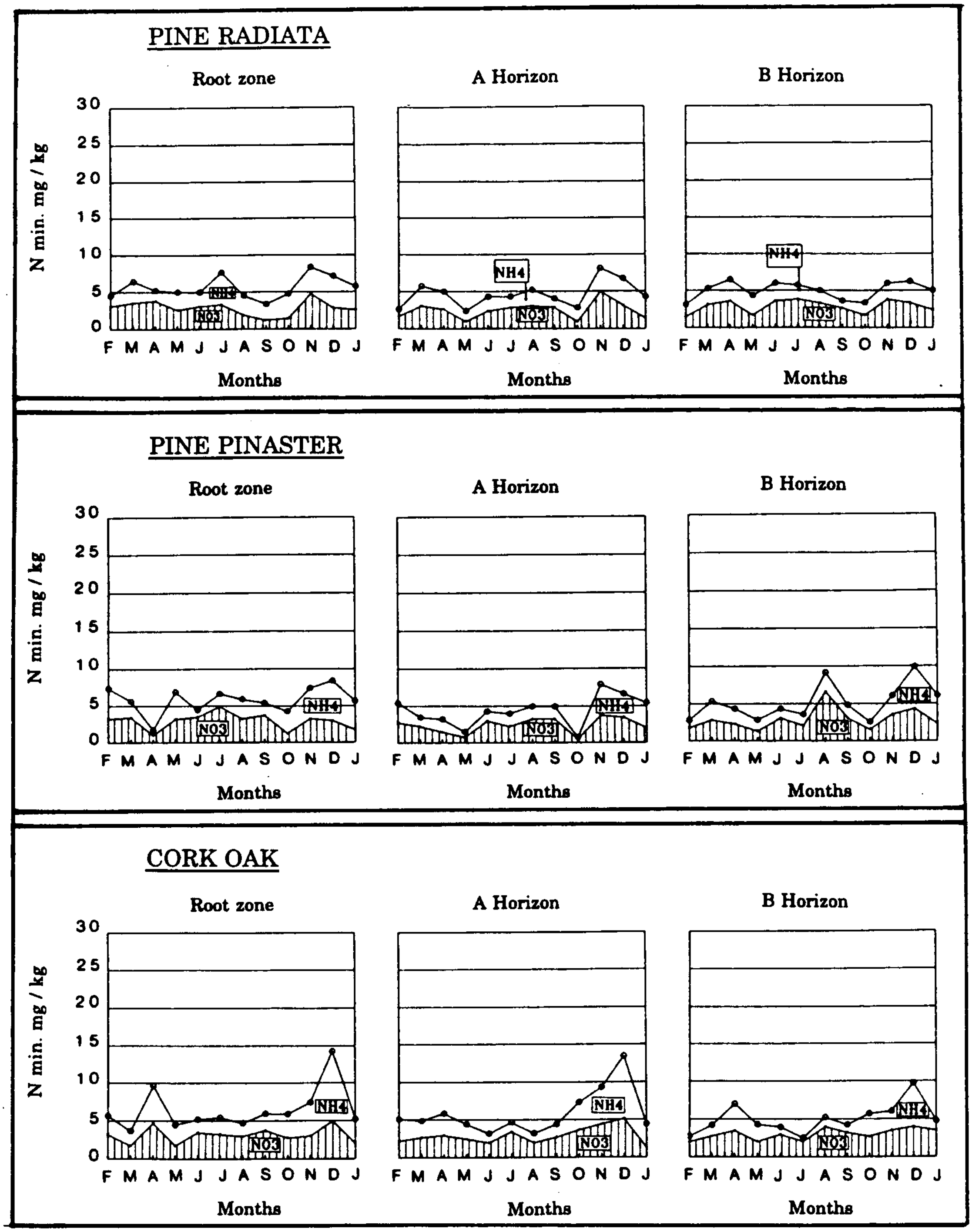
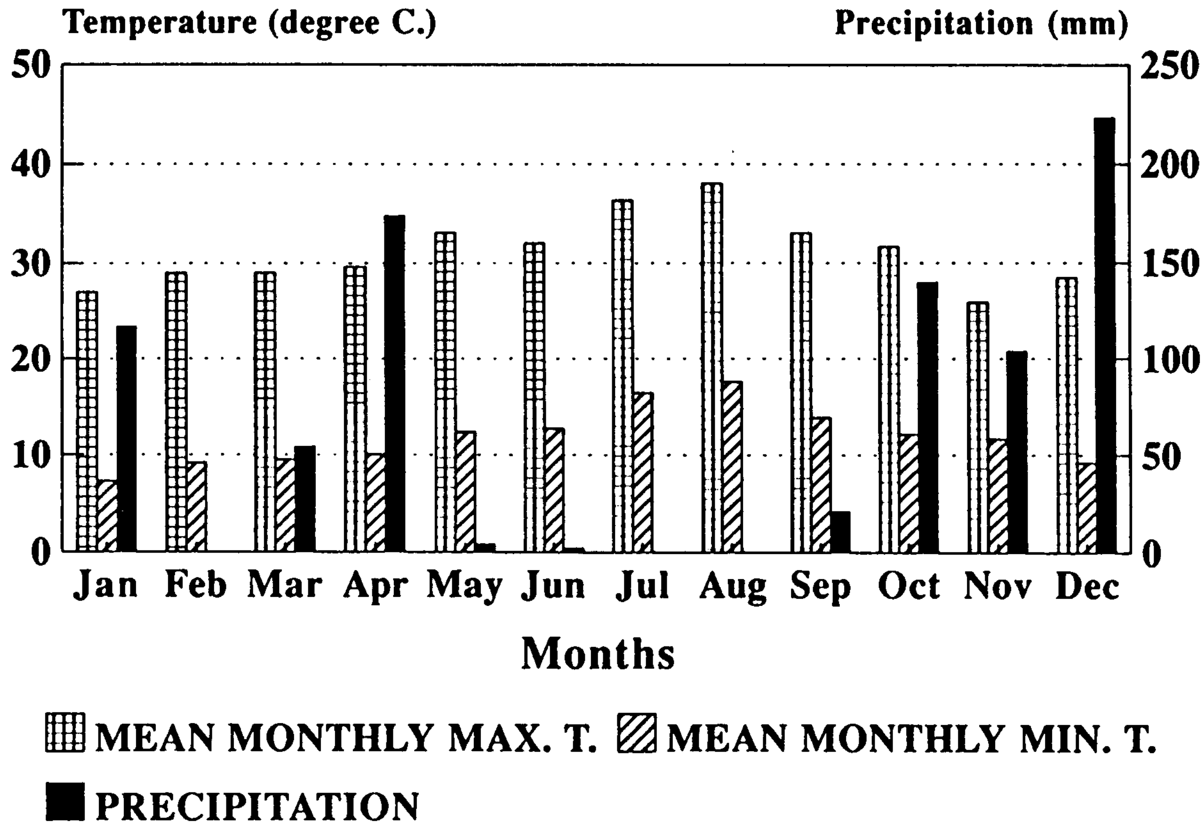


Figure 18: Extractable mineral-N (upper line) and nitrate-N (lower line) in control plots.

