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Water regime of doline soils in the mountains of Crete

Wasserhaushalt von Dolinenböden im Gebirge von Kreta

by

Bernhard R. EGLI

1. INTRODUCTION

Dolines are depressions without superficial discharge, formed by dissolution of calcium carbonate.

A large amount of water and fine material from the environment collects in the concave depressions. Thus the doline soils are usually very rich in clay and quite heavily compressed. Little vegetation or sometimes only some specialised ruderal plants can exist there, also as a result of periodic water logging between autumn and spring. Above 1000 m a.s.l. the dolines serve as grazing land and in the lower regions for agriculture.

The doline soils of the mountains of Crete belong in general to the cambisols and luvisols, in part with chromic or vertic tendencies, and as well in exceptional cases to the planosols. In the higher areas one finds that more belong to the rendzinas, regosols and lithosols.

The wide spectrum of soil types as well as the characteristic karst landscape of Crete with its abundance of doline forms offer an ideal basis for the ecological study of water availability. Until now practically nothing has been documented about the seasonal water management of the soils of Crete. HAGER (1985) has made a few trial tension measurements from which, however, no interpretation was provided.

In mountains up to 2500 m the climate is humid with an annual precipitation of 1000 to 2000 mm. In contrast, the coastal regions have a typical dry mediterranean climate with approx. 500 mm of precipitation annually. This precipitation occurs almost solely between November and April. A five to six months prac-tically precipitationfree period, also in the mountainous regions, results between May and October. (The vegetation and agriculture are affected accordingly).
The field work in Crete was carried out between April 1 - July 25, 1984, April 4 - July 25 and September 3 - November 27, 1985 and May 13 - August 26, 1986. During the research years of 1985 and 1986 there was markedly little precipitation (i.e. little snow during the winter, the end of the spring rains was early and the beginning of the autumn rains was late).
This work constitutes the soil physical basis for the author's dissertation on the vegetation and ecology of dolines in the mountains of Crete carried out at the University of Zurich in collaboration with the Free University of Berlin and the Federal Institute of Technology in Zurich as a project supported by the Swiss National Science Foundation, Project No. 3.575.0.83.

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2. VEGETATION

In the mountainous regions of Crete the forest reaches 1500 m altitude on the northern side and 1800 m on the southern side. Over that the vegetation is characterized by shrubs of *Berberis cretica* and representatives of thorny-cushion plants as *Astragalus angustifolius, A. creticus* and *Acantholimon ulicinum*. The uppermost zones with scanty screes contain a high proportion of endemics.
In dolines with a flat ground where high amounts of soil collects, a group of specialized plant species could establish. In comparison the vegetation of the doline slopes do not differ clearly from the surroundings. For the relations between these characteristic doline plants and the main soil factors see EGLI (1988).

Table 1. Important plant species of the investigated dolines.
Wichtige Pflanzenarten der untersuchten Dolinen.
Nomenclature after BARCLAY 1986 - *Nomenklatur nach BARCLAY 1986*
* = Cretan endemic - *kretischer Endemit*
Life forms according to - *Lebensformen nach MÜLLER-DOMBOIS and ELLENBERG 1974*

PLANT SPECIES		LIFEFORM	NO.DOLINE									EG
			1	2	3	4	5	6	7	8	9	
Polygonum arenastrum s.l.		T r		x	x	x	x	x				
Spergularia lycia		T s			x	x						
Hypericum kelleri	*	Ch f r			x	x						
Polygonum idaeum	*	Ch f r	x	x								a
Scleranthus verticillatus		T s	x									
Mentha pulegium		H r			x							
Trifolium micranthum		T r			x							
Gagea fibrosa s.l.	*	G b		x								
Herniaria parnassica subsp.cretica	*	H r	x	x		x	x	x	x	x		
Lepidium hirtum subsp.oxyotum		H s	x	x		x	x	x	x	x		
Trifolium uniflorum		H c	x	x		x	x			x	x	
Anthemis rigida		T r	x	x	x					x	x	b
Pimpinella tragium subsp.depressa	*	H c	x	x		x	x	x				
Cichorium spinosum		Ch s p	x		x							
Romulea bulbocodium		G b			x							
Atriplex patula		T r	x	x	x	x			x			
Corrigiola litoralis		T r			x							
Convolvulus arvensis		H r									x	c
Crassula tillea		T r			x							
Lythrum hyssopifolia		T r			x							
Crocus sieberi subsp.sieberi	*	G b	x			x	x	x	x			d
Scilla albescens	*	G b	x	x				x	x			
Anthemis abrotanifolia	*	H r						x	x	x		e
Scabiosa sphaciotica	*	Ch h r		x					x			
Asparagus aphyllus		G r		x						x	x	
Senecio fruticulosus	*	Ch s s					x					f
Alyssum fragillimum	*	H s					x					
Geocaryum creticum	*	G r						x				
Erophila verna subsp.praecox		T s	x	x		x				x	x	
Galium murale		T s	x	x	x					x	x	
Myosotis incrassata		T s	x	x						x	x	g
Petrorhagia velutina		T s	x	x	x						x	
Crepis cretica		T s	x	x		x					x	
Berberis cretica		Ch f c	x	x	x	x	x	x	x	x		
Centaurea idaea	*	H s	x	x	x	x		x	x	x	x	
Dactylis glomerata subsp.rigida		H c	x	x	x	x		x	x	x	x	
Cirsium morinifolium	*	H s	x	x		x	x	x	x	x		
Satureja alpina subsp.meridionalis		Ch s r	x	x		x	x	x	x	x		
Prunus prostrata		Ch f r		x		x	x	x	x	x		
Asperula idaea	*	Ch s s		x		x	x	x	x	x		h
Carlina corymbosa subsp.curetum		H s	x	x		x				x	x	
Anthoxanthum odoratum		H c	x	x	x	x				x		
Poa bulbosa		G rh	x	x	x					x	x	
Astragalus creticus		Ch f p	x					x	x	x		
Eryngium campestre		T s	x	x						x	x	
Colchicum cretense	*	G b	x	x		x			x			
Acantholimon ulicinum		Ch f p	x			x	x					
Taraxacum megalorhizon		H s	x	x		x	x	x	x	x	x	
Tolpis virgata		H s	x	x	x					x	x	
Hypochoeris tenuiflora	*	H s				x	x	x	x			i
Trifolium physodes		H r	x		x					x	x	
Scilla autumnalis		G b	x	x	x	x						
Acer sempervirens		P s								x	x	

