EFFECTS OF WATER SHORTAGE ON GROWTH OF *EUCALYPTUS CAMALDULENSIS DEHN* UNDER SAHELO-SUDANIAN CLIMATE IN SENEGAL

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Summary.

Growth and water potentials of *Eucalyptus camaldulensis* Dehn. have been studied under Sahelo-sudanian conditions in Senegal. Water stress adaptation of young seedlings has been tested under semi controlled conditions, revealing a strong growth limitation as soon as predawn water potentials reached values around -1.0 MPa, and a quasi-cessation below -2.0MPa. On an in situ plantation near Bandia, the same values of predawn water potential caused growth cessation, and reversely, growth resuming when water status irnproves above these levels. These features correspond to a poor adaptation to drought conditions. The use of an experimentally established relation between leaf predawn water potential and soil water reserve on young trees in a plantation, allowed a survey of calculated predawn potentials during four successive years. In fact, values below the above mentioned thresholds were often reached, explaining partially the poor growth and survival observed in the field. Years 1983 and 1984 were particularly severe in this regard.

Adaptability of Eucalyptus camaldulensis to sahelo-sudanian irregular water supply conditions appears very poor; this species should be reserved to regions with more important and regular rainfall.

1.Introduction.

The fast dwindling of forested areas in arid and semi-arid tropical regions endangers more and more the supply of fuel wood to local populations. An important effort of reforestation is needed to meet the.continuously increasing demand for fuel wood. Use of fast growing exotic tree species has been thought to constitute a good solution to meet this challenge. Under Sahelo-sudanian conditions with poor soils, long dry periods and irregular rainfall, a good adequacy between the minimal water requirements of afforested species, and the hazardous water supply is of prime importance to allow not only tree survival, but also a significant productivity.

Eucalyptus camaldulensis is frequently used by foresters for new stand installation, because of the short revolutions it may ensure, and of its high productivity and good coppicing ability.

In Senegal, a wide ranged project has been designed near Dakar in order to replace natural tree stands of *Acacia seyal Del.*, showing very low productions (about 1 m3 year-1), by intensively cultivated *Eucalyptus camaldulensis* (Cissokho,1983). A study on Eucalyptus growth potential under limited water supply has therefore been initiated. In fact, in its natural area in Australia, *E. camaldulensis* is rather located near river banks, with some kind of groundwater supply; therefore its adaptation to semi-arid conditions may be questioned.

E. camaldulensis has been intensively studied in respect to rooting ability (Riedacker, 1973, Ame et al, 1976), high temperature resistance (Kreeb 1965), and water consumption (Poupon,1968). Productivity of different origins has also been assessed. But Quraishi and Kramer (1980) and Moreshet (1982) alone have published informations on drought effects on growth in this species.

In order to determine growth potential of *E. camaldulensis* under limited water supply, data from seedlings grown in pots with controlled irrigation have been compared with those obtained on trees growing at Bandia, near Dakar, under natural conditions, without any additional water supply.

2.Material and methods.

Two experiments have been designed, one under natural conditions in a newly planted stand, and one under semi controlled conditions in a nursery.

2.1.Plant material.

In both experiments, seedlings were obtained from seed harvested on trees in Kontal Verger (Kaolack, Senegal, annual rainfall: 790 mm); the Australian origin was Derby (W.A., long.:123 deg. 59' E, lat.17 deg.19' S, alt.12 m, annual rainfall: 610 mm).

2.2.Nursery experiments.

Soil was taken from plot 2 in Bandia (see below). Extractable soil water reserve was estimated as the difference in water content between permanent wilting point (Ψs=-1.6 MPa) and field capacity (Ψs=-0.06MPa.). The relation between soil water potential and soil water content is sketched on figure 1.

They were conducted during two consecutive years, in spring and summer 1984 and 1985 (end of dry period and beginning of rain season). Seeds were germinated in seed beds, and seedlings transplanted to plastic pots (vol: 10 1). They were watered twice daily; as soon as they reached 35 cm height, they were submitted to a water shortage. Intensities of imposed stress in the different treatments are indicatcd in table 1. Transpiration and soil water reserves were measured by daily weighing of individual pots.

As soon as the desired water content was attained, pots were covered with sulfurized paper to avoid direct evaporation from the soil. Water content was maintained by daily partial rewatering up to desired weight. Imposed drought levels were maintained during 30 days.

Seedlings' height was measured daily, and predawn leaf water potential (Ψpd) was estimated with a pressure chamber on 5 and 12 seedlings per treatment respectively in 1984 and 1985. Height growth and water stress intensity relationships were assessed through mean growth and mean Ψpd on each treatment.

2.3. Plantation experiments.

The plantation was installed in the Bandia forest resort, about 70 km southeast from Dakar. This region is submitted to a sahelo-sudanian climate, where annual rainfall exhibits very important variations; for instance, during a six year period (1981-1986), mean annual rainfall was limited to 395,8 mm, with a minimal value of 246,6 mm during 1983 (see table 2). In fact, rainfalls are decreasing in this area, from mean levels of about 600 mm during the fifties, two the low levels of about 400 mm in the eighties.

Annual evapotranspiration has been estimated to about 2000 mm, according to Riou (1975).

Two plots have been defined,corresponding to two different reference soils of Bandia: the fiist one (plot 1) is a haplaquent, and plot 2, a typic eutrochrept (according to american classification, Sall, 1988).

In each plot, an experimental area of 28*28 m. was defined, with 49 trees spaced 4m*4m. Four months old seedlings were planted at the end of July 1981, after a mechanical deforestation and ploughing. 42 trees survived the whole experiment on plot 1 and 39 on plot 2.

Soil humidity was measured from December 1981 to December 1986 with a Campbell 501 B neutron probe. Five 3 m. long duralumin tubes were installed on each plot. During dry season, water content was measured once monthly, and during the rain period (from June to October), once weekly. Humidity measurements were made on 3 m. profiles, but water stocks were calculated over 1.75 m only, as we use them exclusively to assess the relationship between mean soil water content and tree water status. Furthermore, direct observations revealed that no roots grew deeper (Sall, 1988).

Meanwhile, tree heights and circumferences were monitored monthly.

During 1985 and 1986, predawn leaf water potential (¥pd) was monitored in parallel with soil water content, and the daily minimum potential (¥m) was measured at 1 PM UT. Measurements were made with a pressure chamber on 5 trees on plot 1 and 11 on plot 2.