These results are similar to the ones found in some forest soils of the Oregon Cascades (McNabb, 1978). In the surface horizons, NH_4^+ concentrations ranged from 1 to 8 mg-N kg^{-1}, 1.5 to 11 mg-N kg^{-1}, and 2.5 to 20 mg-N kg^{-1} for Pinus radiata, Pinus pinaster and cork oak, respectively; NO_3^- ranged from 1.6 to 12 mg-N kg^{-1}, 0 to 7 mg-N kg^{-1}, and 2 to 7 mg-N kg^{-1}, respectively. In subsoil B horizons, lower values were observed for all sites. The highest NO_3^- production was in Pinus radiata stands whereas the highest NH_4^+ production was in cork oak stands. In the control plots, N uptake by plants reduced NH_4^+ and NO_3^- concentrations, especially for Pinus radiata and cork oak, where the density of plants was relatively high.

The seasonal pattern of inorganic N was similar to that observed in other Moroccan soils (Soudi et al., 1990a). However, the magnitude of mineralized N was different among stands. In control plots (Figure 18) the highest concentrations of mineralized N were in the oak sites in November and December. At this time, the leaves are off (plant N uptake is low) and it is wet (Figure 19), so N cycling is rapid. For the same period (November-December), pine trees still had active N uptake and showed smaller peaks of mineralized N. The rain showers of March and April (over 200 mm) and the relative warm temperatures favored enhanced N cycling (smaller peaks of April). The peaks observed in summer for all species are related to water stress and its consequent restricted H_2O and nutrient uptake, so inorganic N can accumulate in the soil. The flush effect or cumulative effect of the first showers (Figure 19) as a generator for N mineralization has been described by other authors (Broadbent et al., 1964; Van Schreven, 1967). Low winter temperatures were also described as having a flush effect on N mineralization (Laudelout et al., 1978; Soudi et al., 1990a). A likely explanation for this flush (Seneverante et al., 1985) is that summer drought and winter low temperatures (Figure 20) have a sterilizing effect and dead microbial biomass recycling follows immediately. Another explanation is that during the dry summer, soil aggregates are broken apart and following the first showers, the newly exposed organic matter will be used by microorganisms (Soudi et al., 1990a). Wet soil conditions are also important for N mineralization. Soudi et al., (1990b) related both NO_3^- and NH_4^+ to different water contents as a percent of soil water retention capacity for some agricultural soils in Morocco. He found that NO_3^- production increased with soil water content (between 25 and 100 % of soil water retention capacity), whereas the increase of ammonium production was related to soil water

Figure 19: Climatic data (1990).



Climatic station : Chefchaouen C.T.

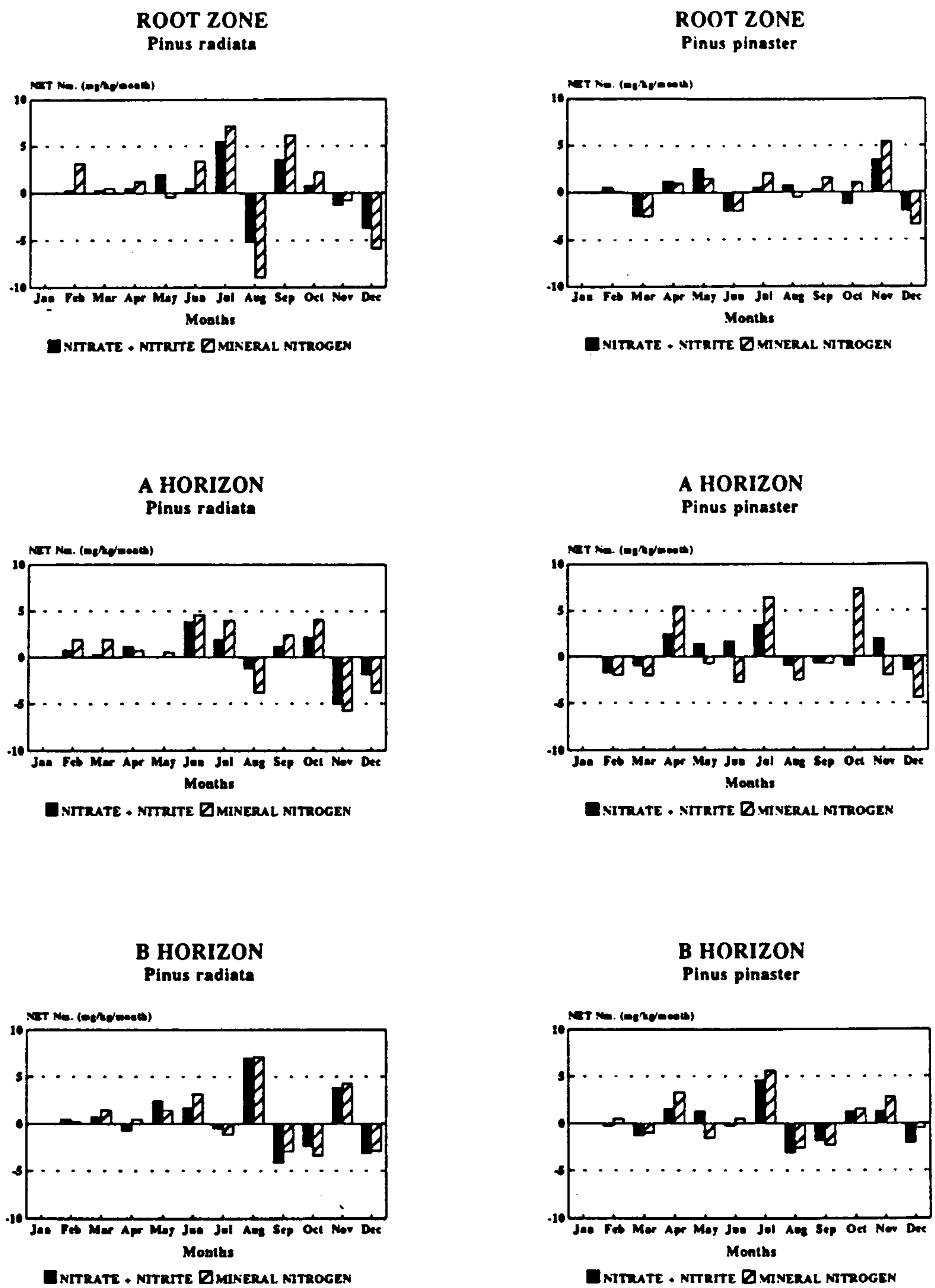
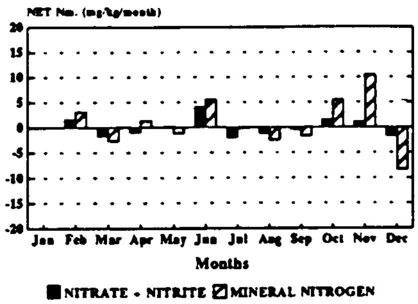
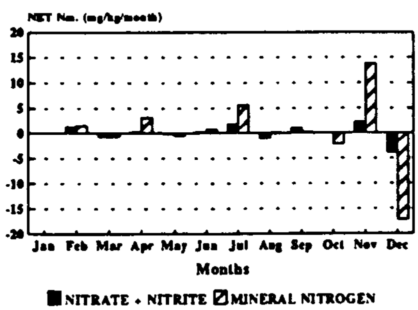


Figure 20: Variation of monthly net mineralized nitrogen. Within each graph the values reported are the means of month to month differences of total mineral-N and nitrate-N in forest stands around Aïn Rami nursery.

