

**EARTH SURFACE TEMPERATURE
PART I. BARE - SOIL SURFACE**

by

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S u m m a r y : Temperatures of bare - soil surface and at 10 cm above it are examined herein, for the city of Thessaloniki (Greece) and for the period between the years 1930 - 1970. Normal temperature values are given (annual, monthly, and daily ones), as well as the extreme values recorded during the period examined.

There is proof of a temperature inversion between ground - surface and air - temperature (inside the meteorological screen), as well as between bare - soil surface and 10 cm above it, during the cold season; while there is a permanent inversion, the whole year through, between the levels of 10 cm above bare ground and 1,5 m above it.

Measurements of bare soil surface temperature were begun in the Meteorological and Climatological Institute of the Aristotelian University on April 1, 1930 (Mariolopoulos 1933¹, Alexandrou 1939²) and continued till October 31, 1940; then they were resumed on April 1, 1946. Thus the interval of World War II, is not included in the period examined herein.

The Met. Station has been functioning in the same location till December 31, 1959; then it was moved to its new installations near the new building of the Met. Institute (Livadas, 1972³) which lies

Notice: A couple of thermometers (max. and min.) are horizontally placed upon the bare ground and their bulbs covered with a thin layer, 1 - 2 mm thick, of natural soil, from the surrounding area, in order to record the temperature of the so - called «inner ground surface». The range of earth - surface thermometers used in Greece is, -30.0°C to $+75.0^{\circ}\text{C}$ (D. Kyriazopoulos - G. Livadas 1969²).

some 220m to the east of the old one, both inside the University campus.

Data used in this paper for the most part have been published in the series «Annuaire de l'Institut Météorologique et Climatologique de Thessaloniki» (Mariolopoulos ⁴, Kyriazopoulos ⁵, Livadas ⁶). We examine herewith the whole amount of data obtained from observations of the 1930 - 1970 period, except for the war period, as already mentioned.

a. *Mean Annual Temperature.* The mean annual temperature, on the bare - soil surface, for the 33 full years in the area examined, is given in Table I.

T A B L E I

Mean and extreme values of bare - soil surface temperature in Thessaloniki (periods: 1931 - 39 and 1947 - 1970).

Warmest year	22.51 C (1952)
Mean Annual	20.50 C \pm 1.02
Coldest year	18.55 C (1969)

From Table I we find that extreme values do not differ very much from each other.

b. *Mean Monthly Temperature.*

Mean monthly values as well as extreme monthly values of bare - soil surface temperature for the period examined are included in Table II, and illustrated in Graph I.

T A B L E II

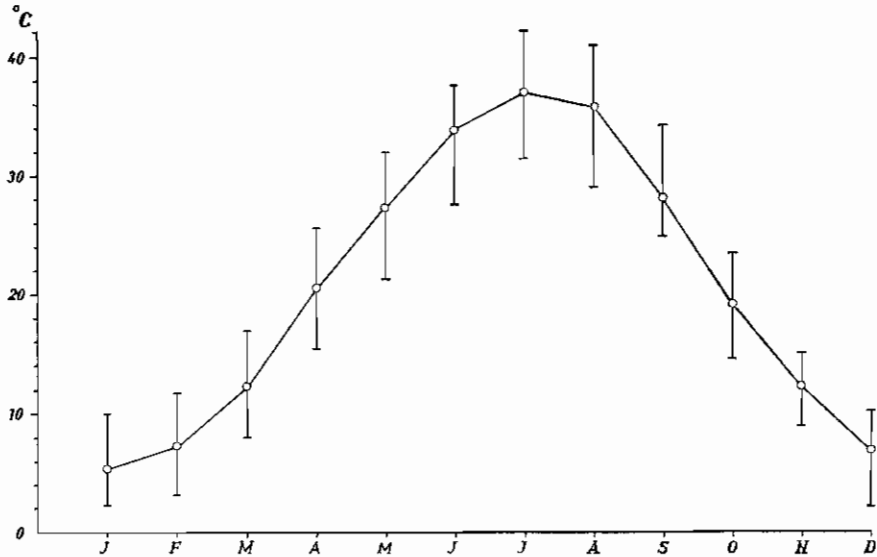
Mean and extreme monthly values of bare - soil temperature (period: 1930 - 1970).