Nine characteristic days were chosen during rain season and dry period, and water potential evolution was followed hourly during these days.

The critical Ybp, as defined by Aussenac and Grnnier (1978) has been established graphically, by plotting together Ybp and maximal' daily variations of ¥.(∂¥), and assuming that this threshold value of Ybp is reached when ∂¥ is lower than 0.3 MPa. This leaf water status level may involve a complete stomatal closure (Aussenac and Granier, 1978).

3.Results.

3.1.Effects of drought on height gromth of young seedlings.

Figure 2 shows results of both experiments (1984 and 1985); a very close relationship appears between mean cumulated elongation and mean Ypd for the different treatments, in spite of some slight differences due to microclimate from one year to the other. Elongation was in both cases drastically limited for Ypd values below -1.9 MPa.; a predawn water potential threshold completly impeding elongation seemed to appear between -1.9 and -2.1 MPa.

3.2.Water potential evolution in the field.

Seasonal evolutions of Ypd and Ym have been followed during 1985 and 1986. A very close relationship appears on each plot between predawn leaf water potential and water stock in the profile (fig. 4). This close relationship allowed an extrapolation of predawn water potentials over the previous growth periods of 1983 and 1984, for each plot. Differences appearing between plots on figure 4 may be attributed to variations in soil texture and soil water characteristics between both plots.

Seasonal fluctuations of Ypd displayed very different pattems from one year to the other, depending on the importance and distribution of rainfall (fig 3). During 1983, Ypb reached -2.35 MPa during dry season, and did not fully recover during rain period (maximal value of -1.6 MPa). Evolution was similar during 1984 with a minimal value of -2.9 MPa, but a better recovery during tht rains (-1.4). Year 1985 was far more favorable, as dry season minimum reached -3.0 MPa, but recovery values attained 0.3 MPa, due to important rainfalls. Following dry season was marked by a limited stress (-1.95 MPa.); and rains induced a good recovery up to -0.6 MPa.

Hourly variations of Ψw are shown on figure 5. During rain season (July 23, August 21 and September 27 1985) Ψw showed important variations with time, reaching an amplitude of about 1.7 MPa. During dry season, in opposition (June, 5 1985), Ψw varied only slightly, staying between -2.9 and -3.4 MPa.

As shown on figure 6, critical Ψpd may be located at a level of about -3.0 MPa, for which daily variation (∂Ψ) remains below -0.3 MPa.

3.3. Effects of drought on growth in the plantation.

Mean yearly productivity, followed during 6 consecutive years, remained very low, reaching only 1.1 m3 ha-l yr-1 on plot 1, and slightly higher values of 4.6 m3 ha-l yr-1 on plot 2.

Figure 7 shows the parallel evolution of mean height and circumference growth and of Ψpd for both plots. From these data, we have dctermined the value of Ypd which was accompanied by a stop of elongation and circumference growth. Table 3 indicates the values obtained during successive years. They väry only slightly, with a mean of about - 2.0 MPa. for elongation and -1.9 MPa. for the diametér. Inversely, after the first rains, growth resumes immediately after the moment where Ypd reached the same values.

From these data, way may determine duration of periods favorable to growth, marked by different threshold values (-1.0, -1.5 and -2.0 MPa., table 3). These periods appear very short during 84 and 85, and far from optimum.

It is of great interest to observe that the Ypd thresholds for growth observed on plantation trees are very narrow to those estimated on young seedlings .

4.Discussion and conclusion.

E. camaldulensis appeared in our experiments, to be submitted to very drastic important water stresses in the sahelo-sudanian zone, which is characterized by low annual rain falls, grouped over a very short period (mid June-mid September). In fact, the predawn leaf water potential (Ypd) remained at levels of about -0.3 MPa. during the rain season, but reached values as low as -3.2 MPa. during the dry period

The presented results show that a critical predawn water potential may appear at levels of about -3.0.MPa. Although no published data are available about a critical Ybp in *Eucalyptus camaldulensis* , some results may support our iden.Runwald and Karshon (1982) observed on the same species that, as soon as Ypd reached -3.0 MPa, Ym never fell below 3.4 MPa. In a other work, Quraishi and Kramer (1980) observed a complete stomatal closure at water potentials below -2.8 MPa. Our results therefore are in accordance with these observations. Critical Ypd levels have been estimated to values between -3.0 to -3.5 for a set of species like *Cedrus atlantica, Quercus ilex, Quercus prrbescens* (Aussenac and Valette, 1952).

This notion of critical Ypd may be questioned, as seasonal variations in osmoregulation may influence the relations between water potential, turgor and therefore stomatal conductance. Myers and Neales (1986), for instance, demonstrated the importance of osmotlc adjustment after preconditioning by drought, on seedlings of various Eucalyptus species *(E. behriana, E. microcarpa, E. polyanthemos).* But on the other hand, Cuyon (1987) showed a good agreement between estimated critical Ypd,' and Yw at loss of turgor, determined during pressure volume experiments.

Our measures allowed a relatively precise determination of a Ypd threshold value, below which no more growth occured. This threshold is located near -2.0 MPa., as well for shoot elongation as for diameter growth. Quraishi'and Kramer (1980) observed growth cessation in the same species at Yw below -2.4 MPa. We may therefore assume that growth is at least drastically limited below -2.0 MPa.. In this respect, *E. camaldulensis* appears less adapted than other Eucalyptus, like *E. polyanthemos* or *E. sideroxylon* (Quraishi and Kramer, 1980). In related species as *E. melliodora* and *E. microcarpa,* Clayton-Greene (1983) observed loss of turgor at Ψ values of about -2,68 MPa., and -2.99 MPa., which seem very narrow to our critical Ypd values. Very low Ψpd values are also reported for *E. globulus* in Portugal (-4.0 MPa.,Pereira et al, 1986), for *E. incrassata* in Victoria, Australia (-3.5 MPa., Wellington, 1984), and for *E. obliqua* and *E. fasciculosa* in Western Australia (-4.0 MPa., Sinclair, 1980). But growth and productivity are very seldom reported together with water status, and no final conclusion may be adopted.