ROOT ZONE
Quercus suber



A HORIZON
Quercus suber



B HORIZON
Quercus suber

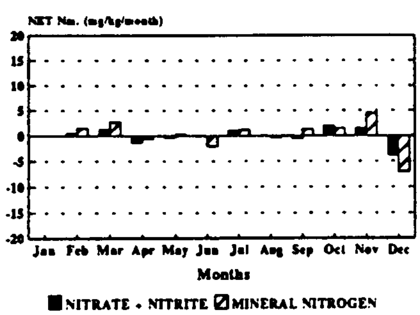


Figure 20: Continued.

content beyond 100 % of soil water retention capacity. *Pinus radiata* stands had a coarse textured soil relative to cork oak stands (Table 48). The finer texture of cork oak stands resulted in a higher water retention capacity and lower water infiltration rates (Aquic criteria are more developed in these sites (see previous chapters on soil genesis and classification). These anaerobic conditions inhibited nitrification relative to N mineralization in cork oak sites. In *Pinus radiata* sites, higher concentrations of NO_3^- relative to NH_4^+ were produced.

B/ Yearly net nitrogen production.

The difference between the final (January 1991) and the initial (February 1990) concentrations of inorganic N forms in the trenched plots is expressed as the yearly net N production.

In trenched plots, yearly net N production varied among sites (Table 56); however, these differences among sites were not statistically significant ($p \leq 0.05$) for any N variables in the root zone because of high within site variability. The differences between A and B genetic horizons was significant only for total net mineral N. For NH_4^+ and NO_3^- the differences with depth were not significant.

Table 56: Yearly net nitrogen mineralization figures (mean values) for nitrate and total mineral-N ($kg\ ha^{-1}\ y^{-1}$) in trenched plots.

Stand reference	Root zone		A horizon		B horizon	
	NO_3-N (CV %)	Tot. min N (CV %)	NO_3-N (CV %)	Tot. min N (CV %)	NO_3-N (CV %)	Tot. min N (CV %)
Pinus radiata	11.3 (156)	29.3 (71)	12.9 (48)	27.8 (18)	6.0 (69)	9.0 (55)
Pinus pinaster	4.4 (218)	11.6 (125)	2.2 (296)	6.6 (59)	2.8 (182)	14.1 (113)
Cork oak	-0.6 (174)	19.9 (86)	1.0 (2)	6.1 (29)	1.8 (236)	12.1 (66)

The monthly fluctuations of net N production varied among the sites (Figure 20). Negative net N production was related to either water stress and high soil temperatures that limit biological activity (summer time) or to the rainy season when the high precipitation promotes leaching of inorganic-N over its accumulation (March-April and December-January)(Figure 19). As a general trend, monthly fluctuations of net N production were higher for pine species than for cork oak (Figure 20). In the root zone, the highest amounts of yearly net NO_3^- production were related to Pinus radiata stands (11.3 kg-N $ha^{-1}\ yr^{-1}$) and the lowest to Quercus suber sites (-0.6 kg-N $ha^{-1}\ yr^{-1}$). In the A horizon net NO_3^- production was somewhat similar to that in the root zone. However, this net production of NO_3-N was two-fold higher in the A relative to B horizon for _Pinus radiata_ stands. In the _Pinus pinaster_ and _Quercus suber_ stands, both NO_3^- and total mineral N showed higher values in the B horizon (Table 56). For NH_4^+ (difference between N-total and NO_3^-), the highest production is related to _Quercus suber_ sites. The variation with depth followed the same trend as NO_3^-. In the three Moroccan agricultural soils from Chaouia and Meknes plateaus (Soudi et al., 1990b), where nitrogen fertilizers are added to soil, much higher amounts of net yearly total mineral N were found (70, 60, and 30 kg-N ha^{-1} yr^{-1}, respectively). In our study, yearly net N production varied from 11.6 kg-N ha^{-1} yr^{-1} in _Pinus pinaster_ sites to 29.3 kg-N ha^{-1} yr^{-1} in _Pinus radiata_ sites for the root zone. Most of net N produced was in NH_4^+ form (more than 60 %). Similar studies in a Mediterranean type of climate (northern California) showed higher values ranging from 19.9 kg-N ha^{-1} yr^{-1} (Red fir) to 58.5 kg-N ha^{-1} yr^{-1} (mixed conifer) when both forest floor and the top 15 cm of mineral soil were considered together. When the top mineral soil is considered alone, net N mineralization varies from 1.2 to 40.4 kg-N ha^{-1} yr^{-1} (Power, 1990). Higher rates of 53.3 kg-N ha^{-1} yr^{-1} of net N mineralization have also been found in some Australian soils (Theodorou and Bowen, 1983b, in the article by Edmonds et al., 1989). Mineralization of N in the field is often balanced by microbial immobilization. This immobilization of N is likely to occur when C:N ratio of the soil is high. Soils in our study had C:N in the root zone ranging from 21 (Pinus radiata) to 31 (cork oak) (Table 48). According to Heilman (1974) (in Edmonds et al., 1989) immobilization of N occurs when C:N is higher than 29. Results showed that most of N immobilization occurred in December and August (Figure 20).

C/ Yearly net N uptake.

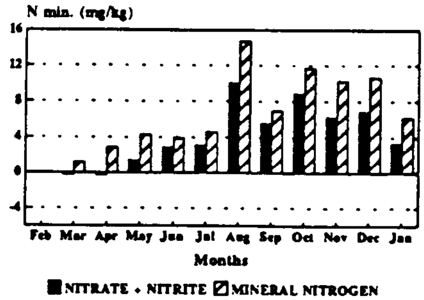
The yearly net N uptake is estimated as the difference of net mineral N production between trenched plots and non-trenched control plots where plants are not clipped. The yearly net N uptake figures (Table 57) were variable among stands but these differences were not statistically significant because of the high within stand variation (CV values in Table 57). The trend of variation was similar to that of yearly net N production. The highest amount of yearly NO_3^- uptake is related to Pinus radiata (13.2 kg-N ha^{-1} yr^{-1}) and the lowest to Quercus suber (2.4 kg-N ha^{-1} yr^{-1}). For NH_4^+, the yearly uptake amounts ranged from 8 kg-N ha^{-1} yr^{-1} (Pinus pinaster) to 18.7 kg-N ha^{-1} yr^{-1} (Quercus suber). In the same way, the monthly fluctuations of N uptake figures (Figure 21) varied among stands and reflected the opposite trends between Pinus radiata and Quercus suber stands for NO_3^- uptake (higher in Pinus radiata) and NH_4^+ uptake (higher in Quercus suber). In Pinus radiata stands, the highest amounts of N uptake occurred from August through January. For Pinus pinaster and Quercus suber the highest figures of N uptake occurred in December and January. It is important to note that cork oak leaves are not totally off in Fall and ground cover (understory plants) is substantial under cork oak trees.