	Maximum warmest		Mean	$\pm \sigma$	coef. of variation	Minimum coldest		Δ
J	9.61	1936	5.24	1.84	35.1 %	1.98	1947	7.63
F	11.79	1966	7.61	1.99	26.1	3.28	1954	8.45
M	16.93	1947	12.30	2.10	17.1	7.90	1956	9.03
A	25.61	1952	20.42	2.51	12.3	15.51	1969	10.10
M	31.98	1951	27.41	2.46	9.0	21.39	1970	10.59
J	37.60	1954	33.67	2.40	7.1	27.45	1968	10.15
J	41.81	1950	37.14	2.10	5.7	31.55	1969	10.26
A	40.96	1946	35.53	2.49	7.0	29.11	1968	11.85
S	34.15	1946	28.17	2.35	8.3	24.61	1968	9.54
O	23.74	1935	19.30	1.89	9.8	14.66	1951	9.08
N	14.89	1963	12.37	1.17	9.5	9.05	1953	5.84
D	10.31	1960	6.97	1.77	25.4	2.08	1948	8.23

T A B L E III
Frequency of monthly mean values

41 - 42								1						
40 - 41								2	1					
39 - 40								5	2					
38 - 39								3	3					
37 - 38						3		8	5					
36 - 37						3		8	6					
35 - 36						3		4	3					
34 - 35						9		1	5	1				
33 - 34						7		2	4	1				
32 - 33						3			4	1				
31 - 32				3		2	1			1				
30 - 31				5		2			1	4				
29 - 30				1	1				1	6				
28 - 29				6	1					3				
27 - 28				4	1					6				
26 - 27			1	6						5				
25 - 26			1	4						7				
24 - 25			1	5						1				
23 - 24			4									2		
22 - 23												1		
21 - 22			8	1								3		
20 - 21			5									5		
19 - 20			7									8		
18 - 19			4									11		
17 - 18			1									2		
16 - 17			2	3								2		
15 - 16			2	1								1		
14 - 15			2									1	4	
13 - 14			6										6	
12 - 13			6										12	
11 - 12		2	7										9	
10 - 11		1	4										3	1
9 - 10	1	4	4										1	3
8 - 9	2	9												4
7 - 8	3	10	1											12
6 - 7	7	2												6
5 - 6	3	1												5
4 - 5	9	1												1
3 - 4	5	4												2
2 - 3	3													1
1 - 2	1													
0 - 1														
0 - 1														

Table II and Graph I show that January has the smallest bare - soil surface temperature values, mean monthly and extreme ones as well; while July has the largest corresponding values.



GRAPH I

The mean annual temperature range of bare - soil surface is: 31.90°C .

There is also a close equivalence between standard deviation (S.D.) and monthly range of temperature values. The smallest range is recorded in November; this month has also a small S.D. value. November, being the first month of the winter season, has many rains but no sudden changes of weather conditions.

Also the coefficient of variation has high values during the main winter season (December - February), with its maximum in January, and small values during the warm season (June - August) with its minimum in July.

From the adjoined *Table III*, containing frequencies of mean monthly values, we find that the cold month of January, regarding the frequency of mean monthly values, holds the lower grades of the temperature scale, and is followed by the months of December and February. The warm month of July holds the highest grades of the scale, outranking even the month of August.

c. *Daily mean.*

The mean monthly, mean maximum and mean minimum values as well as absolute minimum and absolute maximum values of bare-soil surface temperature, are included in the following *Table IV*, and illustrated in Graph II.

TABLE IV

	Maximum			$\pm \sigma$	Minimum			
	Absol.	Mean	Mean		Mean	Absol.		
J	29.6	1963	13.21	5.24	1.84	-2.23	-13.0	1968
F	38.1	1960	18.52	7.61	1.99	0.27	- 9.4	1956
M	48.5	1947	26.13	12.30	2.10	3.07	- 7.5	1949
A	63.4	1947	37.36	20.42	2.51	7.29	- 4.5	1966
M	67.8	1951	45.87	27.41	2.46	12.46	0.4	1966
J	67.8	1939	52.84	33.67	2.40	16.49	5.2	1948
J	70.5	1939	57.08	37.14	2.10	18.94	10.5	1957
A	68.7	1935	55.91	35.53	2.49	18.39	7.7	1930
S	65.0	1952	46.22	28.17	2.35	14.80	0.5	1948
O	54.2	1935	33.00	19.30	1.89	10.20	0.9	1956
N	39.8	1965	21.96	12.37	1.17	6.19	- 6.0	1953
D	32.4	1955	14.65	6.97	1.77	1.68	-10.5	1948
Year			35.23	20.51		8.96		

