Soils of the jurassic formations in the central Algarve, their occurrence, distribution, genesis and site qualities

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RESUMO

Palavras-chave: Solos — Génese — Jurássico médio e superior — Algarve.

Diferentes tipos de solo formaram-se no Algarve central, em função do material de origem, do relevo e da erosão recente. São descritos os padrões gerais de ocorrência e da distribuição dos diferentes solos. Foi estimada a idade de um «eutric Nitosol», e estudada a relação entre o solo e o material de origem. Como exemplos, alguns tipos de solos foram descritos com base nas propriedades químicas e físicas. O balanço hídrico dos solos é apresentado de modo geral, com considerações visando a alimentação do lençol freático e a descarga, em função do clima e para diferentes sítios.

RÉSUMÉ

Mots-clés: Sols — Genèse — Jurassique moyen et supérieur — Algarve.

En Algarve centrale les différents types de sols sont liés à la nature du materiel originel, à leur situation dans la topographie et au rôle de l'érosion récente.

Les conditions d'occurence et de distribution des différents sols sont décrits. L'âge d'un «eutric Nitosol» a été estimé et on a étudié le rapport entre le sol et son materiel originel.

Quelques exemples de sols sont décrits avec leurs propriétes chimiques et physiques. Le bilan d'eau des sols est presenté de façon génerale avec des remarques sur l'alimentation de la nappe phréatique et de son écoulement en fonction du climat en différentes stations.

ABSTRACT

Key-words: Soils — Genesis — Middle and Upper Jurassic — Algarve.

In the central Algarve different soils have developed dependent on petrography of the parent material, slope position and recent erosion. The general patterns of occurence and distribution of different soils are described. The age of an eutric Nitosol is estimated and the relation between the soil and the parent material is investigated. Some different soils are described as examples with their chemical and physical properties. The water budget of soils is described in general with considerations concerning ground water recharge and run-off as well as in dependence of climate and of different site conditions.

1. INTRODUCTION

Soils derived from Jurassic limestones are the most common source for agricultural land-use in the Algarve. From the many abundant field terraces one may estimate, that in the past the soils were used much more intensively than in the last decades, especially in hilly regions. One of the most important factors limiting successful use of the soils in the Algarve, is the climate with water deficiency for many crops which could otherwise bring high benefits. Stony and rocky sites, as well as shallow soils very common on slopes and due to severe erosion, are also limiting factors.

Since improved techniques are being used to provide more groundwater for irrigation the area of intensive use is recently expanding in great extent from the south to the hilly north. As the amount of available water for irrigation increases by construction of dams or artificial groundwater recharge, the pressure on the landscape will also increase and attain sites with minor qualities, probably accompanied by a growing instability of ecological functions.

The purpose of this paper is to describe general properties and development of soils derived from jurassic limestones as well as first results of field measurements concerning the water regime of soils in the Algarve.

2. MATERIALS AND METHODS

This paper refers to a mapped area of about 450 ha's around St. Barbara de Nexe [using FAO classification (FAO-UNESCO, 1974) and detailed analysis of 14 profiles with a total of 48 horizons].

Analysis of the water regime was done by measuring the soil moisture directly with tensiometres (wet conditions) and indirectly with gypsum electrodes (moist conditions). The chemical analysis were carried out according to E. SCHLICHTING & H. BLUME (1966) with the following modifications:

- Particle size analysis according to E. SCHLICHTING & H. BLUME (1966) after H_2O_2 and HCl treatment as well as without carbonate dissolution.
- Conductimetric analyses of total carbon by oxydation of the samples at 1000°C using a WÖSTHOFF-apparatus.
- Conductimetric analyses of carbonates after digestion with H_3PO_4 at 80°C using a WÖSTHOFF-apparatus.
- Analysis of dolomite by HCl-extraction of Ca and Mg at 100°C using atomic absorption spectrometry (Mg) and flame photometry.
- Analysis of potential cation exchange capacity according to C. BOUWER *et al.* (1952) exchange with Na-acetate at pH 8,2.
- Analysis of exchangeable cations according to C. BOUWER *et al.* (1952) exchange with NH_4-acetate at ph 7.
- The extraction with ammonium-oxalate oxalic acid mixture at pH 3,25 room temperature and in darkness according to Tamm & Schwertmann.
- The extraction with sodium dithionite-citrate at pH 7,3 according to Mehra & Jackon.
- Clay mineral analysis fraction ($< 2\,\mu m$) after HCl-dissolution of carbonates down to pH 4-5 on sediment samples, using X-ray diffractometry. Samples where saturated with Mg, K and ethylene glycol as well as heated at 200, 400, and 560°C.
- Water retention was determined with pressure plates, using undisturbed samples for retention < 3 bar.

3. VARIATION, GENESIS AND DISTRIBUTION OF SOILS AND THEIR DEPENDENCE SOIL FORMING FACTORS.

Soils from different areas although generally developed from similar geological formations, may show a great variability, dependent on the conditions during their development. As a first attempt five main factors were chosen to explain the soil variability within the geological formations of the jurassic marls, limestones and dolomites from the series J2 to J5:

- lithological facies
- climatical aspect
- slope position
- time of development
- site management

All these factors influence in different ways and increase soil erosion. However, the dimension of soil erosion varies