Table 1 (continued)
Ecological groups - *Oekologische Gruppen:*
a = characteristic doline plant species - *charakteristische Dolinenpflanzenarten*
b = preferably on deep clayey soils - *vorwiegend auf tiefgründigen tonreichen Böden*
c = ruderals - *Ruderalpflanzen*
d = along snow patches - *entlang Schneeflecken*
e = preferably on gravelly banks - *vorzugsweise auf steinigen Flächen*
f = preferably between stones and rocks - *vorzugsweise zwischen Steinen und Felsblöcken*
g = annuals - *Annuelle*
h = surroundings - *Umgebungspflanzen*
i = without relation - *unspezifische Pflanzen*

3. MATERIALS AND METHODS

3.1. GRAVIMETRIC WATER CONTENT

In the years 1984 - 1986 a total of 218 soil samples were taken from 178 dolines at depths of 10 cm. The gravimetric water content (GWC [Fresh weight - dry weight] / dry weight) was determined by means of drying at 105°C. For the investigation of the top most level of soil, cylindrical soil samples of 15 cm length were removed and slices of 1 cm thick were cut off and weighed.

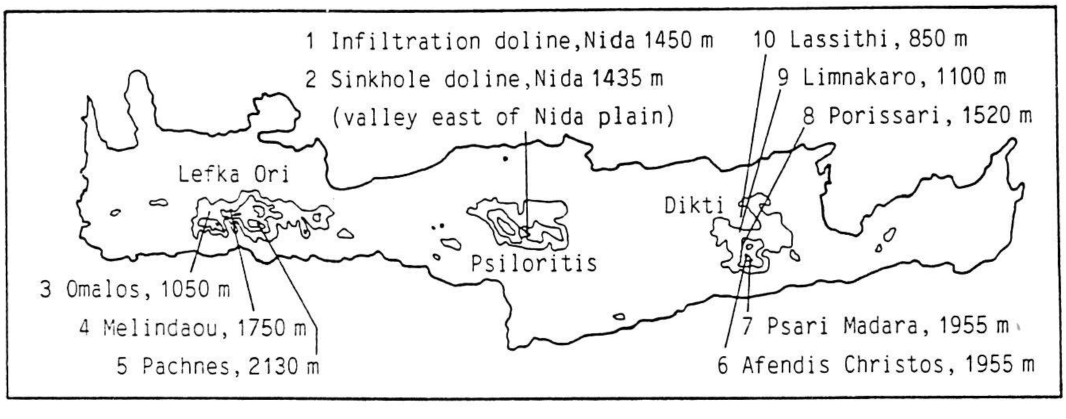


Fig. 1. Crete with the three main massifs (Lefka Ori 2453 m a.s.l., Psiloritis 2456 m and Dikti 2143 m) and the examined places No. 1-10. Contour lines of 1000, 1500 and 2000 m a.s.l. *Kreta mit drei Huptgebirgsmassiven (Lefka Ori 2453 m, Psiloritis 2456 m und Dikti 2143 m ü.M.) und den untersuchten Flächen Nr. 1-10. Höhenlinien von 1000, 1500 und 2000 m ü.M.*

3.2. SOIL MOISTURE CHARACTERISTICS

The method used to determine soil moisture characteristics is described by RICHARDS (1949). The water content of the sample soils were determined in the laboratory at the following pressure levels: 1, 40, 160, 345, 690 and 800 mbar, as well as at 5 and 15 bar. For the pressure up to 800 mbar the porous stainless steel and ceramic plates were used. For 5 and 15 bar the water content was determined with a pressure membrane apparatus. As a control, reference soils with known water content were measured concomittantly with the sample soils.

3.3. MATRIC POTENTIAL

The most suitable instrument for measuring the matric potential in the field is the tensiometer (CASSEL and KLUT 1986). The disadvantage of the old-fashioned tensiometer is its use of mercury as manometer liquid. For this reason the tensiometer with pressure transducer manometer was developed by the Department of Soil Physics of the Swiss Federal Institute of Technology in Zurich (MARTHALER et al. 1983). The water in the soil is absorbed through a porous ceramic cup. Instead of mercury as manometric liquid a cushion of air on top of a water column is used. The pressure in this cushion is measured by a pressure transducer containment.

The confidence limits of the measurements are about 5 mbar. The total possible range for the measurements is from 0 to -900 mbar. This method is simple but the maintenance is time consuming and the instrument electronics are delicate.

In order to avoid the adverse affect on the measurements due to direct sunlight on the tubes and any damage caused by men and cattle, the tubes were completely buried in the ground. The field measurements were made using groups of four tensiometers per selected area with cups at 30 cm, 40 cm, 70 cm and 120 cm depth. In the first measuring period in 1985 three such blocks in one meter distance from each other were installed in doline No. 1. They showed a very good reproducibility of the results due to the good uniformity of the soil profiles and practically no precipitation. Therefore it seemed acceptable to use only one measuring block per doline for the following periods (autumn 1985 and spring to summer 1986).