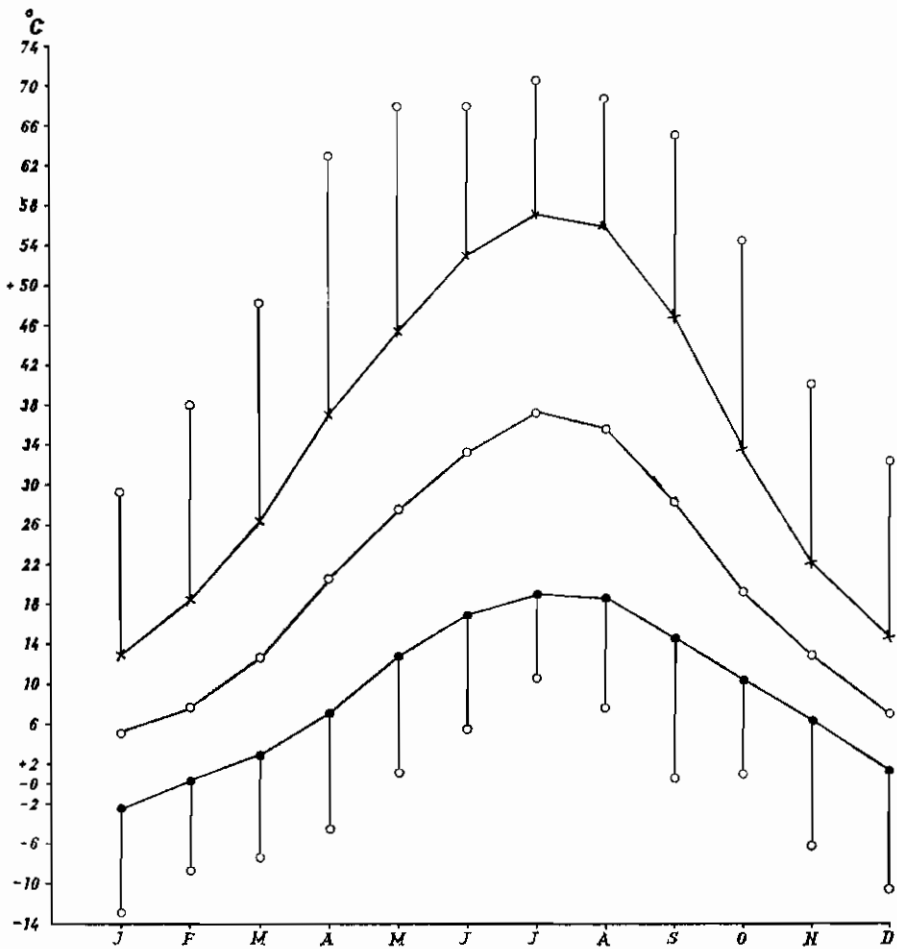
From this Table we find that the *absolute range* of bare - soil surface temperature is 83,5° C.

In Table IV as in Table II, January, the coldest month of the year, has the smallest temperature values in every column of both tables for the whole period examined. On the other hand July, the hottest month of the year, has the largest values of bare - soil surface temperature, in all the columns of the above two tables.

All the above speak for the existence of a close correspondence between temperatures of the lower layers of the atmosphere, that is air temperatures in the shade (within the met. screen and at a height of 1,50m), and bare - soil surface temperatures.

Moreover, from Table IV we also find that there have been recorded *ground - frosts* on the bare - soil surface, that is temperatures $< 0^{\circ}$ C, from November till April; the earliest date of ground frost being 4.11.1969 and the latest 12.4.1949. This means that the absolute maximum of the frost - free period on the bare - soil surface is 205 days.