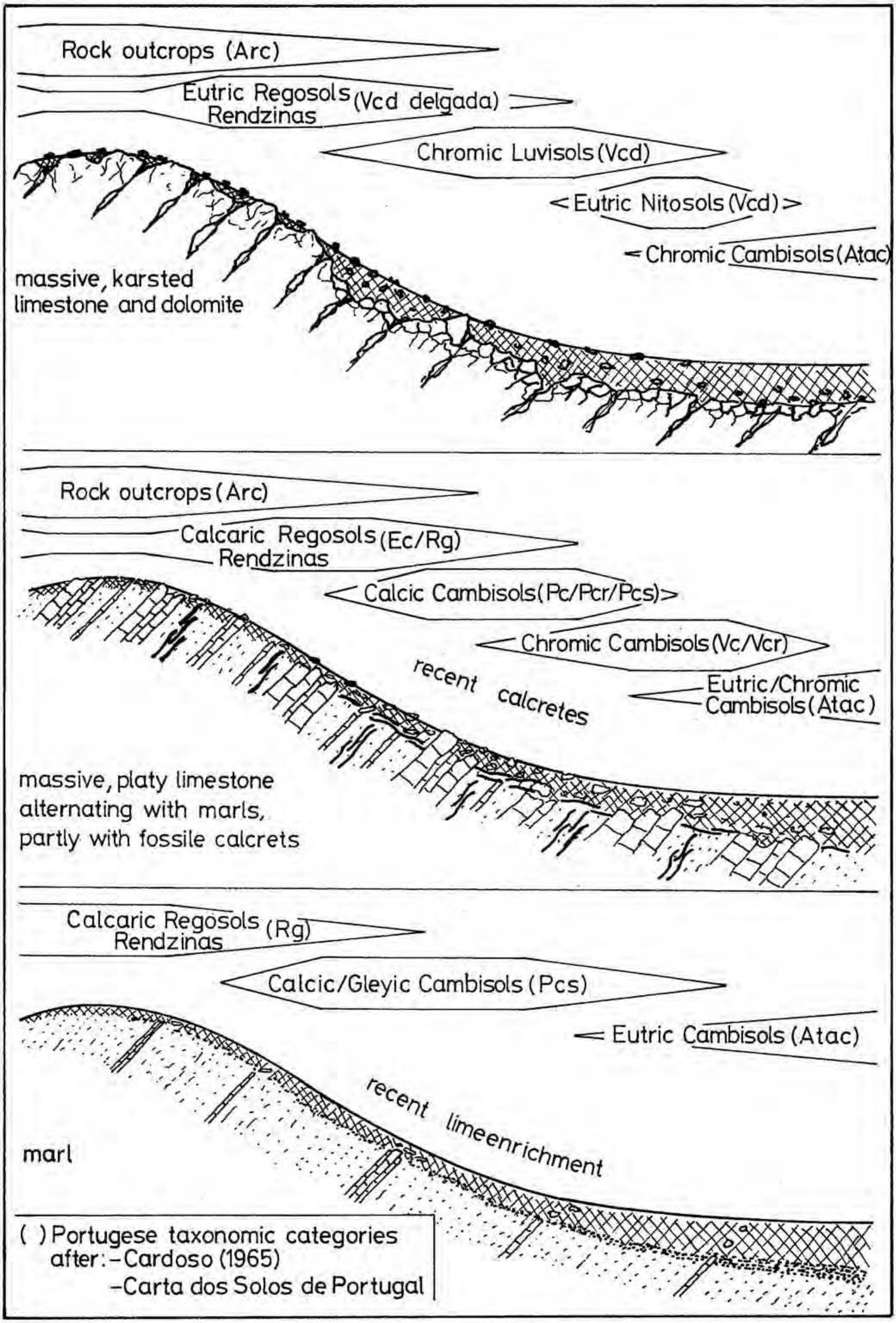

Fig. 1 — Occurence of soils and their distribution in dependence of facies of parent material and slope

very strong among the soils derived from carbonatic parent material with more or less the same chemical and mineralogical properties.

As can be seen in fig. 1, the occurence of soil types is greatly related to slope position and facies of limestone, where in the first instance facies means erodibility and massivity of the stones (see also STAHR *et al.*, 1984).

According to the degree of erosion, fairly old and well developed soils known as terra rossa (chromic Luvisols) typical for limestone weathering in mediterranean climate, are found within areas of massive limestones and dolomites with deep karst clefts and with rock outcrops limiting erosion.

From the weakest and most unstable material, silty to clayey marl, Regosol and shallow Cambisols are derived recently.

The most important soil forming processes in relation to the climate are carbonate dissolution, rubefication, clay movement and formation of peds.

According to B. MEYER & W. KRUSE (1970), rubefication is related to carbonate dissolution. Due to the carbonatic environment, usually no acid reaction will be present during soil formation and therefore no movement of iron will occur. To check the budget of unsoluble minerals and iron within the authochthonous part of an eutric Nitosol (70-150 cm) clay and iron relations of soil and of parent material (dolomite of J4) are shown in the following table 2:

Dolomite		Eutric Nitosol (70-150 cm)	
massive HCl residual (clay + silt)	: 1,16 % 1	clay + silt − (Fe_d · 1,59) : 902 kg	1
HCl soluble Fe	: 0,086 % 0,074	Fe_d	: 71 kg 0,079

As the table shows, the relation between clay + silt and Fe is more or less the same in both the parent material and the soil. With a bulk density of 2,55 g/cm^3 and a massive HCl residual of 1,16% of the dolomite, around 40 m^3 dolomite must dissolute to form 1 m^3 of soil.

We used measured concentrations of about 2 mval Ca/l and 2 mval Mg/l with in the soil solution caused by natural rainfall. In the groundwater, the concentration of Ca and Mg is normally around 3 mval for Ca and Mg and therefore about 0,3 g of dolomite will be dissoluted in each litre of soil solution passing the soil. Calculating with about 200-300 mm groundwater recharge/year, approximately 60-90 g dolomite will be dissoluted each year in the present climatic conditions.

Therefore, around 1,4 milions of years are neccesary to dissolute 40 m^3 dolomite and form 1 m^3 soil. Considering moister conditions in the past and including some marly bands with much quicker weathering usually occuring between the dolomite layers, it would seem that the time until the begin of the middle pliocene would have been enough to form the soils found today.

The rubefication of the typical red mediterranean soils is caused by the forming of goethite and hematite, where by the goethite/hematite ratio governs the soil colour from yellow to red. X-ray diffraction analysis shows that almost all of the goethite and hematite occurs within the clay fraction. The very high cristallinity of the iron oxides is

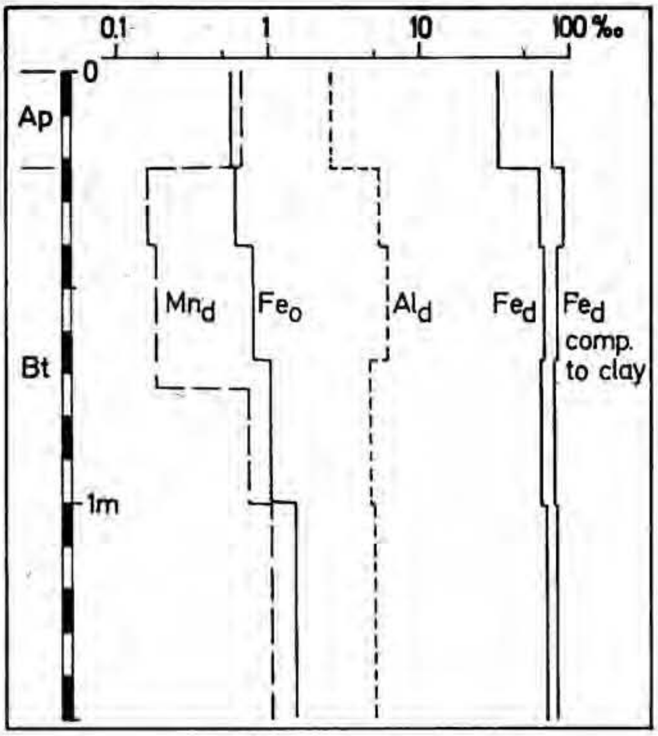

Fig. 2 — Depth function of dithionite citrate soluble Fe, Al, Mn and oxalate soluble Fe of an eutric Nitosol derived from dolomite

characterized by the very low Fe_0/Fe_d ratio (BLUME & SCHWERTMANN, 1969) of about 0,02. An amount of about 10 % iron oxides taken as Fe OOF was measured (fig. 2).