4. RESULTS AND DISCUSSION

4.1. GRAVIMETRIC WATER CONTENT

The water contents show big variations due to the very big differences between the sampling points, more pronounced at higher levels than at the lowest. The drying out rates become progressively flatter at higher levels (Fig. 2).
The values for doline 5: Pachnes, 2130 m in Fig. 3a and b of the water content in the soil profile show only minor changes when the vegetation is sparse (10% of the area covered with herbs), despite a dry period over two and a half months without any measurable rain. The uppermost soil layer dries out very rapidly due to intensive radiation and thus develops an effective evaporation barrier, because the conductivity in dry soils decreases very rapidly. This physical phenomenon is described by PHILIP (1957). The amount of rain was low, as usual during the summer months, so that it penetrated into the soil only a few cm (see the water content directly before and after two hours of slight rain in Fig. 3d and e). Because at this time of the year bad weather never lasts for longer than 1 to 3 days, shortly afterwards practically the whole amount of precipitation evaporates. On the whole the infiltration of water into the soil is negligible between late spring and autumn.

4.2. SOIL MOISTURE CHARACTERISTICS

At high water contents from saturation at -1 mbar until -80 mbar field capacity the curves of Fig. 4a-c and Fig. 5c run relatively flat. In addition at these sampling points large total pore volumes from 55 up to 65% are observed. Both aspects mean a big acceptance and storage capacity for rain water as well as a good air regime. The corresponding relatively dense vegetation of 80-95% coverage is striking. On the other hand, the curves from Fig. 5a and b show large slopes for wet soils. Furthermore the relatively low total pore volumes of 48 and 50% show a lack of coarse pores. The reason for this can be found in the soil compression: in the sinkhole due to the deposition of fine material, suspended in water; on the flat places due to intensive compacting by sheep trampling. As a consequence, the capacity for the uptake of rain water and the access of air is reduced. This may be the reason for a low plant coverage of only 1-30%, despite the higher amount of available water, compared with doline No. 1.

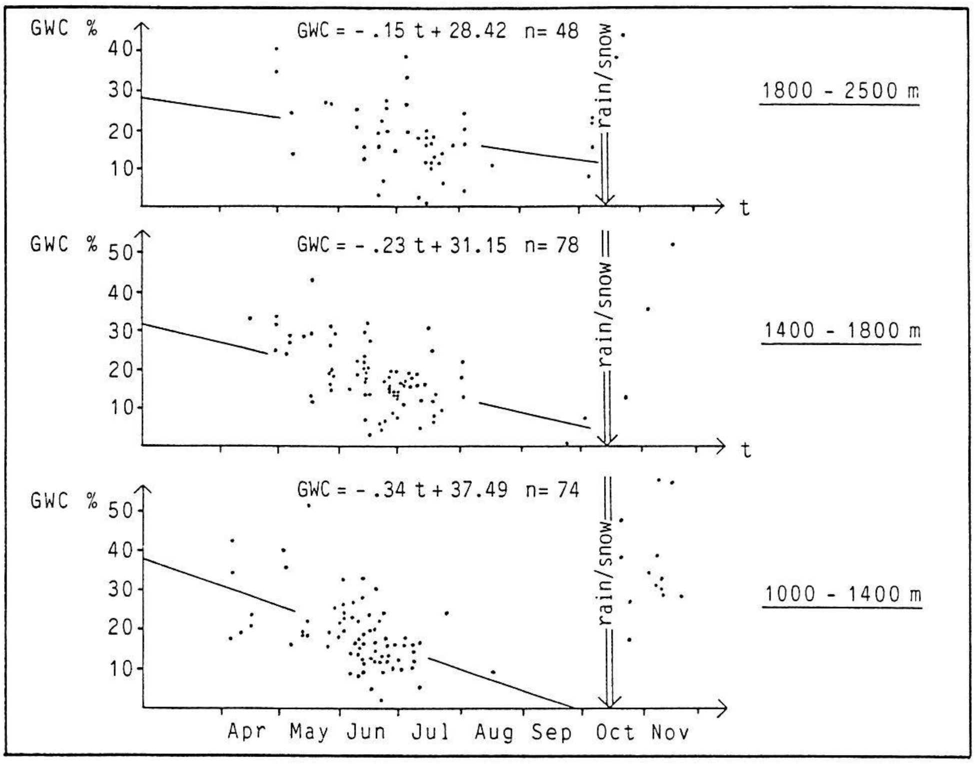


Fig. 2. Gravimetric water content (GWC) in percent of dry weight. 218 measurements from 1984-1986 show the drying of doline soils from April 1 until the first rain or snowfall in autumn (October 14-17, 1985) and the subsequent rewetting until November 30, plotted at the different altitudes.
Gravimetrischer Wassergehalt (GWC) in Prozent des Trockengewichts. 218 Messungen *von 1984-1986 zeigen die Austrocknung von Dolinenböden vom 1. April bis zum ersten Niederschlag im Herbst (14.-17. Oktober 1985) und die folgende Durchfeuchtung bis 30. November, gruppiert nach verschiedenen Höhenstufen.*

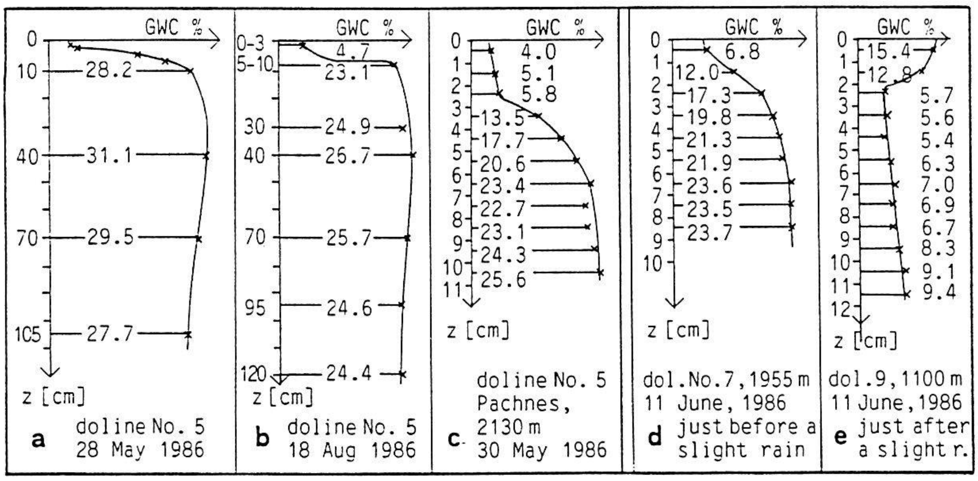


Fig. 3a-e. Gravimetric water content (GWC) in percent against water depth z.
Gravimetrischer Wassergehalt (GWC) in Prozent gegen die Bodentiefe z.