Comparisons with some European trees show that growth cessation occurs at Ypd values of about -0.8 MPa on *Juglans regia* (Dreyer, 1984), -1.1MPa. on *Fraxinus excelsior* and *Quercus robur* (Aussenac and Levy, 1983), -1.5 MPa. on *Pseudotsuga menziesii* (Grieu, 1986), and -2.0 MPa on *Cedrus atfantica.* (Aussenac and Finkelstein, 1983)

Therefore, even if *E. camaldulensis* may grow till quite low Ypd, it is not as competitive as it could have been necessary for a realistic production under sahelo-sudanian conditions. Would other provenances have displayed better productivities? Moreshet (1981) showed that under the exueme conditions of Neguev desert (228 mm annuial rain), a provenance from southern Australia (347 mm) displayed better survival and growth, than one from tropical Australia (958 mm). The provenance used here seems intermediate between both of them, as in Derby annual rainfall reaches 610 mm.

These limited growth abilities of *Eucalyptus camaldulensis* at Ypd below -2.0 MPa, combined with the short period during which water availability is adequate for tree life, explains the very low productions measured on the plots: after 6 years of plantation, the mean productivity never exceeded 4.6 m-3 ha-l yr-1. Use of the same seed on other sites with same water supply, confirmed that production never exceeded this value.

At the same time, in Senegal, studies conducted with the same species, under sudanian climate (annual rainfall between 600 and 750 mm), showed that the production could reach 7 to 8 m3 ha-l yr-1, and even 17 to 18 m3 ha-l yr-1 under guinean climate (1200 mm rainfall) (Sall, 1988).

These data confirm clearly that, for a significant wood production in the sahelian zone, it is of no interest to use E. *camaldulensis*. Question arise to know which species, from the local flora, or imported, may have a significant wood production potential with less than 500 mm rainfall. Trials have to be undertaken in coming years with different Acacia species(A. *albida, A. senegal*), which present the important advantage of being of great utility in african agroforestry systems.

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TABLES.

Table 1. Characterization of drought treatments applied to *Eucalyptus camaldulensis* seedlings cultivated in pots during 1984 and 1985.

Year	Number of seedlings	R.E.W. %	¥soil (MPa.)	Mean Ypd (MPa.)
1984	9	100	-0.06	-0.7±0.17
	9	50	-0.16	-0.9f0.13
	9	25	-0.35	-1.1±0.18
	9	5	-0.89	-1.87rt0.22
1985	10	25	-0.35	-0.92±0.05
	10	20	-0.45	-1.10±0.05
	10	15	-0.56	-1.28±0.03
	10	10	-0.79	-1.60±0.05
	10	5	-0.89	-1.91±0.11

REW: relative extractable water content, expressed as fraction of total extractable water (840 g per pot)

¥soil: calculated mean soil water potential in the pots; these values are determined according to potential-water content relation plotted on figure 1.

Ypd: mean predawn leaf water potential measured with a pressure chamber during the treatments, indicated values display confidence limits at 5%.

Table 2. Annual rainfall evolution at Bandia, during the experiment (mm) .

years	1981	1982	1983	1984	1985	1986	Mean
rainfall	403.0	445.5	246.6	327.9	474.2	478.9	395.8

Table 3. Predawn leaf water potential (Ypd, MPa.) levels for which growth cessation and resuming occurred, during successive years, at Bandia.

Year	Diameter growth cessation	resuming	Height growth cessation	resuming
1983				
plot 1	-1.7		-1.7	
plot 2	-2.35	-2.15	-2.15	-2.15
1984				
plot 1	-1.8	-1.75	-1.7	-1.75
plot 2	-2.35	-2.35	-2.0	-2.35
1985				
plot 1	-1.85	-1.85	-1.85	-1.85
plot 2		-1.85	-1.85	
1986				
plot 1 / plot 2		-1.85		-1.85
mean	**-2.01±0.3**	**-1.97±0.23**	**-1.87±0.17**	**-2.0±0.28**

Table 4. Duration of periods (months) marked by predawn leaf water potentials (Ypd) above threshold values of -1.0, -1.5 and -2.0 MPa. in the plantation at Bandia.

	Plot 1			Plot 2		
Ypd	-1.0	-1.5	-2.0	-1.0	-1.5	-2.0
years						
1983	0		5	0	0	4
1984	0	0	6	0	1	3
1985		4	5	4.5	5	55
1986	2.75	4	5	3.5	6	12’

FIGURES.

Figure 1. Relationship between soil water potential (MPa), and water content for the soil used to grow potted Eucalyptus seedlings. Drawn lines represent the limits used to define extractable soil water content.

Figure 2. Relationship between mean predawn leaf water potential (Ypd) and mean elongation for potted Eucalyptus seedlings submitted to drought treatments as described in table 1. Mean values are estimated for each treatment; bars represent confidence intervals at 5%. Note that results of year 1985 (open symbols) and 1984 (closed symbols) display only a slight drift.