In fig. 3, for exemple, X-ray diffractograms (clay fraction) of the HCl residual of a dolomite, and of a B_t horizon derived from the same dolomite are shown. In both samples the great amount of kaolinite (7.2 and 3.57 Å) and illite (10,5, 3,3 Å, stable at 550°C) is obvious. Only traces of expandible layer silicates are present. As can be seen on the dolomite diagram, some vermiculite shifts the right shoulder of the 10 Å peak after Mg^{++} and ethylene glycol saturation into the 14 Å region, and a 4,7 peak occurs.

The lower intensities and the B_t-diagram are caused by disordering of the original proper cristallisation under soil conditions, and by back scattering and mass absorption to oxide enrichment. The changing ratio between kaolinite and illite from the dolomite sample to the B_t sample with higher kaolinite contents in the B_t horizon may be due to desilification of illite and forming of kaolinite during soil development.

Goethite and hematite are characterized by the 4,18 and 2,69 Å lines. Only traces of goethite were found in the dolomite sample, but a great amount of goethite and hematite in the B_t sample. The iron is bound in the dolomite partly as carbonate or dissoluted with the carbonate destruction. Clay movement als well as swelling and shrinking formed shiny surfaces on polyedric peds, which characterize the B_t-horizons of Luvisols and Nitosols. Normally no eluvial horizons are found above argillic horizons due to erosion processes.

In many cases, rock type determines the drainage conditions of the soils (comp. fig. 4). The maximum drainage (within the range of precipitation of 400-600 cm) is reflected by slightly leached B_t-horizons above chalky formations. The base saturation of these horizons within the jurassic

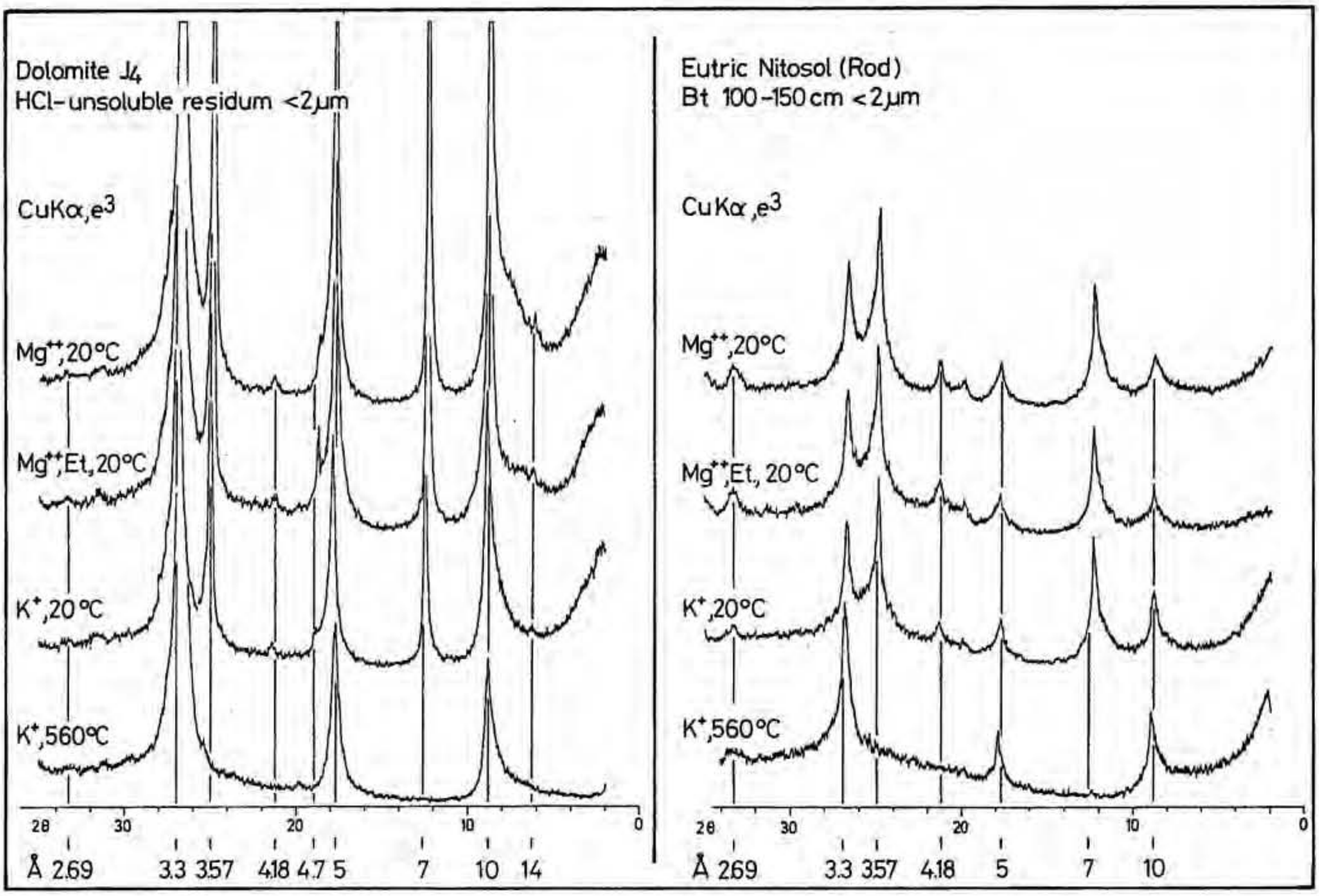

Fig. 3 — X-ray diffractograms of the HCl unsoluble clay of a dolomite and the clay of a Bt-horizon, derived from the dolomite