Table 57: Yearly N uptake estimated from monthly difference figures between trenched plots and control plots (Mean values, root zone only)(kg ha^{-1} yr^{-1}).

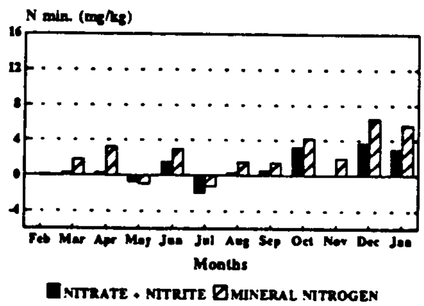
Stand reference	Root zone	
	NO_3-N (CV %)	Tot. min N (CV %)
Pinus radiata	13.2 (54)	24.5 (12)
Pinus pinaster	8.8 (114)	16.8 (54)
Cork oak	2.4 (87)	21.1 (63)

The relatively higher altitude of Pinus radiata stands and the consequent lower temperature and higher humidity are likely to favor N uptake through summer time.

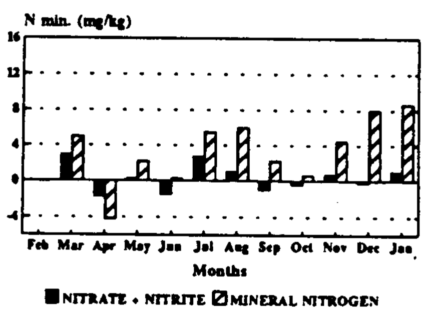
ROOT ZONE
Pinus radiata



ROOT ZONE
Pinus pinaster



ROOT ZONE
Quercus suber



<u>Figure 21</u>: The monthly variation of mean concentration differences between trenched plot and control plot figures of total mineral-N and nitrate-N for the principal forest stands around Aïn Rami nursery.

The yearly net N uptake values ranged from 16.8 (Pinus pinaster) to 24.5 kg-N ha^{-1} yr^{-1} (Pinus radiata). Compared to values reported by Keeny (1980) for different forest species (5.6-23 kg-N ha^{-1} yr^{-1}), the amount of N mineralized in our study may be considered adequate to supply the needs of forest trees.

IV.3.2.4. **Comparison of methods.**

With few exceptions (e.g., the A horizon of both Pinus pinaster and Quercus suber), the potentially available soil N (N_0) as estimated from the first-order model (21-week aerobic incubation) was 1.5 to 5-fold higher than N_{min} (1-week anaerobic incubation) (Table 58). In the root zone, both aerobic and anaerobic indices were much higher than yearly net mineral nitrogen and N uptake (Table 58). However, yearly net mineral N and N uptake showed the same trend of variation for all three stands.

As expected, N_{min} and N_0 were much higher than yearly net mineral N in the genetic A horizon; however, N_{min} and yearly net mineral N were similar in the B horizon for all sites with differences in the within stand variation (CV values)(Table 58).

Table 58: Comparison between aerobic, anaerobic, yearly net nitrogen mineralization, and N uptake figures. Mean values of total mineral nitrogen figures (mg kg^{-1}).

	Anaerobic index N_{min}	Aerobic index N_0	Yearly net mineral N	N Uptake
		Root zone		
Pine radiata	17.8	45	7.4	6.2
	(72) #	(37)	(71)	(12)
Pine pinaster	22.8	45	3.9	5.7
	(39)	(87)	(126)	(54)
Cork oak	18.2	29	8.1	8.6
	(17)	(62)	(86)	(63)
		A horizon		
Pine radiata	11.5	54	6.7	
	(76)	(41)	(18)	
Pine pinaster	30.9	31	2.2	
	(30)	(56)	(59)	
Cork oak	45.6	32	4.4	
	(38)	(39)	(47)	
		B horizon		
Pine radiata	7.2	27	7.9	
	(156)	(79)	(55)	
Pine pinaster	3.7	11	6.4	
	(14)	(9)	(114)	
Cork oak	3.4	17	3.2	
	(2)	(68)	(66)	

Values inside parentheses are CV,s (coefficient of variation from the means, %) .

A/ Yearly net N mineralization.

Forward stepwise regression analysis were used to to establish regression models and correlations from the root zone data. Smith (1965) showed that both NO_3^- initially present in soil and N derived from mineralization are highly correlated with N uptake. Gianello et al., (1986) developed a simple chemical method for a potentially available organic N index, which is highly correlated with biological incubation methods. In this experiment, the yearly net N mineralization figures were considered as dependent variables and were regressed against different sets of aerobic and anaerobic incubation variables (Table 59).

When each N variable was considered separately, the only significant r^2 observed was when yearly net NH_4-N and yearly net mineral-N were regressed against N_0 (values between brackets in Table 59); the regression of yearly net NO_3-N against each N variable showed values of r^2 lower than 0.20. For the other combinations of variables, the highest r^2 (significant values) were observed when yearly net figures were regressed against all N variables. The other significant r^2 were related to the regression of yearly net NH_4^+-N and mineral N against aerobic N variables and to the regression of yearly net NO_3-N with anaerobic N variables and TKN (Table 59).

Table 59: Relation of yearly net nitrogen mineralization figures with all variables (Y_1), anaerobic variables (Y_2), anaerobic variables and TKN (Y_3), Aerobic variables (Y_4), and aerobic variables and TKN (Y_5). (N_{min}, N_0, and yearly net figures in mg kg^{-1}; k in $week^{-1}$; and TKN and N_{min}/TKN in percent).

Yearly net figures	Regression equation coefficients							r^2
	N_{min}	N_{min}/TKN	TKN	N_0	N_0/TKN	k	Constant	
Min. NH_4 = Y_1	- 1.46 (0.01) #	14.37 (0.08)	0.0008 (0.13)	0.10 (0.43)	- 3.53 (0.18)	10.03 0.02	16.29	0.69 *
Min. NO_3 = Y'_1	1.30 (0.16)	- 16.63 (0.20)	- 0.02 (0.05)	0.05 (0.13)	- 0.77 (0.02)	6.68 (0.16)	22.94	0.91 *
Min. NTot = Y''_1	- 0.15 (0.02)	- 2.26 (0.00)	- 0.12 (0.19)	0.15 (0.58) *	- 4.31 (0.18)	16.71 (0.03)	39.23	0.85 *
Min. NH_4 = Y_2	- 0.28	4.34					3.81	0.15
Min. NO_3 = Y'_2	- 0.04	- 1.37					4.39	0.20
Min. NTot = Y''_2	- 0.33	2.97					8.20	0.07
Min. NH_4 = Y_3	0.11	0.02	- 0.004				8.09	0.17
Min. NO_3 = Y'_3	1.57	- 19.01	- 0.02				21.88	0.90 *
Min. NTot = Y''_3	1.68	- 19.00	- 0.02				29.96	0.42
Min. NH_4 = Y_4				- 0.16	0.33	- 28.13	14.60	0.54 *
Min. NO_3 = Y'_4				- 0.05	0.31	16.25	- 0.04	0.23
Min. NTot = Y''_4				- 0.22	0.64	- 11.88	14.56	0.61 *
Min. NH_4 = Y_5			- 0.01	- 0.01	- 1.68	- 20.49	22.98	0.62 *
Min. NO_3 = Y'_5			- 0.0005	- 0.04	0.16	16.82	0.58	0.23
Min. NTot = Y''_5			- 0.01	- 0.04	- 1.52	- 3.67	23.56	0.68 *

: Values between brackets are r^2 of the regression of Yearly net N mineralized with each N variable considered alone.