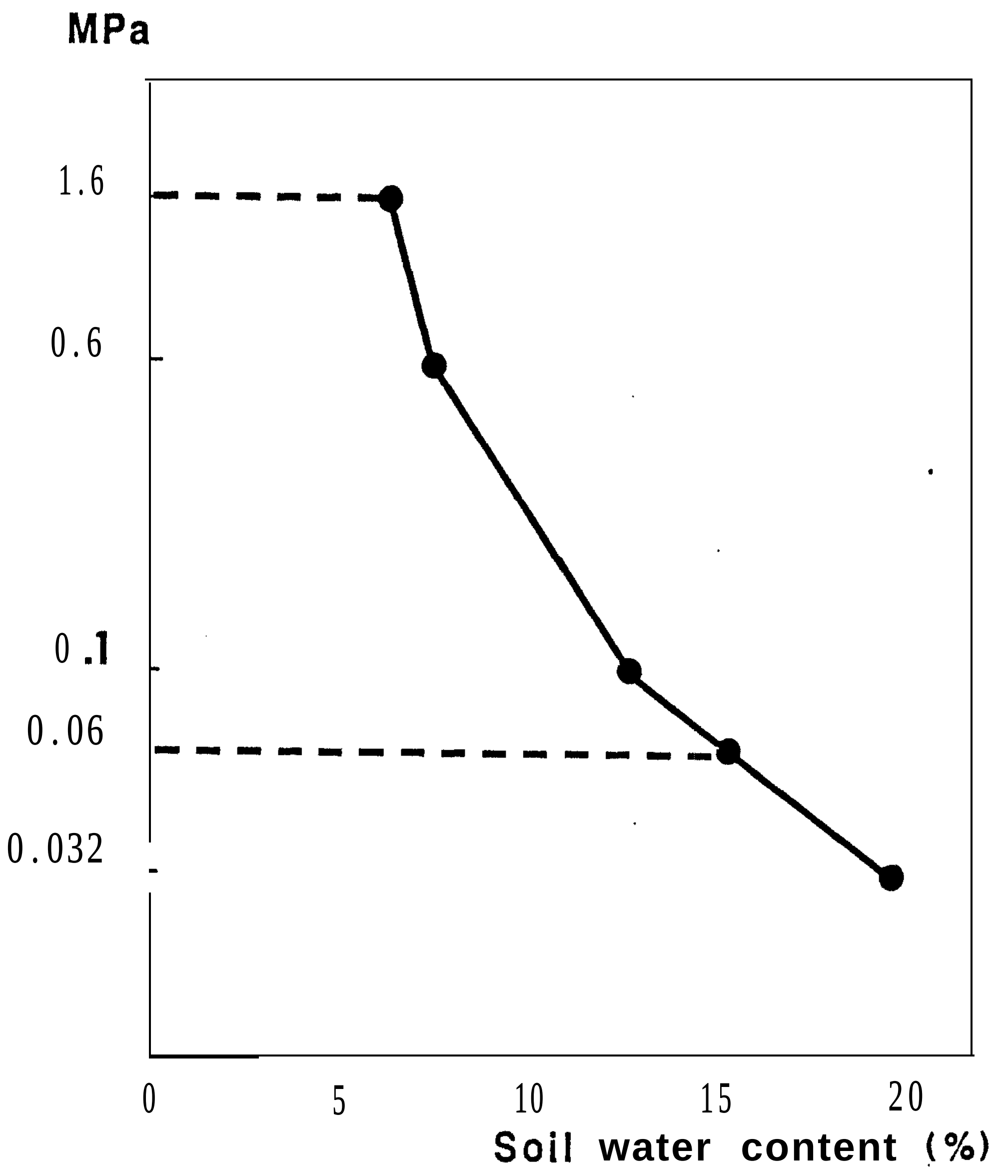
Figure 3. Relationship between measured predawn leaf water potential (Ypd) of Eucalyptus grown in Bandia, and water content of soils, expiessed as mm in a 1.85 m profile. Open symbols: plot 1, closed symbols: plot 2.; curve fitted by eye. On each plot, the relation appears very well defined all over measurement years 1985 and 1986. Plots differ because of there different soil qualities. These relations were used to extrapolate Ypd over two years previous to measurements.

Figure 4. Evolution over 4 years of monthly precipitations (bars), and measured or estimated predawn leaf water potential (Ypd) of *Eucalyptus camaldulensis* grown in Bandia; 4a, plot 1; 4b plot 2. Notice the length of periods with very loti Ypd.

Figure 5. Daily variations of leaf water potential (Y) on *Eucalyptus camaldulensis* grown in Bandia, during different days along rain and dry season.1985. Selected trees were located on plot2.

Figure 6. Relation between leaf predawn water potential (Ypd) of *Eucalyptus camaldulensis* grown in Bandia, and daily amplitude of variations (∂Y). A critical Ypd may be defined as the value below which ∂Y remains below approximately 0.3 MPa.

Figure 7. Evolution of mean height (h), mean circumference *(c)* of *Eucalyptus camaldulensis* grown in Bandia on plot 1, during 1985 and 1986, and their mean predawn leaf water potential (Ypd).Growth cessation and recovery occured at Ypd values of about -1.9 MPa.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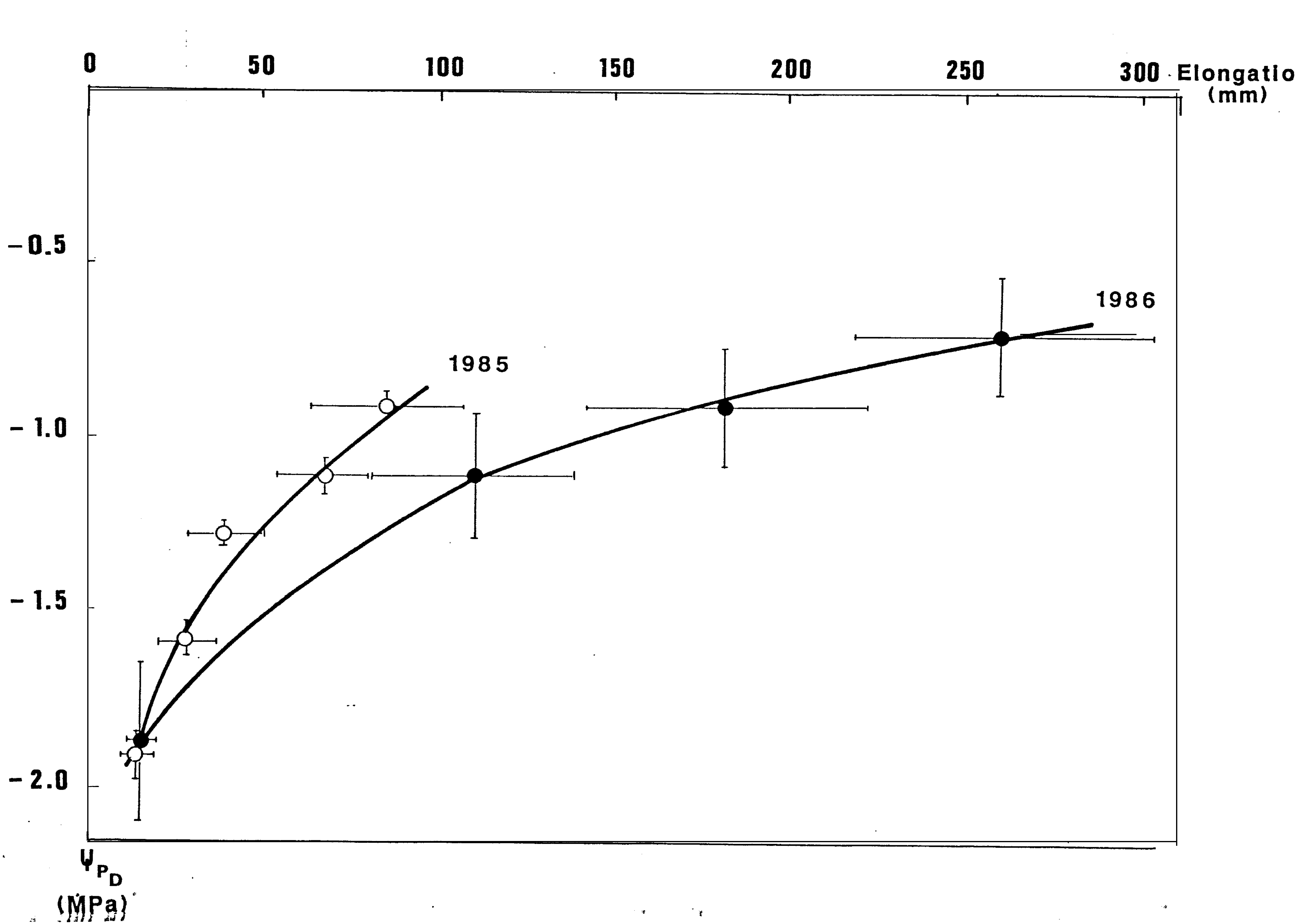
0.06
0.032
0
5
10
15
20
Soil water content (%)