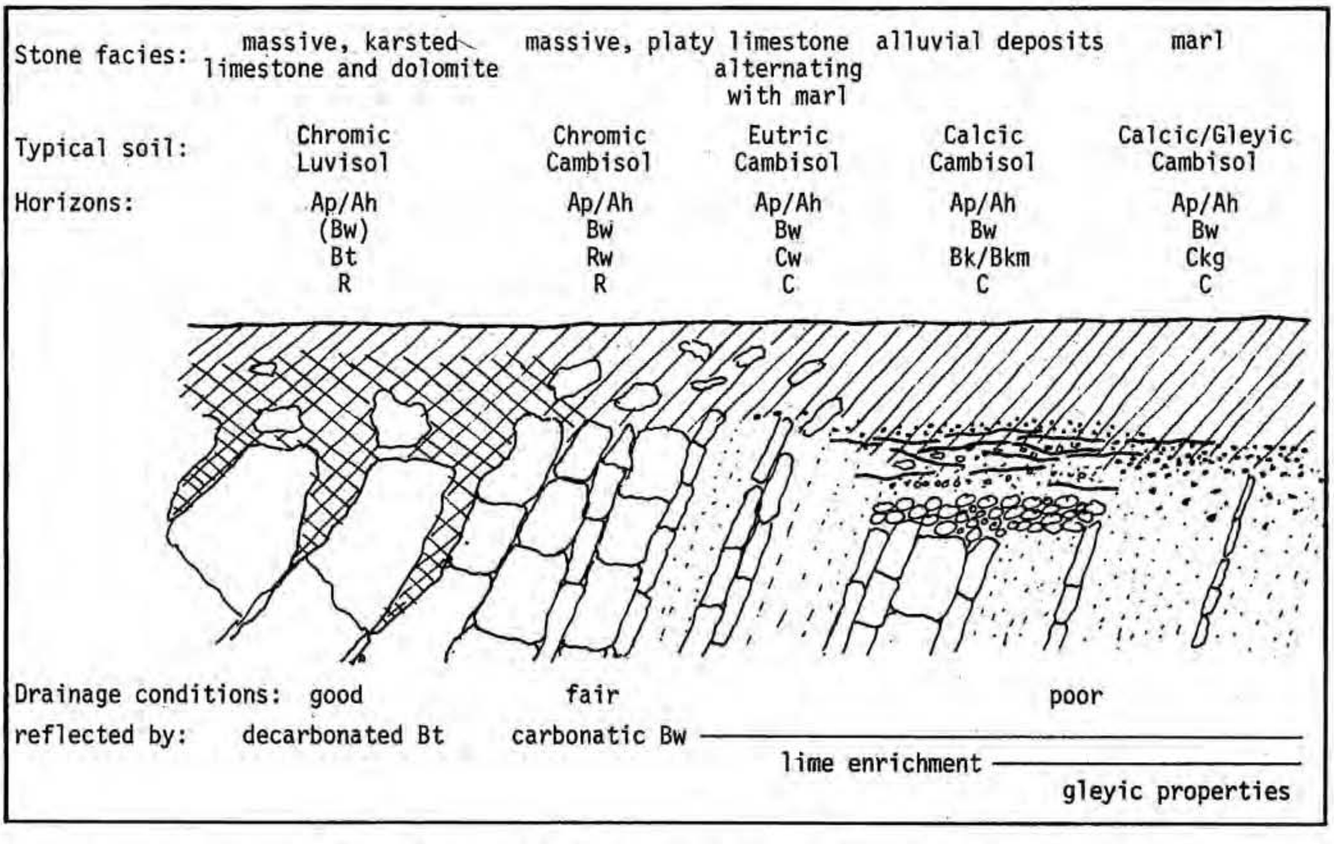

Fig. 4 — Combination of horizons of different soils, reflecting drainage conditions, dependent on facies of the parent material

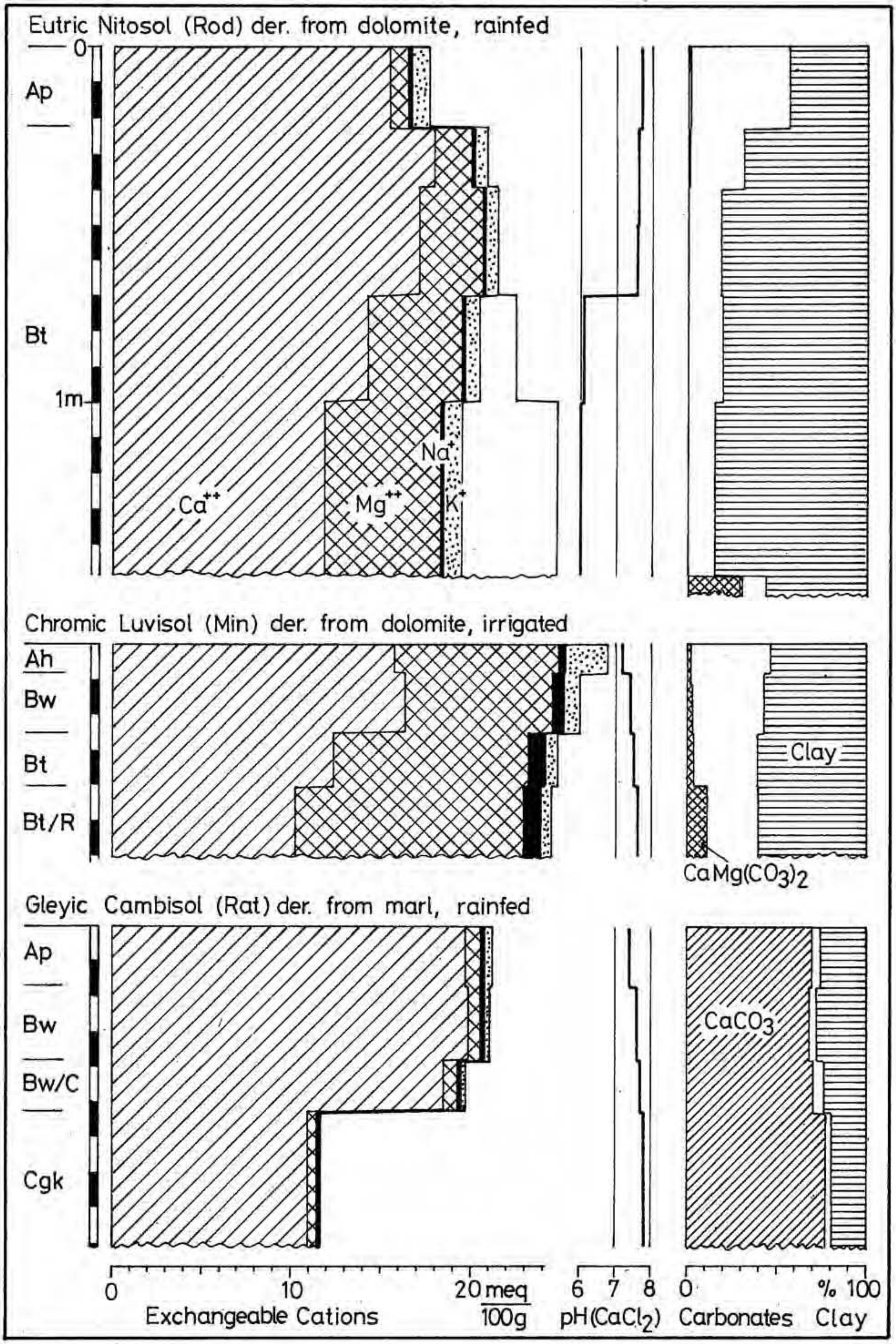

Fig. 5 — Depth functions of exchangeable cations, pH, carbonates and clay of three typical soils, derived from different material and under different agriculture use

formations will usually not decrease below 50%. A weak drainage leads to the Regosols and Cambisols with gleyic properties, derived from marls. Lime enrichments in soils from marl and above slightly cemented alluvial conglomerates also show limited infiltration rates. Enriched soluble salts caused by irrigation during the summertime will usually be leached during the rainy season.