From the adjoined Table V, containing frequencies of daily minima



GRAPH II

of bare - soil surface temperature, we draw the following conclusions:

a. Temperatures $< -10,0^{\circ}\text{C}$ have been recorded during the two months of December and January.

b. Temperatures $< 0,0^{\circ}\text{C}$ have been recorded during the six - months period from November to April; while the probability of ground frost on the bare - soil surface increases from November till January and then gradually decreases till April.

TABLE V
Frequency of daily minima of bare - soil surface temperature.

	J	F	M	A	M	J	J	A	S	O	N	D	
-16,1 - (-18)													1
-14,1 - (-16)													2
-12,1 - (-14)	1												5
-10,1 - (-12)													7
-8,1 - (-10)		4	1										49
-6,1 - (-8)	25	13	4										222
-4,1 - (-6)	87	73	13								9		14.35 %
-2,1 - (-4)	197	147	61	2							25	134	566
0 - (-2)	286	237	125	8							63	194	913
0 - 2	188	197	199	45	2					14	98	191	934
2,1 - 4	119	146	226	91	3					36	123	159	903
4,1 - 6	79	101	226	200	8	1			4	90	155	146	1010
6,1 - 8	49	36	136	256	49	1			19	148	157	87	938
8,1 - 10	14	6	53	247	161	13	5		44	213	158	45	959
10,1 - 12			10	129	259	40	8	10	110	206	126	7	905
12,1 - 14				34	277	140	16	27	216	213	66	4	993
14,1 - 16				7	193	257	74	113	272	99	9		1024
16,1 - 18				1	78	289	249	278	241	29			1165
18,1 - 20					19	191	381	340	90	6	1		1028
20,1 - 22					2	66	253	221	20				562
22,1 - 24					2	15	62	46	4				129
24,1 - 26						5	5	10					20
26,1 - 28					1	1	1	1					4
28,1 - 30						1	1	1					3
30,1 - 32													
32,1 - 34							1						1
TOTAL	1054	960	1054	1020	1054	1020	1051	1052	1020	1054	990	1021	42350
													5.81 %
													718
													0.08 %

T A B L E VI

Probability of ground - frost occurrence on bare - soil surface.

	Observational Days	Days with ground frost	%
November	990	97	9.80
December	1091	382	37.41
January	1054	605	57.40
February	960	474	49.38
March	1054	204	19.35
April	1020	10	0.98
		1772	

Generally out of 12350 observational days on which temperatures were taken with minimum thermometer:

—1.772 days, that is a percentage of 14,35 %, had temperatures $<0,0^{\circ}$ C.

—4.744 days, that is a percentage of 38.41 %, had minimum values between $0,0^{\circ}$ C and $+10,0^{\circ}$ C.

—5.115 days, that is a percentage of 41 - 42 %, had values between $10,1^{\circ}$ and $20,0^{\circ}$ C.

—718 days, that is a percentage of 5.81 %, had values between $20,1^{\circ}$ and $30,1^{\circ}$ C.

—1 day only, the 31.7.1958 had a value of $33,2^{\circ}$ C.

d. Temperature at 10 cm above ground.

Of paramount importance for the applications of Meteorology in Agriculture, are «frost days» (that is a period of 24 hours, in which the minimum air temperature in the screen, at 1,50 m from the ground, was below 0° C), as well as «ground frost days».

For the determination of «ground frost days», besides readings of grass minimum thermometers, we have used minimum thermometers mounted on special stands so that their bulbs would be at 10cm above ground; for the grass minimum thermometer, mounted at 10cm above ground, the grass tops were maintained at the same height.

Observations for these thermometers too were made thrice daily, and readings were taken from the position of the spirit within the thermometer tube; also minimum values were taken during the morning observation.

Notice: Minimum thermometers used, were of the spirit type, manufactured by R. Fuess, Casella, and others.

a. *Temperature at 10cm above bare ground.*

Temperature measurements at 10cm above bare ground were started on 1.1.1948 and are carried-on ever since.