0
50
100
150
200
250
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1985
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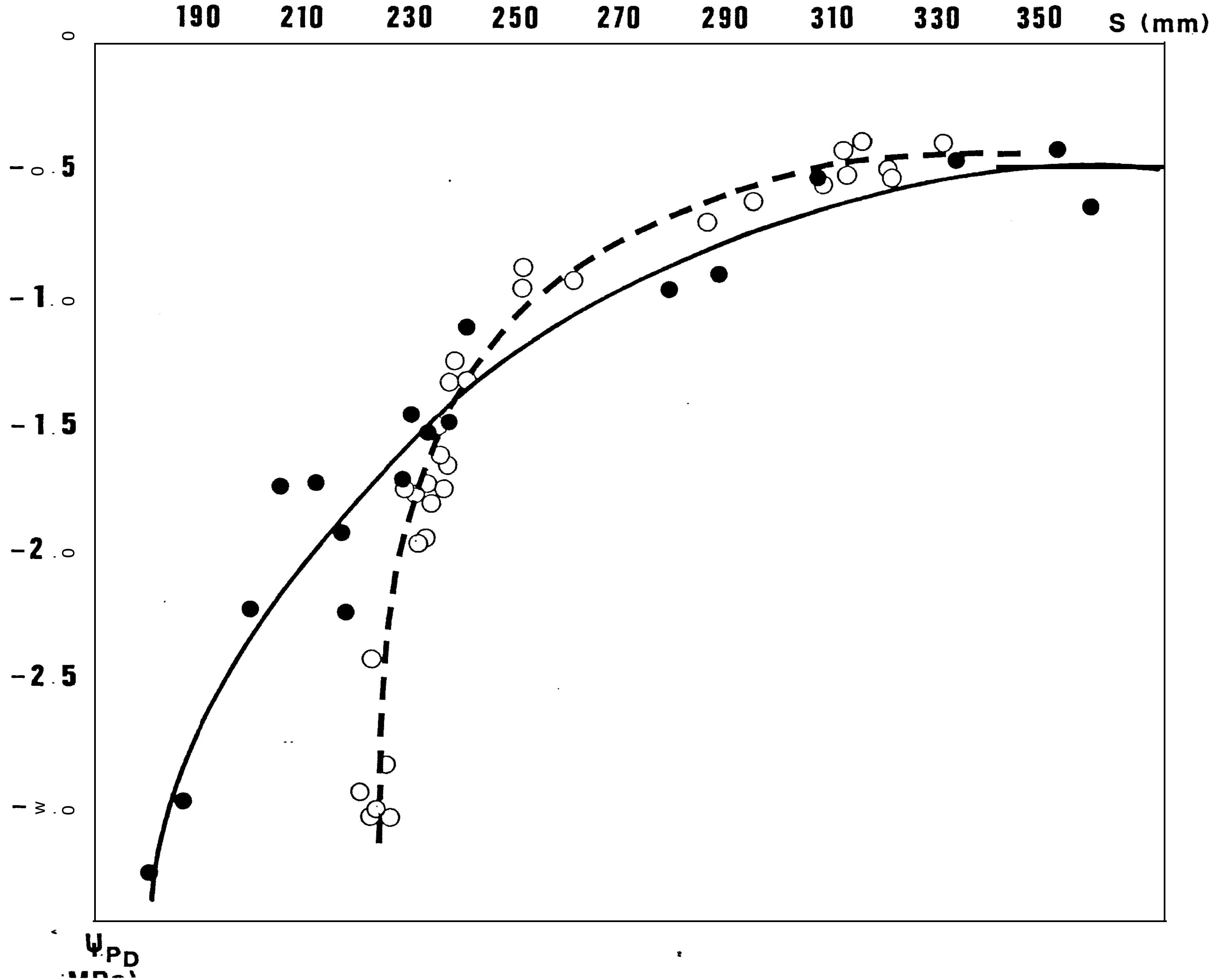
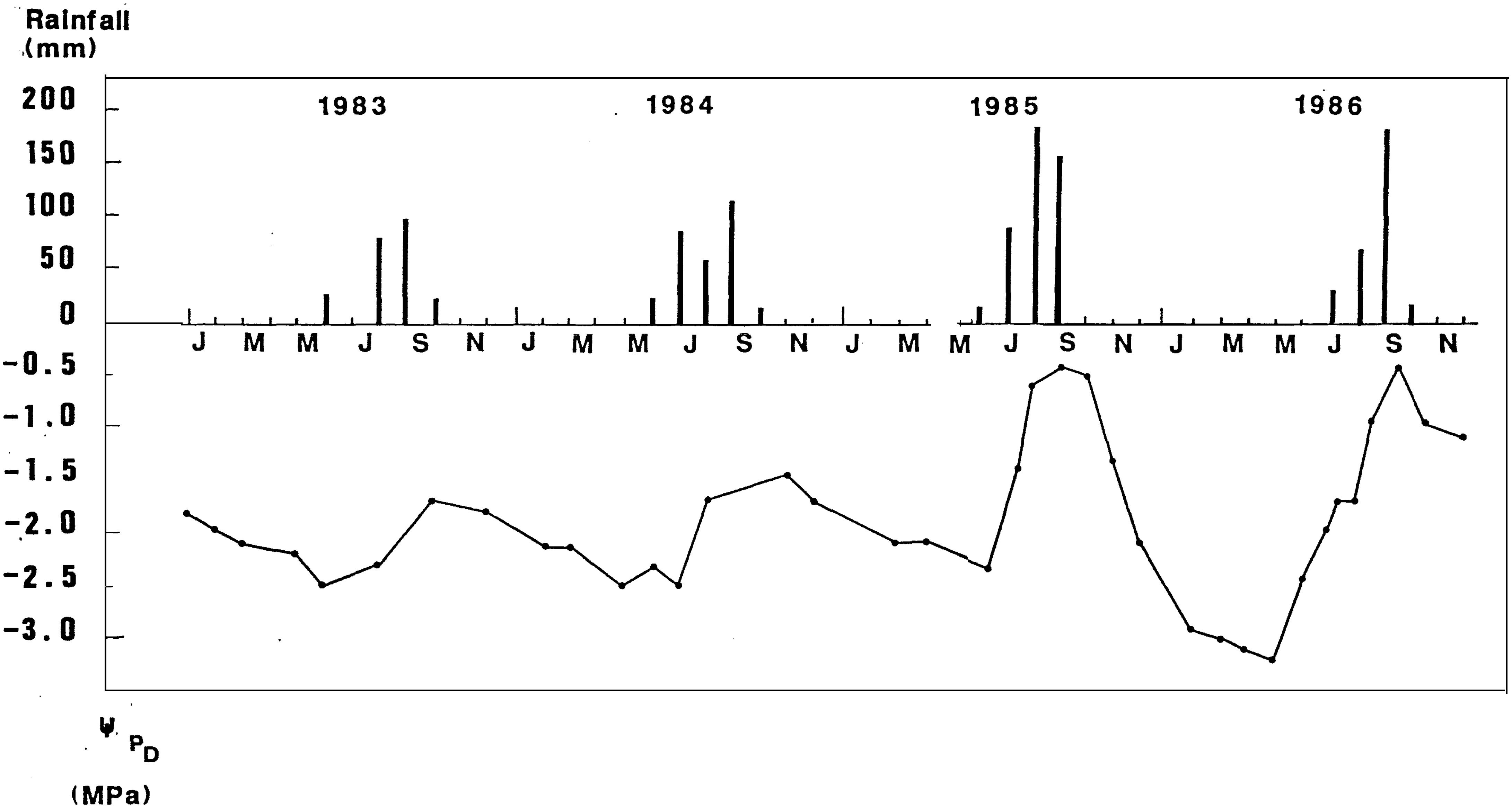
(3)