B/ N uptake.

The relation of N uptake to different N variables has been investigated (Hanway et al., 1966; Keeney et al., 1966; Baerug et al., 1973; Stanford, 1982). In this study, both aerobic and anaerobic indices, TKN, and yearly net N mineralization figures were used in stepwise regression analysis as independent variables. A summary of these results is shown on Table 60.

When N uptake was regressed against each variable considered individually, the only significant r^2 were related to yearly net NH_4^+ (0.86), yearly net mineral-N (0.72) and N_0 (0.43). With the one exception, when N uptake was regressed against anaerobic N variables and TKN (r^2 = 0.25), all the other multiple regression models had highly significant r^2 (Table 60). As a general trend, aerobic N variables and yearly figures were more highly correlated with N uptake than anaerobic variables.

IV.4. CONCLUSION.

Nitrogen mineralization was studied in forest soils around Chefchaouen, Morocco. Both laboratory (the survey experiment) and field (the trenching experiment) studies were done.

The five forest stands used in the survey experiment were: <u>Abies marocana</u> (fir), <u>Pinus pinaster</u> var.

Table 60: Relation of N uptake (Y_i: i=1...20) to different N variables in the root zone. (yearly net N mineralization, aerobic incubation, and anaerobic incubation).

Regression equations	r^2
$Y_1 = 0.56\ X_3 - 1.45\ X_4 + 15.70\ X_5 + 0.10\ X_6 - 1.79\ X_7 + 13.06\ X_8 + 0.01\ X_9 - 3.03$	0.996 *
$Y_2 = 0.60\ X_1 + 0.06\ X_2 - 1.79\ X_4 + 20.15\ X_5 + 0.09\ X_6 - 1.41\ X_7 + 10.61\ X_8 + 0.01\ X_9 - 10.66$	1.00 *
$Y_3 = 0.37\ X_3 + 0.05\ X_6 - 1.19\ X_7 - 11.84\ X_8 - 0.005\ X_9 + 14.16$	0.83 *
$Y_4 = 0.04\ X_6 - 1.74\ X_7 - 13.18\ X_8 - 0.007\ X_9 + 22.00$	0.72 *
$Y_5 = 0.71\ X_3 - 1.11\ X_4 + 13.28\ X_5 + 0.01\ X_9 - 10.59$	0.97 *
$Y_6 = 0.07\ X_4 - 0.13\ X_6 - 0.004\ X_9 + 10.57$	0.25
$Y_7 = 0.57\ X_1 + 0.13\ X_2 + 0.05\ X_6 - 0.80\ X_7 - 3.61\ X_8 - 0.003\ X_9 + 9.53$	0.92 *
$Y_8 = 0.70\ X_1 + 1.15\ X_2 - 1.81\ X_4 + 21.75\ X_5 + 0.02\ X_9 - 20.27$	0.99 *
$Y_9 = 0.48\ X_3 - 0.03\ X_4 + 0.11\ X_7 - 15.71\ X_8 + 6.83$	0.78 *
$Y_{10} = 0.51\ X_3 - 0.14\ X_4 + 2.49\ X_6 + 2.30$	0.82 *
$Y_{11} = 0.70\ X_1 + 0.17\ X_2 + 3.01$	0.88 *
$Y_{12} = 0.69\ X_1 + 3.26$	0.86 *
$Y_{13} = 0.13\ X_2 + 6.63$	0.01
$Y_{14} = 0.54\ X_3 + 3.34$	0.72 *
$Y_{15} = 0.01\ X_4 + 6.68$	0.0002
$Y_{16} = 1.15\ X_5 + 5.00$	0.07
$Y_{17} = -0.09\ X_6 + 10.44$	0.43
$Y_{18} = -0.61\ X_7 + 8.06$	0.14
$Y_{19} = -2.06\ X_8 + 7.22$	0.002
$Y_{20} = -0.003\ X_9 + 11.28$	0.23

Y_1 = Total N uptake (NO_3^- - NH_4^+) (mg kg^{-1} yr^{-1})
X_1 = Yearly net mineralized NH_4 - N (mg kg^{-1} yr^{-1})
X_2 = Yearly net mineralized NO_3 - N (mg kg^{-1} yr^{-1})
X_3 = Yearly net mineralized NTot - N (mg kg^{-1} yr^{-1})
X_4 = N_{min} (anaerobic) (mg kg^{-1})
X_5 = N_{min} / TKN (%)
X_6 = N_0 (aerobic) (mg kg^{-1})
X_7 = N_0 / TKN (%)
X_8 = k (rate constant) ($week^{-1}$)
X_9 = TKN (%)

moghrebiana (pine), Cedrus atlantica (cedar), Quercus rotundifolia (green oak), and Quercus pyrenaïca (deciduous oak). The trenched plot experiment was conducted in three forest stands (Pinus radiata and Pinus pinaster (pine plantations) and Quercus suber (cork oak)) around Aïn Rami nursery.

In both experiments, two indices of N mineralization potential were determined: N_{min} (7-day anaerobic incubation) and N_0 (21-week aerobic incubation). A first-order model was used to predict the potentially available soil N index (N_0) and the rate constant of N mineralization (k). Trenched plots were used in the field experiment to measure annual net N mineralization and plant N uptake.

All indices of N mineralization varied among sites; however, the differences were not statistically significant because of high within site-variability in the root zone. There was a significant decrease of both N_{min} and N_0 from surface A horizon to subsurface B horizon. This decrease of N_{min} and N_0 with depth was consistent with the lower concentrations of organic total Kjeldahl nitrogen (TKN) in the B horizon. The significant decrease of the ratios N_{min}/TKN and N_0/TKN with soil depth suggested that not only is there less organic N in the B horizon, but also that it is less available for microbial mineralization.

In the root zone, the highest concentrations of N_{min} and N_0 were found in fir sites, with 80 and 143 mg-N kg^{-1}, and deciduous oak sites, with 78 and 12 mg-N kg^{-1}, respectively. The lowest concentrations (N_{min} of 24 and N_0 of 88 mg-N kg^{-1}) were found at the green oak site. Fir had highest NO_3^- pool; and deciduous oak had highest NH_4^+ pool.

Nitrogen mineralization generally proceeded immediately in the surface horizon but nitrification had a one to two week lag time. In the subsurface horizon lower rates of N mineralization occurred with a one to two week lag time for nitrification.