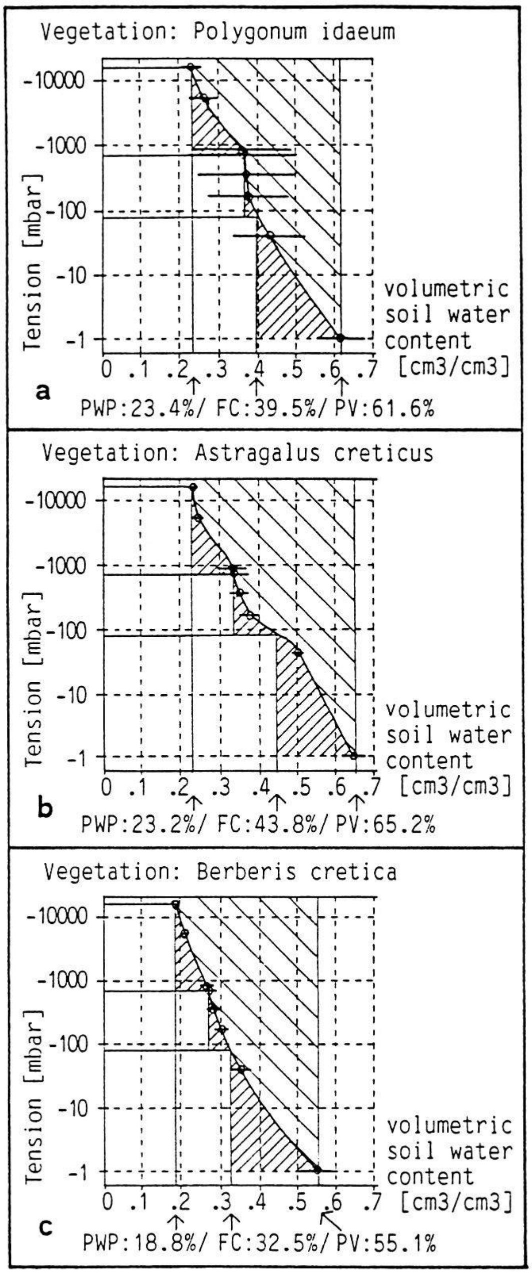


Fig. 4a-c. Doline No. 1: Nida, 1450 m. Soil moisture characteristics of a typical small infiltration doline, without superficial discharge. Clayey soil (see also Fig. 6a)
Desorptionskurven einer typischen kleinen Infiltrationsdoline, ohne oberflächlichen Abfluss; toniger Boden (s. auch Fig. 6a)

Soil samples from 10-20 cm depth - *Bodenproben aus 10-20 cm Tiefe.*
Pore volume emptied from water between the specified tensions:
Porenvolumen, zwischen den folgenden Saugspannungen entwässert:
FC = field capacity at 80 mbar - *Feldkapazität bei 80 mbar*
PWP = permanent wilting point at 15 bar - *permanenter Welkepunkt bei 15 bar*
PV = total pore volume at 1 mbar - *totales Volumen bei 1 mbar*
Air filled pore volume - *luftgefülltes Porenvolumen*

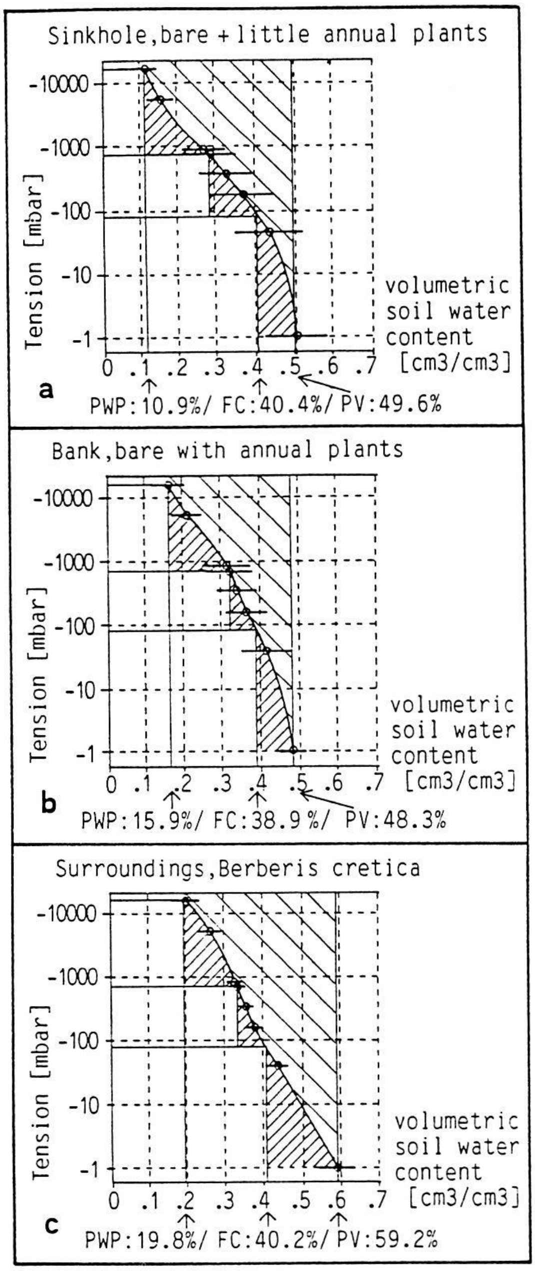


Fig. 5a-c. Doline No. 2. Ida, 1435 m. Soil moisture characteristics of a plain with several sinkholes, where the water disappears, silty soil. (See also Figs. 4 and 7a)
Doline Nr. 2: Nida, 1435 m. Desorptionskurven einer Ebene mit mehreren Schlucklöchern, worin das Wasser abfliesst; schluffiger Boden. (s. auch Figs. 4 und 7a*)*