Rainfall (mm)
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50
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1985
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Ψ PD
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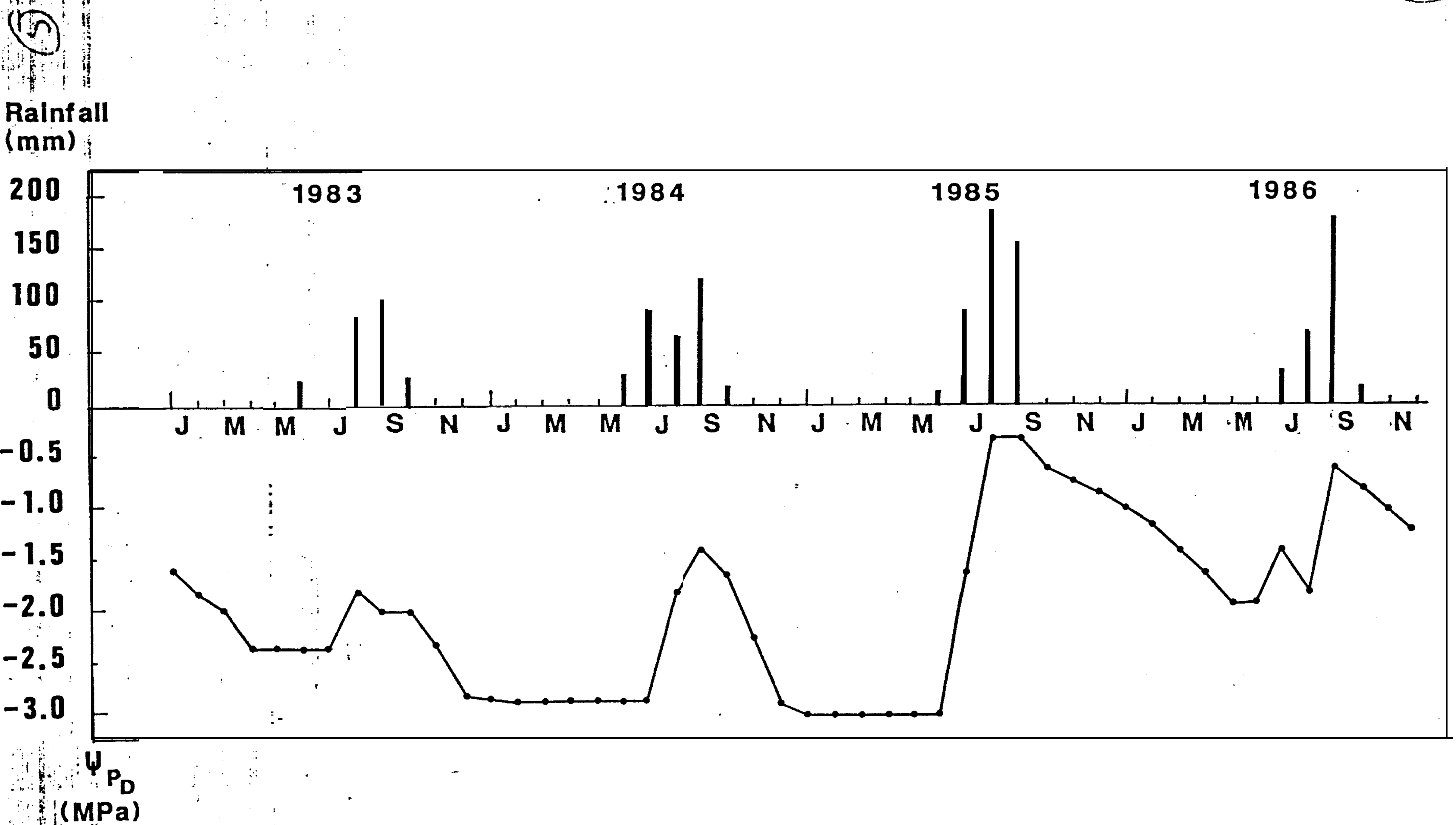