T A B L E V I I

*Mean and extreme air temperatures at 10cm above bare soil surface
(Period: 1948 - 1970)*

	Mean	Mean Minimum	Absol. Minimum
J	4.87	— 0.62	—12.3
F	6.42	— 0.04	—10.5
M	9.29	2.32	— 7.5
A	14.37	5.25	— 3.9
M	20.32	9.70	0.2
J	24.86	13.65	5.2
J	27.78	16.06	1.5
A	27.34	15.97	4.5
S	22.39	13.67	1.5
O	16.48	8.62	0.2
N	11.63	5.23	—10.4
D	6.88	0.77	—15.4
	19.254		
Y	16.05		

In Table VII we observe that, January is the coldest month for air temperatures at 10cm above bare ground too, and July the warmest; while the mean annual temperature range is 22.91° C.

Absolute minima <0° C occur during the six - month period from November to April, while during the four - month period from November to February they are <—10.0° C.

From Table VIII we find that, out of 8.222 daily observations, in a percentage of 16,2 % minimum values are below freezing point (0° C), in a percentage of 39.8 % minimum values are >10.0° C, while the percentage is very small (1,4 %) for values >20.0° C.

Conclusions.

From the examination and study of bare - soil surface temperatures, we draw the following conclusions:

a. Mean and extreme bare - soil surface temperature values are recorded as a rule, the smallest ones during the coldest month of the year (January: mean monthly air temperature inside the screen

TABLE VIII
Frequency of temperature minima at 10cm above bare ground.

	J	F	M	A	M	J	J	A	S	O	N	D
14,1-(-16)	1											4
12,1-(-14)	2											1
10,1-(-12)	11	2									1	10
8,1-(-10)	14	9									8	17
6,1-(-8)	37	21	9								3	23
4,1-(-6)	84	56	34								12	60
2,1-(-4)	97	105	53	4							24	61
0 - (-2)	145	139	86	28	2						54	115
0 - 2	120	133	134	83	2				1	24	57	127
2,1-4	68	86	142	118	22		1		6	71	94	111
4,1-6	52	73	146	168	77		2		15	91	105	94
6,1-8	31	23	76	171	106	2	3		26	98	109	49
8,1-10	12	3	25	82	160	17	2		66	142	96	30
10,1-12	1		3	30	168	43	3		134	110	85	5
12,1-14			1	3	116	184	36		183	101	28	
14,1-16				1	42	182	101		139	41	4	
16,1-18					7	104	188		72	2	1	
18,1-20					3	37	116		13	1		
20,1-22						9	43					
22,1-24							7					
24,1-26							3					
26,1-28								2				
28,1-30								7				
30,1-32												
32,1-34												
34,1-36												
TOTAL	675	650	709	688	703	684	705	679	658	681	681	709

+ 5.86° C), while the largest ones occur in the warmest month (July: mean monthly air temperature +26.47° C).

T A B L E I X

	January	July
Absol. Max.	29.60 (1963)	70.50 (1939)
Mean Max.	13.21	57.08
Warmest month	9.61 (1930)	41.81 (1950)
Monthly mean	5.24 ± 1.84	37.14 ± 2.10
Coldest month	1.98 (1947)	31.55 (1969)
Mean Min.	- 2.23	18.94
Absol. Min.	-13.00 (1968)	±10.50 (1957)
Temp. Range		83.5
Annual range		82.9

b. Something like happens in the layer of 10cm above bare ground: again the months of January and July hold mostly the extreme values recorded.

T A B L E X

	January	July
Absol. Minimum	-12.30	+1.50
Mean Minimum	- 0.62	16.60
Mean monthly	+ 4.87	27.78