Soil samples from 10-20 cm depth - *Bodenproben aus 10-20 cm Tiefe.*
/// Pore volume emptied from water between the specified tensions:
Porenvolumen, zwischen den folgenden Saugspannungen entwässert:
FC = field capacity at 80 mbar - *Feldkapazität bei 80 mbar*
PWP = permanent wilting point at 15 bar - *permanenter Welkepunkt bei 15 bar*
PV = total pore volume at 1 mbar - t*otales Volumen bei 1 mbar*
\\\ Air filled pore volume - luftgefülltes Porenvolumen

In the medium range of tension from -80 to -690 mbar the curves of Fig. 4a-c show a steepening with lower water capacity, typical for soils rich in clay. The curves for the silty soils run remarkably flatter in the medium range of -80 to –690 and up to -1000 mbar.
In the fine pore range above the permanent wilting point at -15 bar the curves from Fig. 4a-c and Fig. 5c show a high percentage of soil water scarcely or non–accessible to plants of 19 to 23% compared with only 11-16% from Fig. 5a and b.
Summarising the comparison of Figs. 4 and 5, one finds that under a dense vegetation of shrubs a big portion of coarse pores are formed and kept, while bare areas scarcely have coarse pores and therefore have a deficient aeration and a low total water capacity. This important function of the shrubs should be taken into account before considering forming open pastureland by burn clearing.

4.3. MATRIC POTENTIAL CURVES

All three curves of doline No. 1, Fig. 6a-d run similarly exponentially. This is typical for soils rich in clay. In detail some differences are apparent: under *Astragalus creticus* the upper layers (30, 40 and 70 cm depth) dry out much quicker than under *Polygonum idaeum* and *Berberis cretica* because *Astragalus* first develops leaves for assimilation and therefore immediately starts to transpire. Under *Berberis* the upper layers in the range from -200 up to –1000 mbar dry out more slowly, probably because of the shadow of the up to 2 m high shrubs.
The curves of doline No. 2, Fig. 7a-d, run rather linearly, at least in deeper layers (120 cm), due to a consistent upward water percolation in silty soils. Out of the same reason the differences between the measured depths are much smaller than in doline No. 1. In the sinkhole due to additional water penetrating from the sides the soil remains wet up to the surface for a long time. The shadow under *Berberis* also reduces the drying out of the upper layers. Quite in contrary are the compressed areas, having a poor vegetation: the soil poor of pores can store only little amounts of rain water and the upper layers dry out very rapidly.
The drying of the soils during the summer season due to the hot south aegean-mediterranean climate is markedly reduced or actually eliminated due to the height above sea level and special edaphic conditions. Due to the measurements of different soil types at different altitudes in the autumn of 1985 in the Lefka Ori (Fig. 8a-e) and spring to summer 1986 in the Dikti (Fig. 9a-e) the conditions

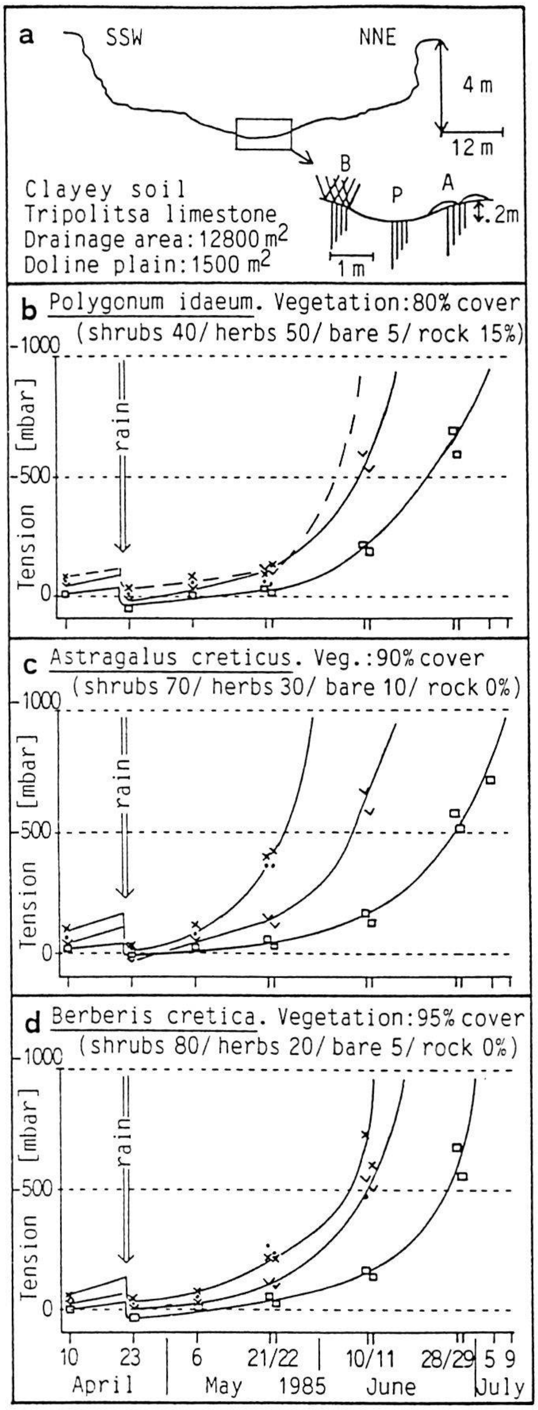


Fig. 6a-d. Matric potential curves of the infiltration doline No. 1: Nida 1450 m
Saugspannungskurven der Infiltrationsdoline Nr. 1: Nida 1450.
Valley east of Nida plain, between Alikadam and Melidomaskala mountains. Tensiometers reach 30 cm (x), 40 cm (•), 70 cm (v), and 120 cm (□) depth.