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Rainfall (mm)
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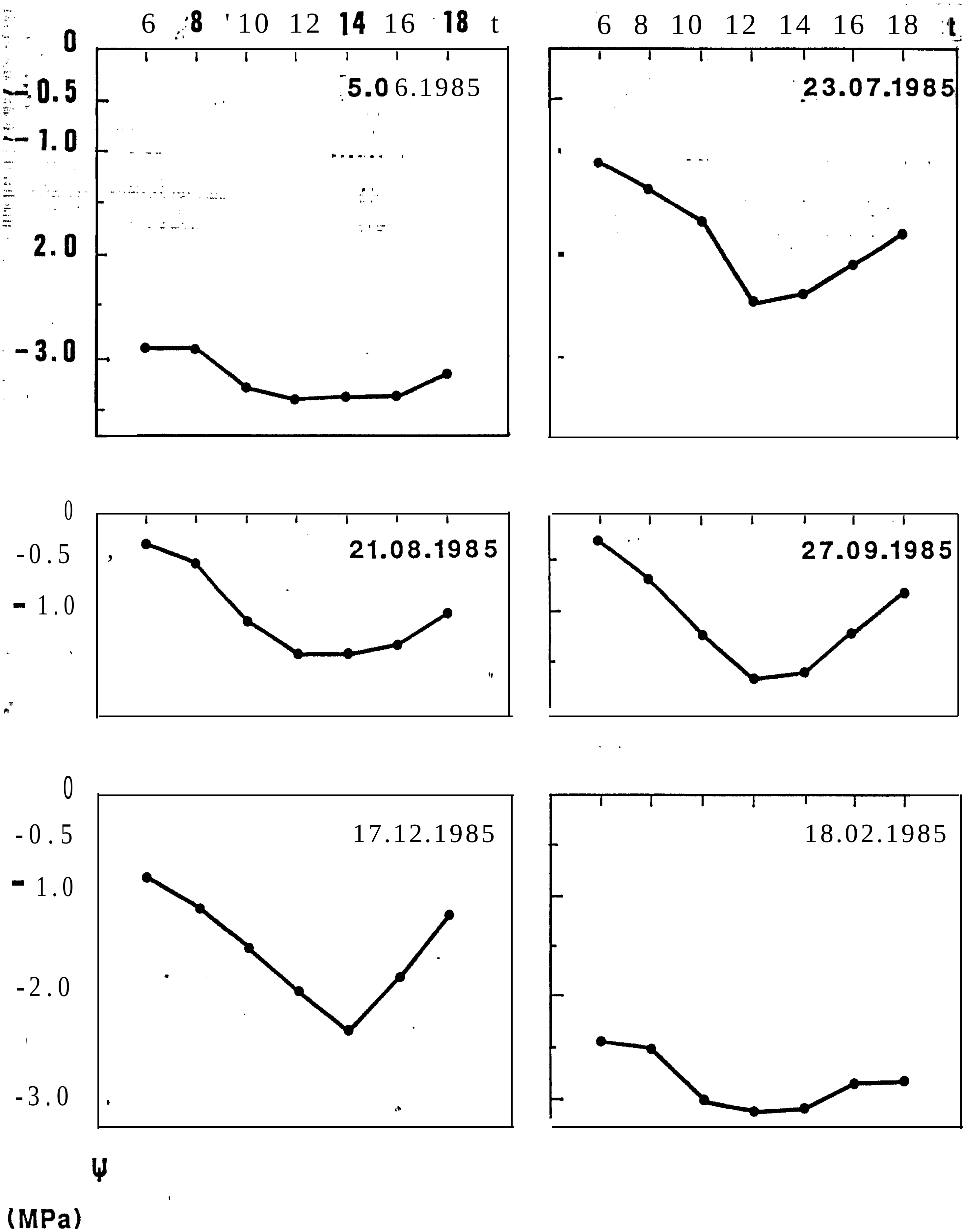
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6 8 10 12 14 16 18 t
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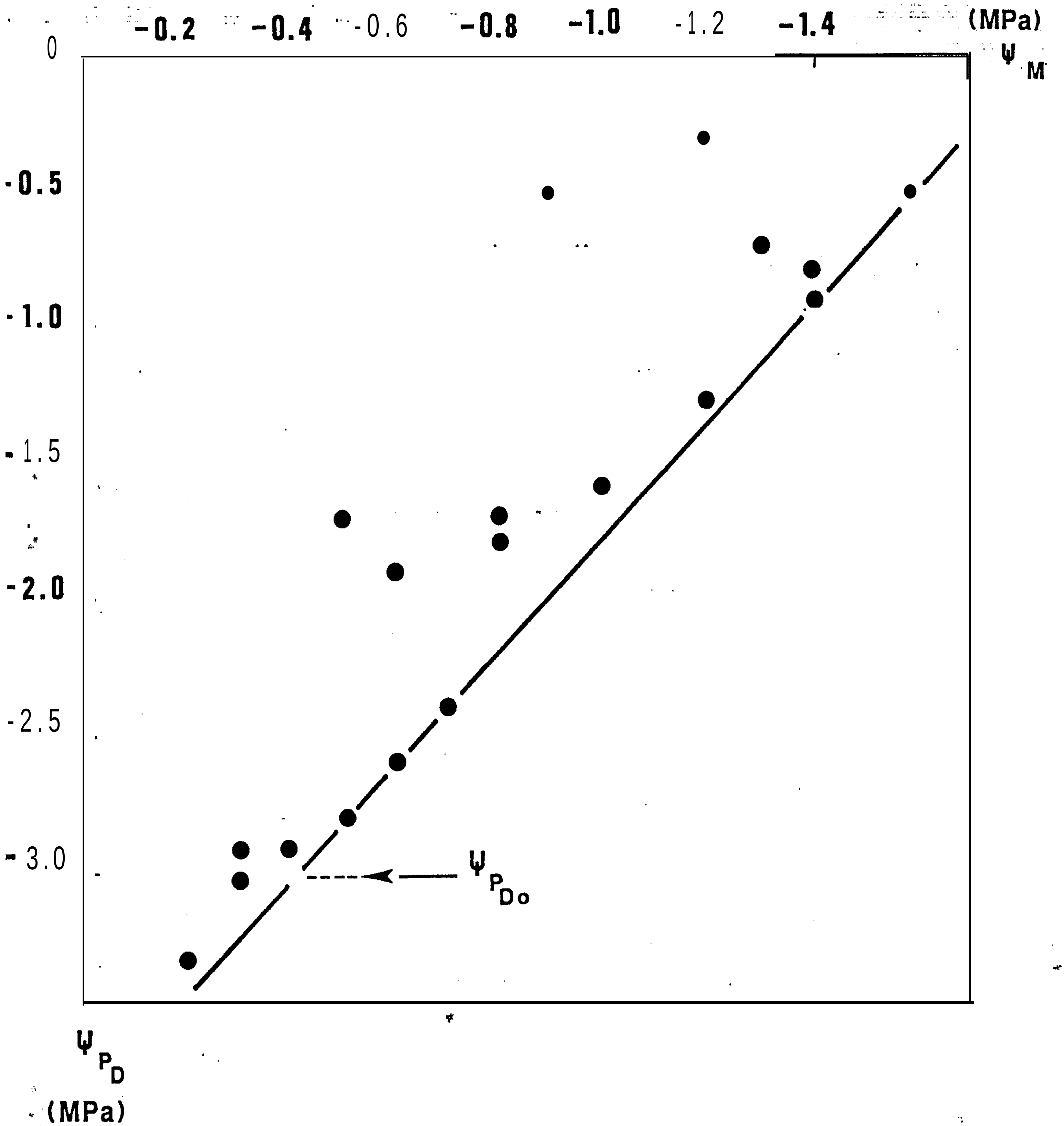