The climatic variability influences the organic matter content and the soil moisture regime. The organic matter content in general is low within the research area, but there is a gradient related with increasing precipitation. At about 200-300 m above sea level topsoils change from ochric to mollic because they then meet the structure requirements.

4. CHEMICAL PROPERTIES

Due to the presence of carbonates in the whole environment within the area of jurassic sediments, no strongly leached soils do occur. Also in fairly old soils, which are decalcified, a base saturation less than 80% can not be observed.

Normally the exchange complex is still dominated by Ca. The Mg-saturation increases remarkably with the presence of dolomite, if the calcite content is low (fig. 6).

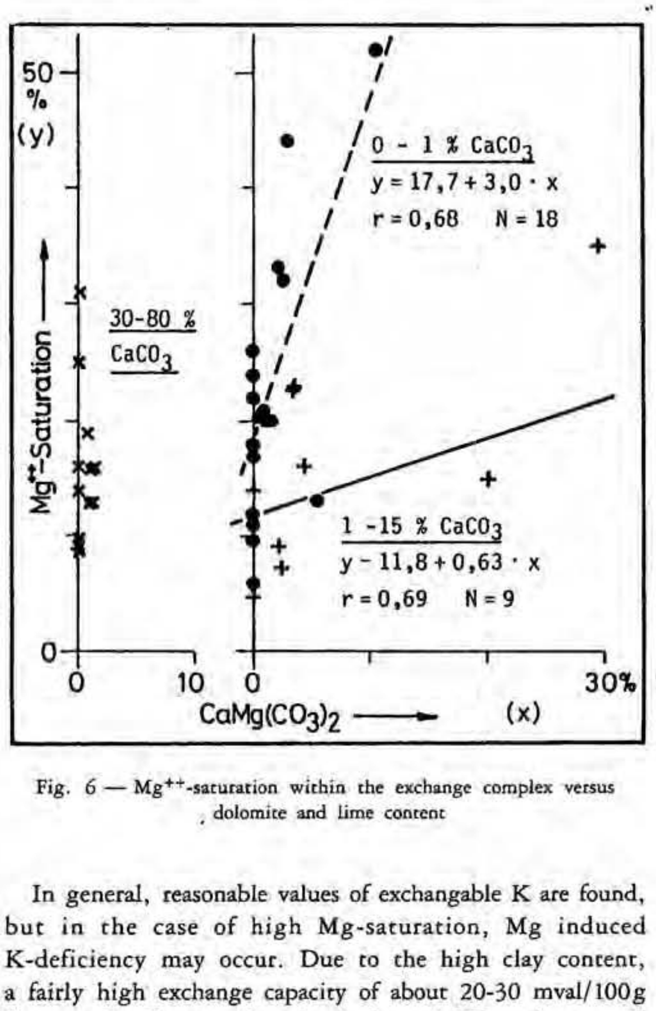

Fig. 6 — Mg^{++}-saturation within the exchange complex versus dolomite and lime content

In general, reasonable values of exchangable K are found, but in the case of high Mg-saturation, Mg induced K-deficiency may occur. Due to the high clay content, a fairly high exchange capacity of about 20-30 mval/100g fine earth characterizes Luvisols and Nitosols as well as altered red Cambisols. In relation to clay the content exchange capacities of around 30 mval/100g clay are considered to be low, due to the dominance of kaolinitic and illitic clay minerals.

In general, no pronounced enrichment of easily soluble salts could be found the whole year round. In irrigated plantations on well drained soils using irrigation water with an electrical conductivity below 1 mmhos the sum of soluble cations reach 1 mval/100 g soil as a maximum. The content of organic matter within irrigated citrus plantations and rainfed fruit plantations in the plains is medium to low, whereas on slopes with decreasing landuse intensity and increasing biomass of Garique and Macchia (also with cooler temperatures) the content of organic matter will increase. C/N ratios around 10 qualify the organic matter as favourable.

Fig. 5 shows as an example of depth functions of three different soils. The eutric Nitosol and chromic Luvisol are derived from dolomite and are characterized by high Mg-saturation of the exchange complex. Furthermore, the chromic Luvisol, irrigated since about 14 years has higher exchangable sodium. The minor development of the gleyic Cambisol from marl is characterized by a high concentration of lime and a relatively small content of clay (clay is determined after HCl treatment and computed back to lime containing fine earth).

5. PHYSICAL PROPERTIES

The physical properties, described by texture, density, pore size distribution, aggregation and soil depth, vary in relation to parent material and weathering stage of the soil.

Soils derived from massive limestone and dolomite are mostly heavy clayey soils and because of their higher age strongly aggregated to polyedric peds. The soil depth normally varies dependent on erosion processes.

A greater variability of texture is found in soils derived from marls due to their weathering stage. Within recently eroded sites the properties of the soil (Regosol) will be determined by the properties of the C-material with high contents of lime and silt. Soils derived from marl, with an higher degree of weathering (Cambisols, Luvisols) may have properties in the topsoil more or less close to soils derived from massive limestones. However, soils above marls are

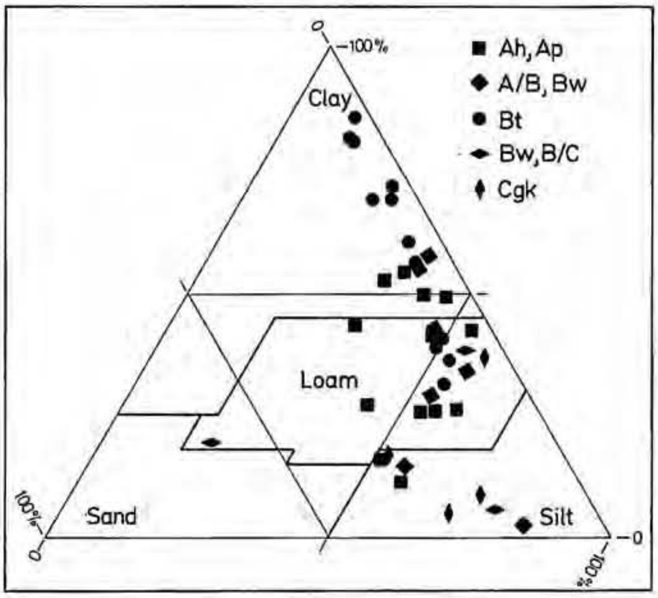

Fig. 7 — Texture of different horizons, derived from limestone, dolomite and marl (grain size analysis without carbonate dissolution)

characterised by worse drainage conditions in the subsoil as indicated by lime enrichment and gleyic properties.