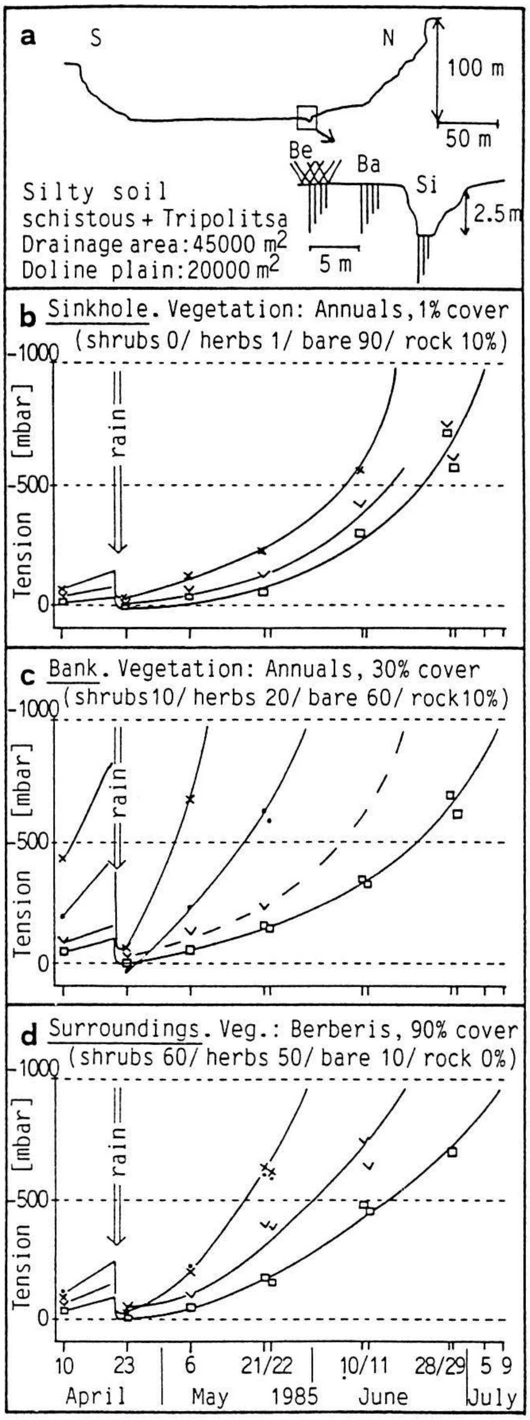


Fig. 7a-d. Matric potential curves of the sinkhole doline No. 2, Nida 1435 m.
Saugspannungskurven der Schlucklochdoline No. 2: Nida 1435 m.
Valley east of Nida plain, between Alikadam and Melidomaskala mountains. Tensiometers reach 30 cm (x), 40 cm (•), 70 cm (v), and 120 cm (□) depth.