In trenched plot experiment, N_{min} and N_0 were lower than those of the survey experiment. N_{min} was around 20 mg-N kg^{-1} and N_0 ranged from 29 to 45 mg-N kg^{-1} in the root zone. In trenched plots, NH_4^+ and NO_3^- accumulated during the one-year period. Because of N uptake by plants, there was a reduction of NH_4^+ and NO_3^- accumulation in the surface horizon outside of trenched plots. The peaks of inorganic N production in November-December, March-April, and summer time (June-July) outside of trenched plots reflected the seasonal variation of N production and were explained either by soil wetness and warm soil temperature that favor enhanced N cycling (fall and spring time) or by summer water stress and its consequent restricted water and nutrient uptake by plants, which permitted the accumulation of N in soil.

In the root zone of trenched plots, yearly net N production ranged from 12 to 29 kg-N ha^{-1} yr^{-1} and yearly net N uptake from 17 to 25 kg-N ha^{-1} yr^{-1}. The highest rates were observed in *Pinus radiata* stands; the lowest in *Pinus pinaster* stands.

Stepwise regression analysis showed that aerobic N variables and yearly net N mineralization figures were more highly correlated with N uptake than were anaerobic variables.

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GENERAL CONCLUSION

The success of both rural and urban development is highly dependent upon planning that recognizes the proper use of soil resource information. Soil profiles and soil profile descriptions are of interest to everyone involved in using the land. The aim was to develop soil related information that may help forest managers, land planners, and land users in understanding the soil component of forest ecosystem. This study of forest ecosystems of the western Rif was done to better understand soils and their relationship to the landscape.

The soils of the forested area of western Rif were described and classified along altitudinal gradients (toposequences). Nitrogen mineralization was studied in the laboratory and in the field.

The study area included the forests of Jbel Alam (cork oak), Talassamtane (fir), Madissouka (natural pine), Chefchaouen (cork oak and pine plantations), Khezana (deciduous oak), Taznote and Mounzel (green oak), and Ketama (cedar). The study sites were organized into four broad geological groups of colluvium-residuum deposits that comprise calcareous and dolomitic, sandstone, mixed schistous sandstone, and mixed quartzitic sandstone deposits. Forty-four soil profiles were described by genetic horizons along altitudinal transects, according to vegetation type and lithological substrata. A total of 182 horizon samples were analysed for physical, chemical, and mineralogical soil characteristics.

All the major factors of soil formation (climate, parent material, relief, time, and vegetation) vary widely within these highland forests as does their relative influence on soil characteristics. Most of the soils were shallow, unstable, and were limited in their productive capability. They were classified as Entisols and Inceptisols (both indifferent to parent material), Mollisols and Alfisols (both on calcareous parent material), and Ultisols (on acidic parent material). Younger soils, including Entisols, Inceptisols, and some Mollisols, occurred mainly on ridge crests and steep slopes. Soils with developed Bt horizons comprising Alfisols, Ultisols, and some Mollisols, occupied more stable sites including flat benches and valley bottoms.

The soils under forest showed good to moderate nutrient levels. Fertility is likely maintained by the high base levels of some of the parent materials and closed cycling of nutrients through the vegetation, litter, and soil organic matter.

Because most of the area had steep slopes and V-shaped topography, soil erosion is probably the most destructive process reducing the production capacity of the land.

The main internal soil developing processes were melanization and rubifaction. Melanization imparted dark color to upper horizons. Rubifaction was most distinct at lower elevations, particularly around Chefchaouen where Ultisols were more prevalent and where high temperatures and stable landscape positions combined to develop deeply leached soils with reddish and yellowish colors according to the degree of hydration of iron oxides.

Clay minerals were mostly inherited from parent materials. Kaolinite, illite, chlorite, interlayer clays, quartz, and feldspars were common to all toposequences, whereas smectite, palygorskite, and dolomite were specific to calcareous and dolomitic parent material. The tropical type of climate under which clays were produced by a strong chemical alteration (during the Pliocene-Inferior Villafranchian epoch) did not exist while the soils formed.

The potentially available soil nitrogen, N_{min} (7-day anaerobic incubation period) and N_0 (21-week aerobic incubation period), showed a variation among sites; however, these differences were not statistically significant because of large within-site variability.

N_{min} ranged from 22 to 87 mg-N kg^{-1} in the mineral surface horizon and from 3 to 31 mg-N kg^{-1} in the subsurface horizon. N_0 ranged from 48 to 143 mg-N kg^{-1} and from 18 to 57 mg-N kg^{-1} in the upper and lower horizons, respectively. The rate constant of N mineralization (k) ranged from 0.130 to 0.253 $week^{-1}$ in the surface horizon and decreased significantly with depth. The highest values of potentially available organic N were found at the fir, cedar, and deciduous oak sites. The lower altitudinal sites from the trenched plot experiment (Quercu suber, Pinus pinaster, and Pinus radiata) had the lowest figures. In this experiment N_{min} ranged from 11 to 46 mg-N kg^{-1} and N_0 from 29 to 54 mg-N kg^{-1}, with a significant decrease with depth for both N indices.

In the field, yearly net N mineralization varied from 6 to 29 kg-N ha^{-1} yr^{-1} in the surface soil, and from 9 to 14 kg-N ha^{-1} yr^{-1} in the subsurface horizon. Yearly net N uptake was highly correlated with net N mineralization and varied from 17 to 25 kg-N ha^{-1} yr^{-1}. In comparison with the values reported elsewhere, this amount of N mineralized were considered adequate to supply the needs of forest trees.

Most of the forests in the area are subject to human inpact and erosion hazard, particularly grazing, clearing, and cultivation. The soil related information developed in this study may help the forest manager and land user if well understood. Each soil class is defined by certain morphological, chemical, and physical properties, which may then be used for determining the best potential land use. Educational programs will be needed to successfully convey this information.

Where clearing and cultivation of soil becomes necessary, poorly drained soils of concave spots on midslopes and valley bottoms could be extensively used for cultivated field crops provided appropriate agronomic techniques and that artificial drainage is feasible. For a better control of erosion problems in the area the most suitable use of the soil is the retention as woodland.

In the sites where reforestation is required, adequate selection of adapted species and appropriate plantation techniques are imperative. Consultation with specialists will be necessary to do this well .

Nitrogen cycling is important in forest ecosystem. Understanding N variability among different forest stands and the potential of soil under different species to produce inorganic forms of nitrogen may guide the forest manager and planner in the area with better choices of the forest species to be used as plantations and the land potential for agricultural uses.