Soils on alluvial deposits in foot hill situations are mostly characterized by the high content of gravels, which limit agricultural use. Fig. 7 shows the grain size composition of some horizons. Almost all soils have loamy and clayey textures. High contents of silt were found in soils with a low weathering stage on marl. In contrast, B_t-horizons may have clay contents up to 85 %. A-horizons, in general, contain some more sand either by loss of clay due to illuvation or selective erosion of clay and silt.

However, the weathering of the jurassic limestones, dolomites and marls led to clayey soils which in dry conditions are very hard and very sticky when wet. In any case they are rather difficult to till and manage for plant cultivation. As a result of the clay content formation of peds by swelling and shrinking, high bulk density and microaggregation by oxides are special reasons for the typical pore size composition of mediterranean soils. As shown in fig. 8 the pore size

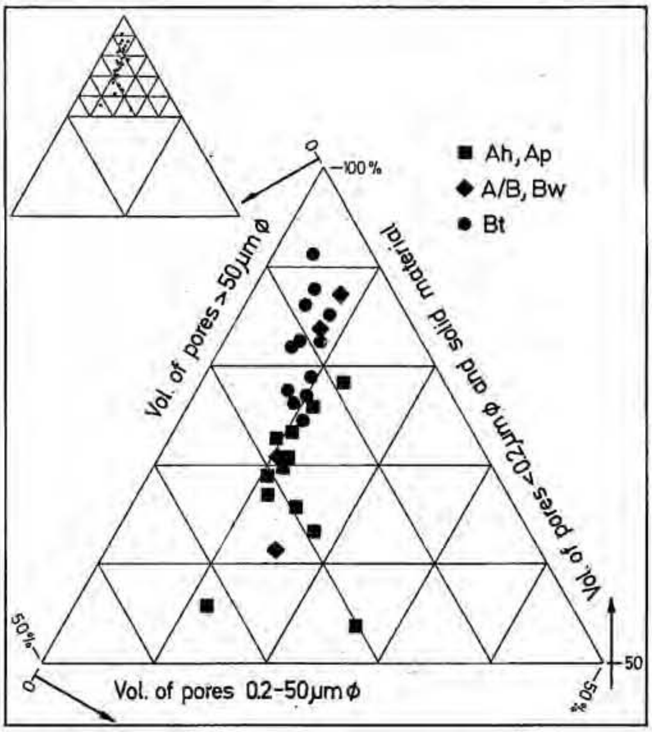

Fig. 8 — Pore size composition of different horizons, derived from limestone, dolomite and marl

distribution varies within a wide range. As a rough approximation the following rages were found:

	Draining pores Vol %		Pores holding plant available water		Pores holding plant unavailable water
pF:		1,8	Vol %	4,2	Vol %
Pore size (µm)		50		0,2	
Ah, Ap	10-30		10-25		10-25
A/B, Bw	5-25		8-15		13-27
Bt	5-15		4-10		20-35

The general characteristics are:

— A relatively great amount of coarse pores, which control infiltration of water, even within clayey B_t-horizons.

— The pores retaining plant available water, most important for agriculture use, are present to a considerable level only in silty soils derived from marl, but are few whithin the B_t-horizons of Luvisols and Nitosols.

— Because of the high clay contents, the amount unproductive water bound at >15 bar is generally high, especially within B_t-horizons.

6. WATERREGIME

Due to the existing variability of soils, as described before, the parameters controlling the waterregime also have a great variability. Porosity, stone content and soil depth determine the storage capacity of water as well as drainage conditions.

As an example, fig. 9 shows the distribution of soils and pore volumes along a slope catena. In the landcape at the top of the hill, where rock outcrops and shallow soils are dominating, the total volume of pores found is about 45 $1/m^2$. At the bottom of the hill where deeper soils are wide spread, the total volume of pores increases to about 300 $1/m^2$. Therefore, the respective volume to store rainwater varies from about 30 to 200 $1/m^2$ at the end of the dry season within this catena.

The infiltration rates for rainwater also vary to a great extent, in dependence on cultivation practices. Infiltration rates of 60-1200 cm/day for different A-horizons and rates of <3 cm/day for B-horizons were measured with a double-ring infiltrometer. Therefore A-horizons normally may swallow heavy rains until total saturation before runoff occurs.

In wet conditions (4pF 1,8), a volume of about 20 to 40 $1/m^2$ in A-horizons is provided to take up rainwater within a short time. Consequently, runoff in brooks usually is observed after rain of approximately 30 mm.

The danger of runoff and therefore also of erosion within a qualitiv scale for different sites is as follows:

Runoff-probability:

low
— Frequently loosened Cambisols and Luvisols as mostly common under citrus plantations and rainfed managed fruit tree plantations.
— Maccie and garique with Cambisols, Luvisols, Rendzinas and Regosols (soil depth 30 cm), without rock outcrops.
— Rainfed fruit tree plantations with chromic/eutric Cambisols.
— Rainfed fruit tree plantations on Luvisols and gleyic/calcic Cambisols.
— Maccie and garique on soils with shallow depths (<30 cm) and high proportions on rock outcrops.
high
— Sealed areas (roads, housing areas).

Examplarily, fig. 10 shows the moistening and drying of an eutric Nitosol caused by the precipitation during the rainy season 1984/85. The Nitosol at wiltingpoint has a watervolume of 485 $1/m^2$ and a field capacity of 630 $1/m^2$, resulting in a volume of plant available water of 145 $1/m^2$.