Ψ
(MPa)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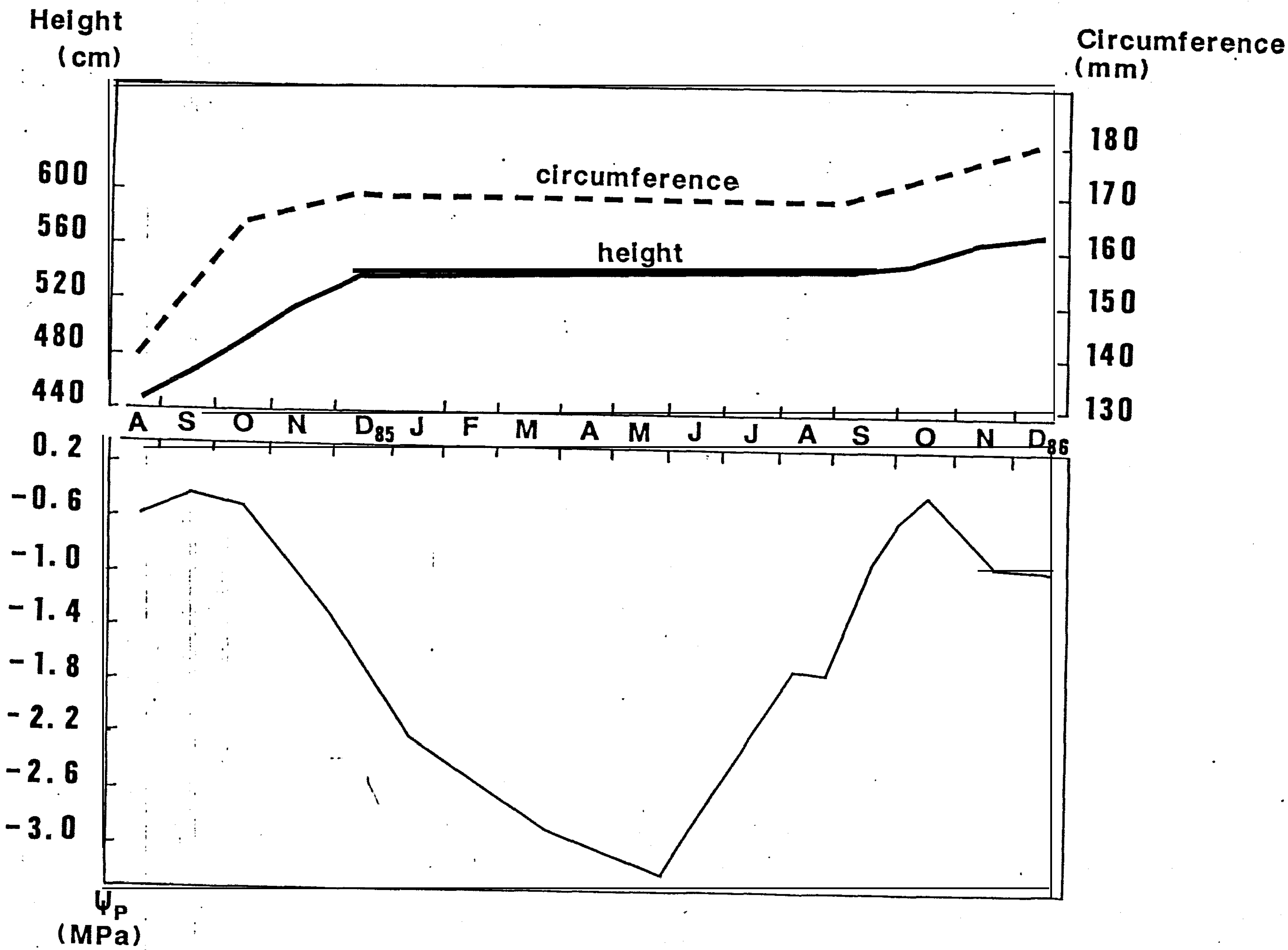
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Circumference
(mm)
180
170
160
150
140
130
circumference
height
A S O N D85 J F M A M J J A S O N D86
0.2
-0.6
-1.0
-1.4
-1.8
-2.2
-2.6
-3.0
Ψp
(MPa)