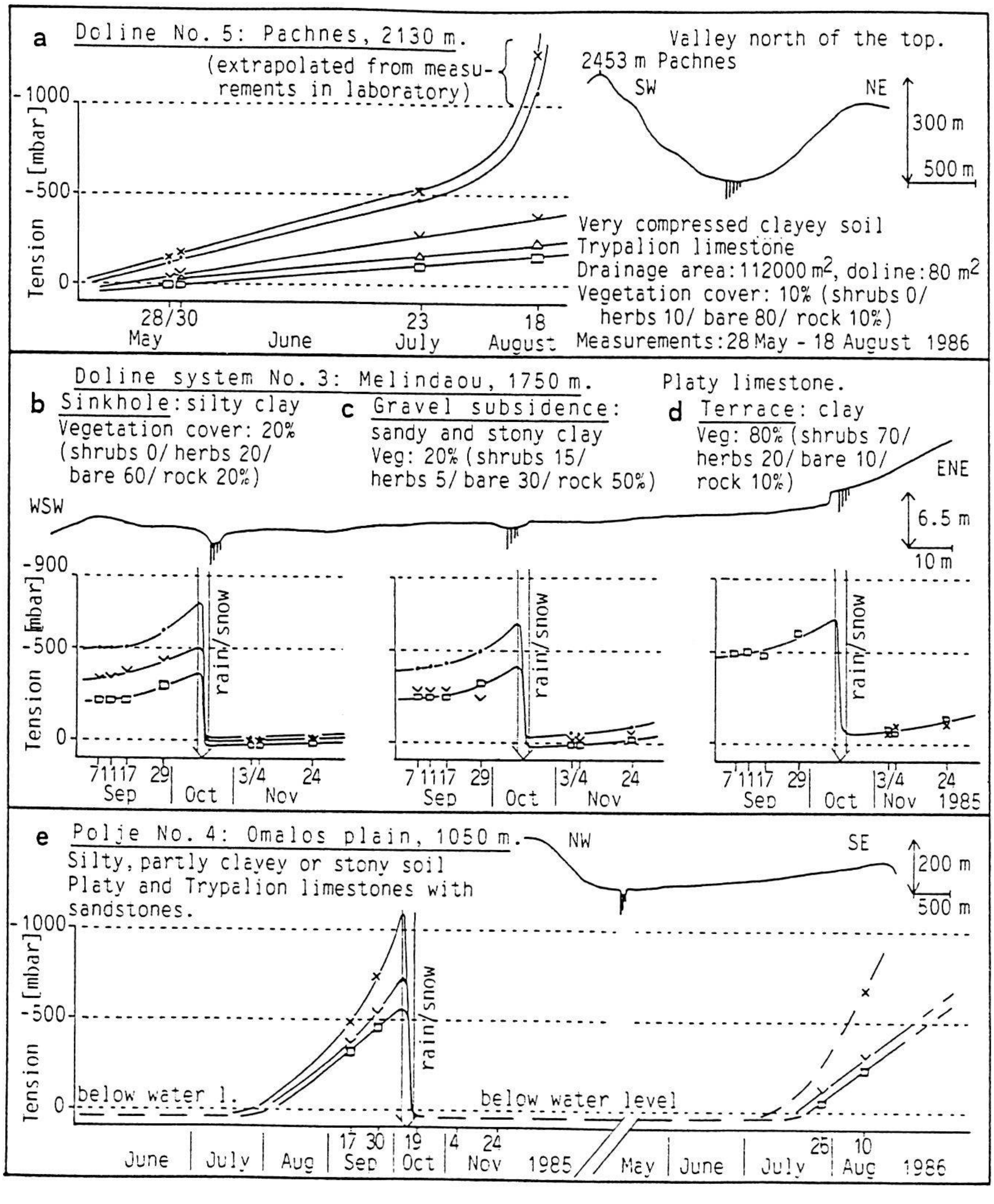


Fig. 8a-e. Matric potential measurements in the Lefka Ori mountains. Tensiometers reach 30 cm (x), 40 cm (·), 70 cm (v), 110 cm (◬), and 120 cm (◘).
Under different conditions the soils remain wet despite no measurable precipitation over four summer months.
Saugspannungsmessungen in Lefka Ori-Gebirge. Unter verschiedenen Bedingungen bleiben die Böden feucht trotz keinerlei messbaren Niederschläge während vier Sommermonaten.

Fig. 8a-e (continued)

a. Pachnes, 2130 m: a very compressed clayey soil is building a very dry uppermost soil layer which prevents the lowermore layers from evaporating the water (see also Fig. 3a-c and discussion) - *Pachnes, 2130 m: Ein stark verdichteter Tonboden bildet eine sehr trockene oberste Bodenschicht aus, welche die tiefer liegenden Schichten vor Wasserverlust durch Evaporation schützt (s. Fig. 3a-c und Diskussion).*

b-d. Melindaou, 1750 m: A silty clay (b) or a sandy and stony clay (c) in a depression guarantees an optimal uptake and storage compared with the clay on the terrace (d) - *Melindaou, 1750 m: Ein schluffiger Ton (b) oder ein sandiger steiniger Ton (c) in Muldenlage garantieren optimale Wasseraufnahme und -speicherung, verglichen mit dem Tonboden der Terrasse (d)*

e. Omalos, 1050 m: This soil at the deepest part of the Polje is overflooded most time of the year and therefore the soil dries only little - *Omalos, 1050 m: Dieser Boden in den tiefsten Teilen der Polje ist die meiste Zeit des Jahres überflutet, deshalb trocknet er nur wenig aus.*

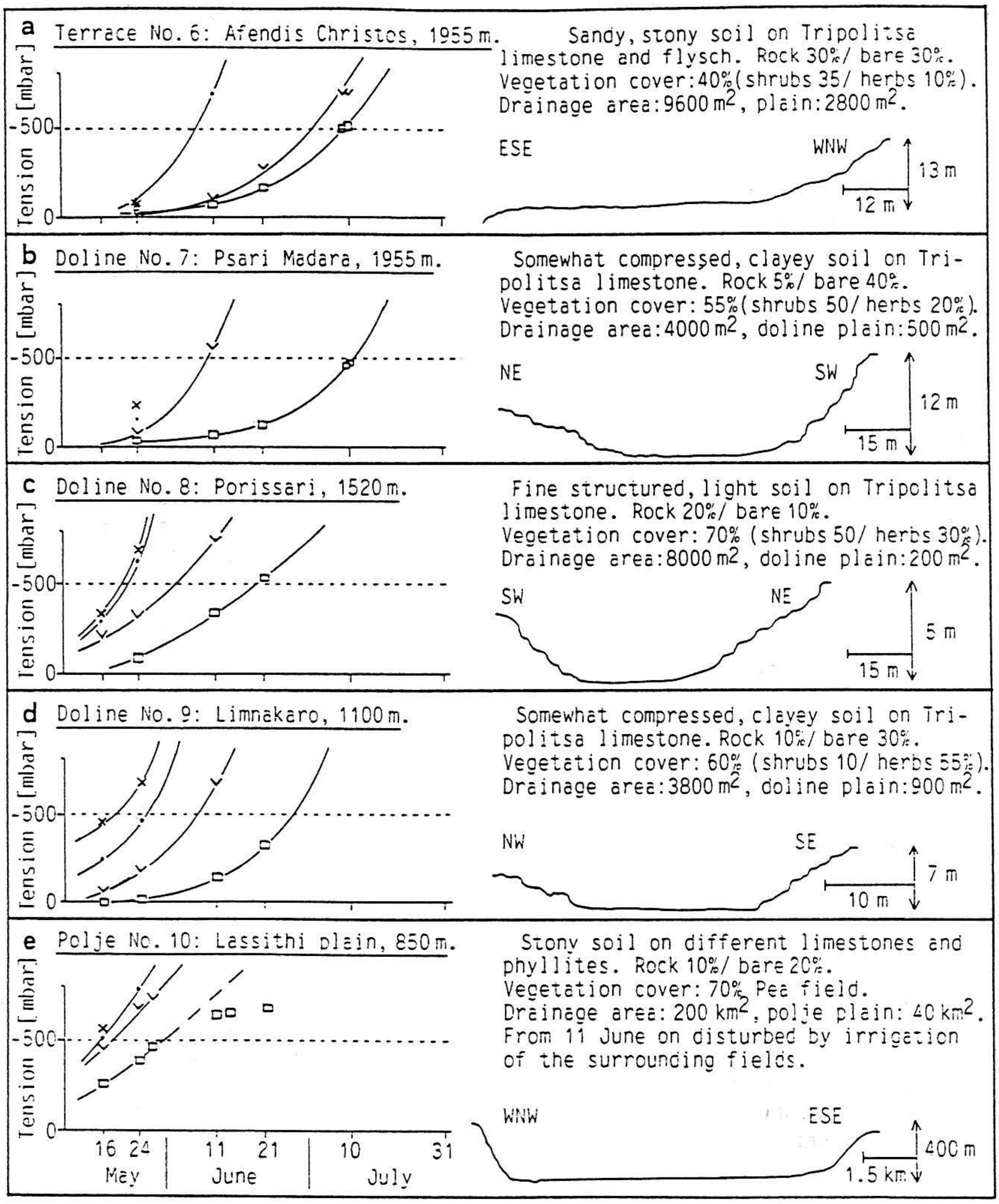
Fig. 9a-e (p.161). Matrix potential measurements in Dikti mountain region.
Measurements from May 15 to July 31 (e to June 21) 1986
Tensiometers: 30 cm (x), 40 cm (.), 70 cm (v), 120 cm (◻).
Saugspannungskurven im Diikti-Gebirge.
Gemessen wurde vom 15. Mai bis 31. Juli (e bis 21 Juni) 1986.