This soil was completely moistened (all parts of the soil have pF $<1,8$ fieldcapacity) in the middle of December after a cumulative rainfall of 235 mm. From this date, 80 days

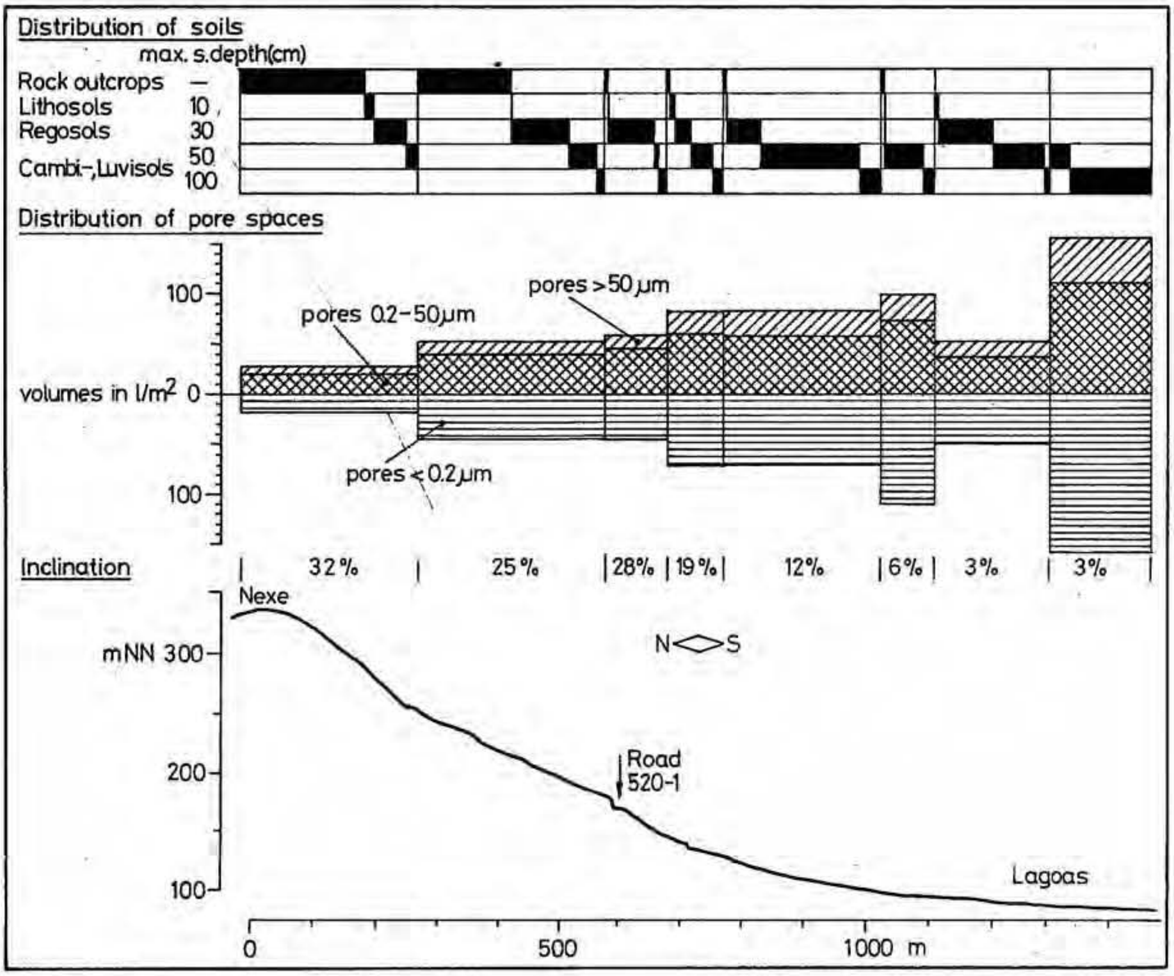

Fig. 9 — Distribution of soils and pore space volumes along a slope catena near St. Bárbara de Nexe

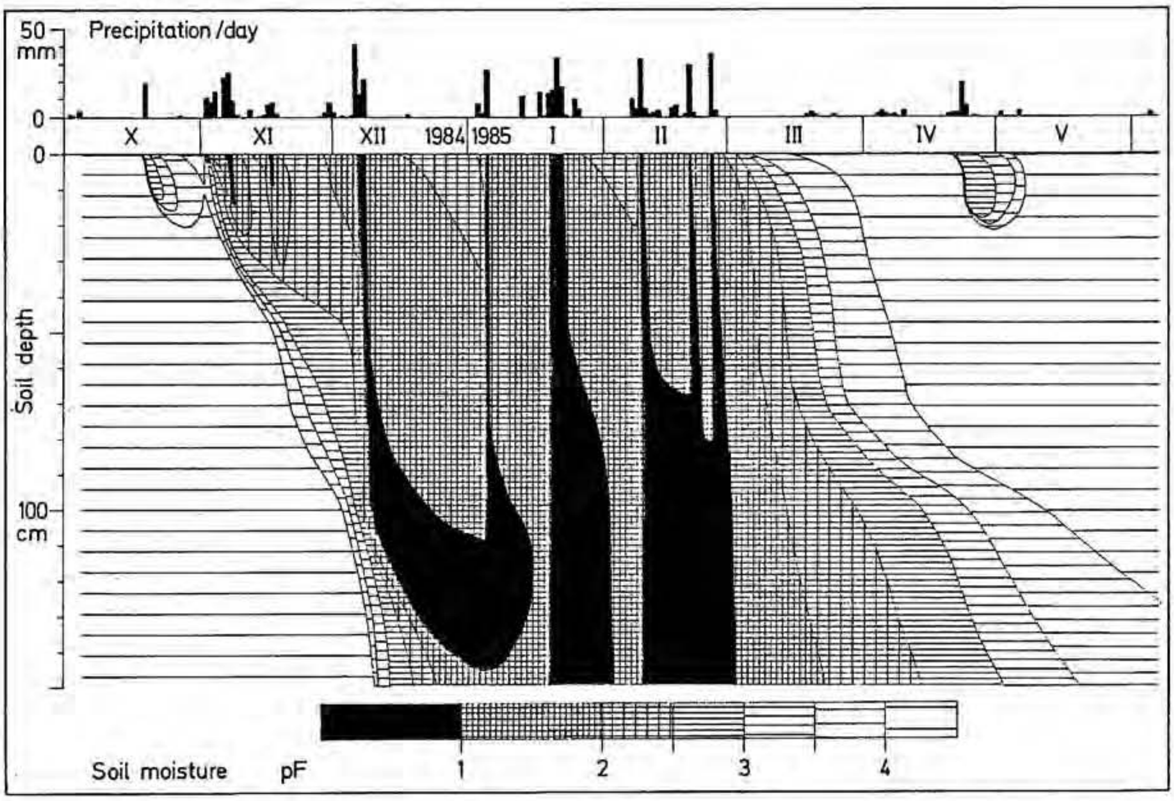

Fig. 10 — Precipitation and distribution of soil moisture within an eutric Nitosol during the rainy season 1984/1985