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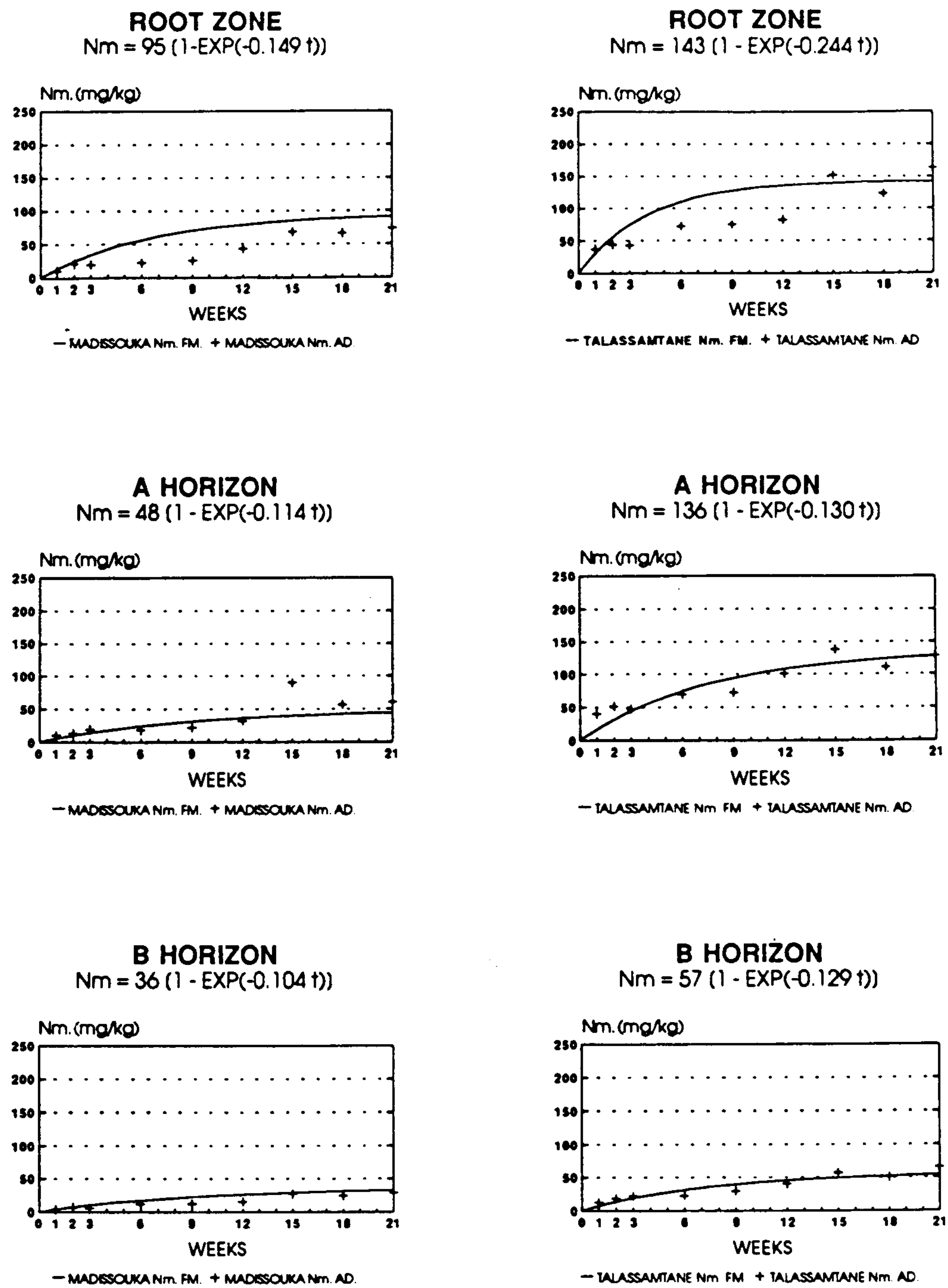
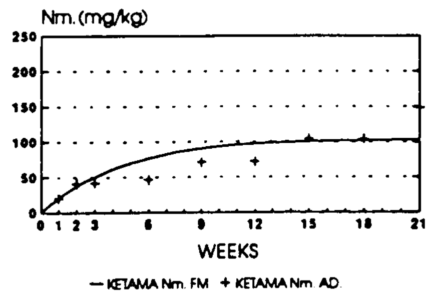
APPENDICES

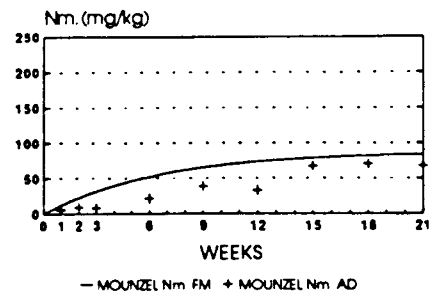


Appendix 1: Fitted models to static aerobic incubation data for different forest types and different depths. Within each graph, the curve represents the fitted first order model (F.M.), while the points represent the curent data (A.D.), for total concentration of extractable mineral nitrogen (ammonium + nitrate + nitrite).

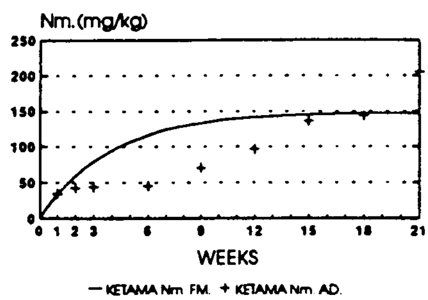
ROOT ZONE
Nm = 104 (1 - EXP(-0.221 t))



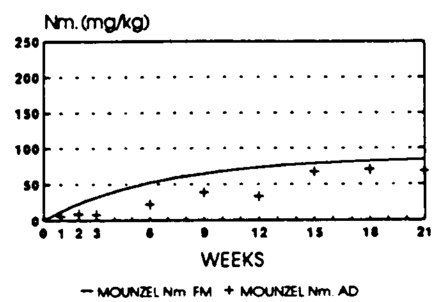
ROOT ZONE
Nm = 88 (1 - EXP(-0.147 t))



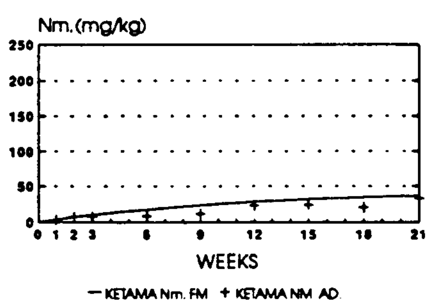
A HORIZON
Nm = 148 (1 - EXP(-0.253 t))



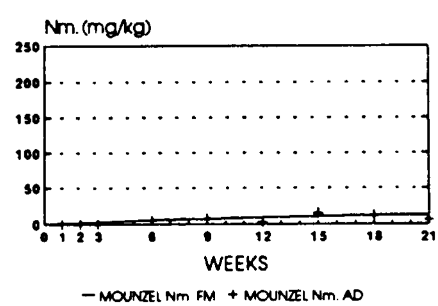
A HORIZON
Nm = 88 (1 - EXP(-0.147 t))



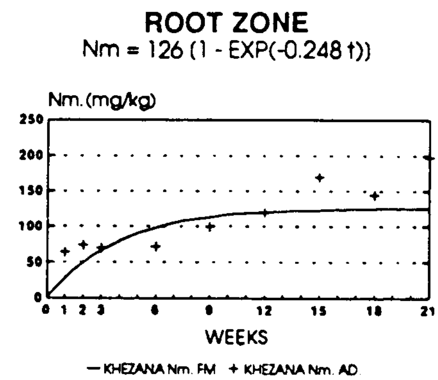
B HORIZON
Nm = 45 (1 - EXP(-0.078 t))