b, d: comparison shows first a delayed and then an exponential accelerated desiccation typical for clayey soils - *Für Tonböden typisch: zuerst eine verzögerte und dann eine exponentiell beschleunigte Austrocknung.*

c, e: On the contrary the light and stony soils proceed nearly linear - *Bei lockeren und steinigen Böden verlaufen Kurven nahezu linear.*

b, d: Show the delay of the similar proceeding curves due to the different altitudes and the longer remaining of b near soil water saturation - *Zeitliche Verschiebung der ähnlich verlaufenden Kurven und das längere Verbleiben von b nahe der Wassersättigung aufgrund der unterschiedlichen Höhe über Meer.*

b, a: The very big differences between 70 and 120 cm depth point to a deficient water percolation in compressed clayey soils - *Grosse Unterschiede zwischen 70 und 120 cm Bodentiefe deuten auf eine gehemmte Wasserzirkulation in verdichteten Tonböden.*



a Terrace No. 6: Afendis Christos, 1955 m.
Sandy, stony soil on Tripolitsa limestone and flysch. Rock 30%/ bare 30%.
Vegetation cover: 40% (shrubs 35/ herbs 10%).
Drainage area: 9600 m2, plain: 2800 m2.
ESE
WNW
13 m
12 m
b Doline No. 7: Psari Madara, 1955 m.
Somewhat compressed, clayey soil on Tripolitsa limestone. Rock 5%/ bare 40%.
Vegetation cover: 55% (shrubs 50/ herbs 20%).
Drainage area: 4000 m2, doline plain: 500 m2.
NE
SW
12 m
15 m
c Doline No. 8: Porissari, 1520 m.
Fine structured, light soil on Tripolitsa limestone. Rock 20%/ bare 10%.
Vegetation cover: 70% (shrubs 50/ herbs 30%).
Drainage area: 8000 m2, doline plain: 200 m2.
SW
NE
5 m
15 m
d Doline No. 9: Limnakaro, 1100 m.
Somewhat compressed, clayey soil on Tripolitsa limestone. Rock 10%/ bare 30%.
Vegetation cover: 60% (shrubs 10/ herbs 55%).
Drainage area: 3800 m2, doline plain: 900 m2.
NW
SE
7 m
10 m
e Polje No. 10: Lassithi plain, 850 m.
Stony soil on different limestones and phyllites. Rock 10%/ bare 20%.
Vegetation cover: 70% Pea field.
Drainage area: 200 km2, polje plain: 40 km2.
From 11 June on disturbed by irrigation of the surrounding fields.
WNW
ESE
400 m
1.5 km
Tension [mbar]
-500
0
16 24
May
11 21
June
10 31
July

can be described under which the doline soils in the mountains keep a well levelled water content during the whole summer with tensions between –1 and –1000 mbar:

* Soils rich in clay form an evaporation barrier by drying out in the uppermost layers.
* Moreover low vegetation coverage from zero to about 20% guarantees a low transpiration loss.
* Soil depths of several meters represent a high water storage. If the soils are silty or gravelly percolation from deep lying water tables to higher levels is possible.

SUMMARY

Via water content and matric potential curves made from field measurements and water retention curves using laboratory measurements, the water regime of doline soils in the mountains of Crete are presented. The influence of the altitude, topography, soil type and vegetation is important.
Moist soils can be found throughout the summer in certain areas in the mountains under the following conditions:
1. Soil depths of several meters and corresponding high water storage.
2. Silty or gravelly soils allowing the percolation of water from deep lying water tables to higher levels.
3. Soils rich in clay, drying out in the uppermost layers and thus producing an evaporation barrier.
4. Low vegetation coverage (about 10%), only a few ruderal plants, therefore very low losses by transpiration.

ZUSAMMENFASSUNG

Der Wasserhaushalt von Dolinen-Böden im Gebirge von Kreta wird dargestellt anhand von Wassergehalts- und Saugspannungskurven aus Feldmessungen, sowie Desorptionskurven aus Labormessungen. Entscheidend sind die Einflüsse von Höhe über Meer, Topographie, Bodentyp und Vegetation.
Feuchte Böden können in den Bergen unter folgenden Bedingungen den ganzen Sommer über gefunden werden:
1. Bodentiefen von mehreren Metern mit entsprechend hoher Wasserspeicherung.
2. Schluffige oder steinige Böden, welche die Wasserversorgung von tiefer liegenden Grundwasserspiegeln erlauben.
3. Tonreiche Böden, welche in der obersten Schicht austrocknen und damit eine Evaporationsbarriere entwickeln.
4. Geringe Pflanzenbedeckung (um 10%) von einigen Ruderalpflanzen und damit sehr geringe Verluste durch Transpiration.

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