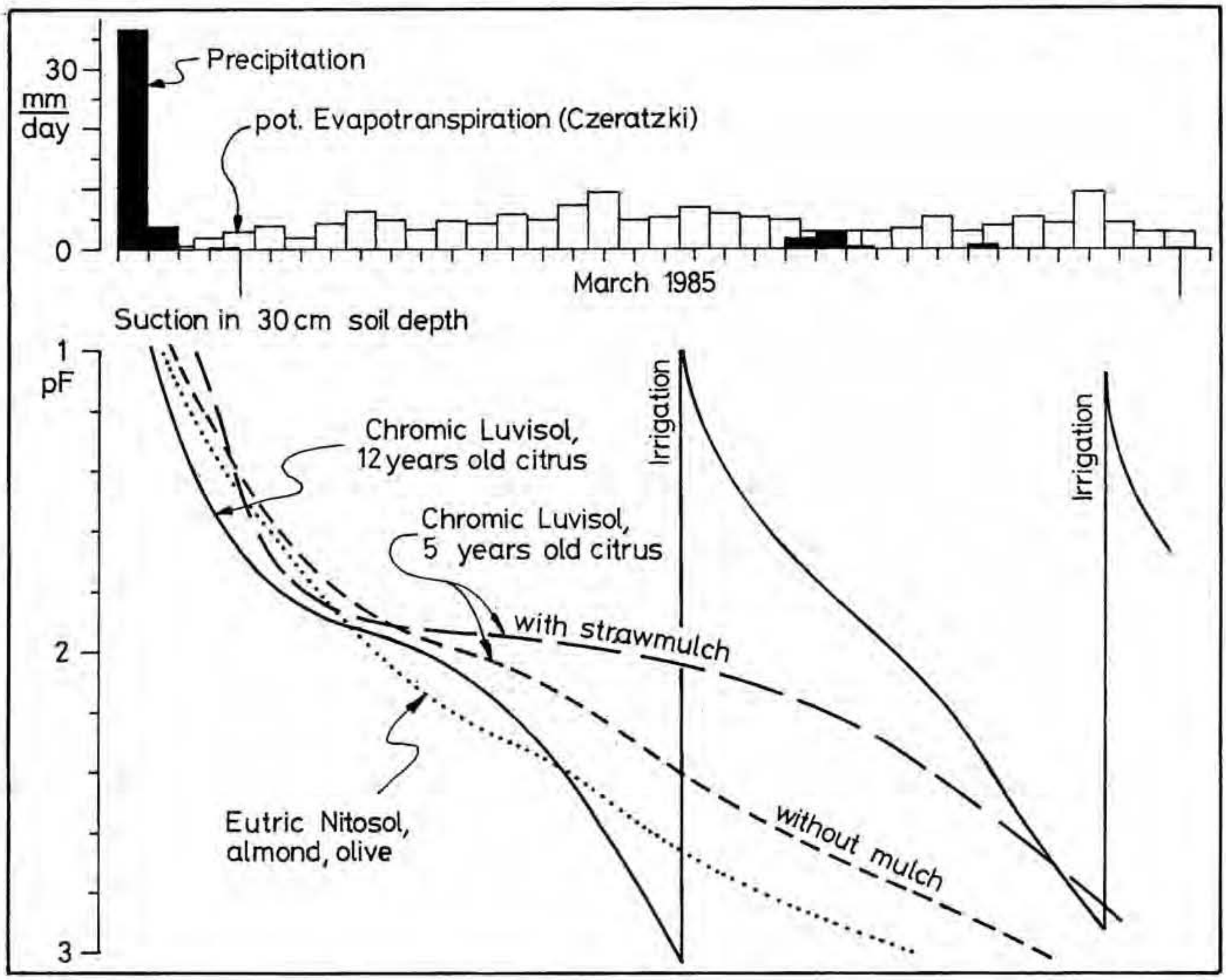

Fig. 11 — Precipitation, pot. evapotranspiration and moisture conditions for Nitosols and Luvisols under different managing practises

were counted with a pF value < 1,8 within the subsoil. This is about the period where moving water within coarse pores can reach the bottom of the soil and drainage towards the groundwater is possible. Reasonable runoff occurs for 6 days, allways caused by heavy rain with more than 20 mm within 24 hours or a shorter time.

Another very interesting point is the period where the soils dry out. As shown in fig. 10, heavy rain stops at the end of February and we observed a quick drying out of the soil in shallows depths. The drying is caused by evapotranspiration but the quick drying is forced by the very narrow volume of plant availabe water holding pores (pF 1,8-4,2) with less than 10% within B_t-horizons. We counted about 150 days from November to April where the soil is moist within the upper 70 cm.

Only in greater depths we found a longer period with moist conditions. However, the time of moist conditions may vary from soil to soil and also according to the management of farming. Fig. 11 shows the period of drying for different soils. We found a steeper drying curve in the rainfed managed Nitosol (almond and olive with low plant density) than in a chromic Luvisol under 12 year-old orange trees. On this site it was necessary to start irrigation already in the middle of March.

For comparison, we drew another line for a chromic Luvisol without mulch under only 5 year-old orange trees. The differences in both Luvisols are mainly given by differences of plant-consumption, but also by small differences in the pore size distribution. Finally, the gentlest curve was found in a chromic Luvisol, also under 5 year-old orange trees, but with straw mulch on the soil. At measuring time, the mulch was not in the best condition (due to the rainy season), however, distinct differences between a site with and without straw mulch are determinable. As a rough estimation for the whole growing season, it will be possible to save about one third of irrigation water by this measure. This amount may decrease in older orange farms, because the plant consumption becomes more important in relation to evaporation.

8. ACKNOWLEDGEMENTS

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REFERENCES

BLUME, H. P. & SCHWERTMANN, U. (1969) — «Genetic evaluation of the profile distribution of aluminum, iron and manganese oxides». *Soil Sci. Soc. Am. Proc.*, Madison, n.° 33, pp. 438-444.

BOUWER, C. A.; REITEMEIER, R. F. & FIREMAN, M. (1952) — «Exchangeable cations of saline and alkali soils». *Soil Sci.*, Baltimore, n.° 73, pp. 251-261.

CARDOSO, J. C. (1965) — «Os solos de Portugal. 1 — A Sul do rio Tejo». *Secr. Est. Agric., D. G. Serv. Agric.*, Lisboa.

FAO-UNESCO (1974) — «Soil map of world». Vol. 1-Legend.

MEYER, B. & KRUSE, W. (1970) — «Untersuchungen zum Prozeß der Rubefizierung (Entkalkungsrötung) mediterraner Böden am Beispiel kalkhaltiger, marokkanischer Küstendünen». *Gött. Bodenkdl. Ber.*, Göttingen, n.° 13, pp. 77-140.

SCHLICHTING, E. & BLUME, H. P. (1966) — «Bodenkundliches Praktikum. Hamburg, Berlin (Parey), pp. 1-309.

STAHR, K.; GAUER, J. & JAHN, R. (1984) — «Bodenvergesellschaftung vom Mediterraneum in die Volllwüste». *Mitteil. Dtsch. Bodenkdl. Ges.*, n.° 40, pp. 223-230.

Carta dos solos de Portugal na escala 1/50000. Folha 53-A. *Min. Economia, Secr. Est. Agric.*, Lisboa.