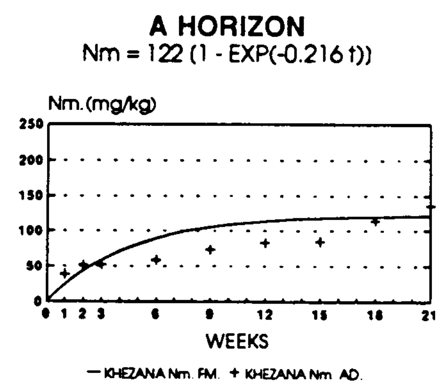


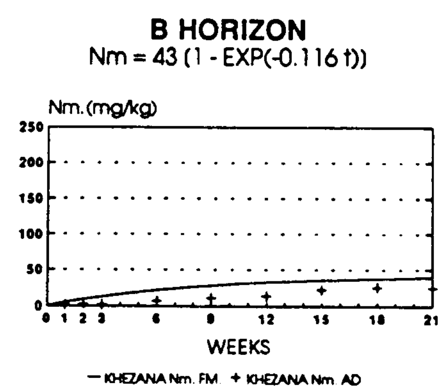
B HORIZON
Nm = 18 (1 - EXP(-0.055 t))



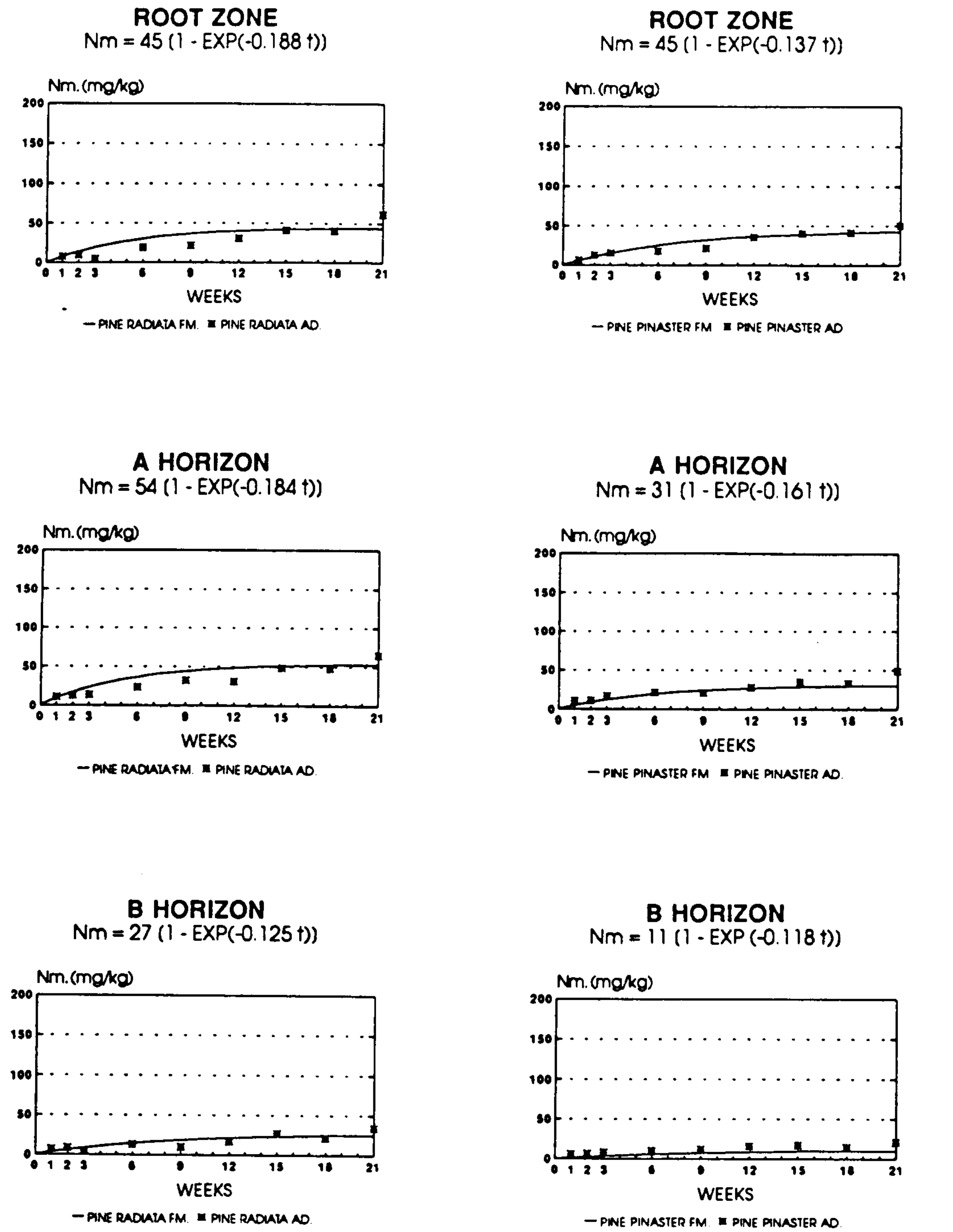
Appendix 1: Continued.





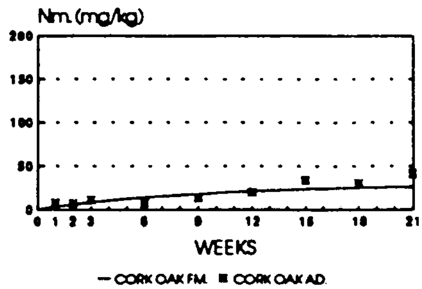


Appendix 1: Continued.

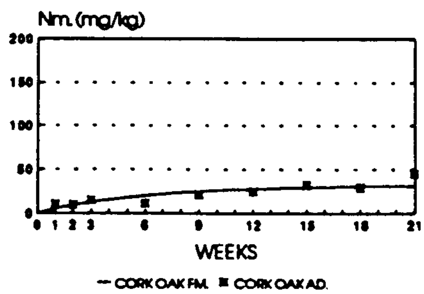


Appendix 2: Fitted models (F.M.) and current data (A.D.) of the principal forest stands around Aïn Rami nursery, for total concentration of extractable mineral nitrogen (ammonium + nitrate + nitrite).

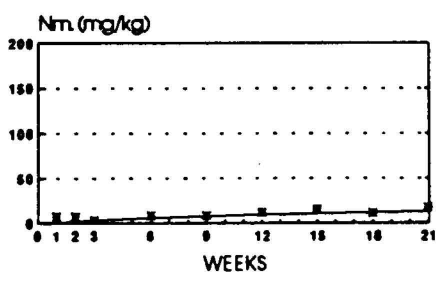
ROOT ZONE
Nm = 29 (1 - EXP(-0.108 t))



A HORIZON
Nm = 32 (1 - EXP(-0.160 t))



B HORIZON
Nm = 17 (1 - EXP(-0.064 t))



Appendix 2: Continued.