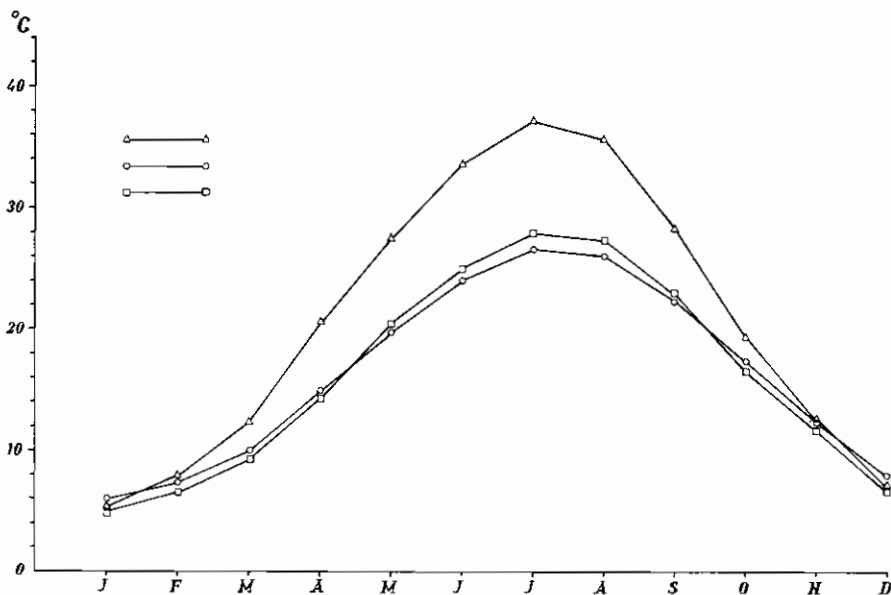
c. Comparing temperature values at the following levels: bare soil surface, 10cm above bare ground, and air-temperature at 1,5 above ground (inside a Stevenson screen), we observe that the air temperature in the shade (inside the met. screen, and at 1,5m above ground) is higher than temperature values upon the bare - soil surface and at 10cm above it.

1. During the November - January three-month period, first indication of temperature inversion in the surface layer in Thessaloniki (surface inversion).

2. Only during the estival five months from May to September, is the temperature at the level of 10cm above bare ground higher than

TABLE XI

	Air - Temp. (1930 - 70)	Bare - soil surf.	10cm above bare ground	Δ		
				1 - 2	1 - 3	2 - 3
J	5.86	5.24	4.87	+ 0.62	+0.99	+0.37
F	7.30	7.61	6.42	- 0.31	+0.88	1.19
M	9.92	12.30	9.29	- 2.38	+0.63	3.01
A	14.69	20.42	14.37	- 5.73	+0.32	6.05
M	19.58	27.41	20.32	- 7.83	-0.74	7.09
J	23.86	33.67	24.86	- 9.81	-1.00	8.81
J	26.47	37.14	27.78	-10.67	-1.31	9.36
A	26.28	35.53	27.34	- 9.25	-1.06	8.19
S	22.32	28.17	22.39	- 5.85	-0.07	5.78
O	17.31	19.30	16.48	- 1.99	+0.83	2.82
N	12.49	12.37	11.63	+ 0.12	+0.86	0.74
D	7.95	6.97	6.88	+ 0.98	+1.07	+0.09
Y	16.17	20.51	16.05	- 4.34	+0.12	+4.46



GRAPH III

that of the 1.5m level. This is the second indication of a surface inversion in the area examined.

3. The temperature of bare - soil surface is as an average higher during the whole year than that of the 10cm level. Meaning that we have a permanent temperature inversion between the ground surface and the 10cm above bare ground level.

The above three data, finally prove that in Thessaloniki there is a strong temperature inversion in the lowest layer of the atmosphere, which is due to the effects of strong nocturnal radiation in this area.

ΠΕΡΙΛΗΨΙΣ

Μελετᾶται ἡ θερμοκρασία τῆς ἐπιφανείας τοῦ γυμνοῦ ἐδάφους, ὡς καὶ εἰς ὕψος 10 ἐκ. ὑπεράνω αὐτοῦ, εἰς τὴν πόλιν τῆς Θεσσαλονίκης, διὰ τὴν χρονικὴν περίοδον 1930 - 1970. Δίδονται δὲ τόσον αἱ μέσαι κανονικαὶ τιμαὶ τῆς θερμοκρασίας (ἐτήσiai, μηνιαῖαι, ἡμερήσiai), ὅσον καὶ αἱ ἄκραι τιμαὶ αἱ ὁποῖαι ἐσημειώθησαν κατὰ τὴν ὑπὸ μελέτην περίοδον.

Ἐπίσης προκύπτει ὅτι, ὑφίστανται ἀναστροφαὶ τῆς θερμοκρασίας, τόσον μεταξὺ ἐπιφανείας ἐδάφους — θερμοκρασίας ἀέρος (μετεωρολογικοῦ κλωβοῦ), ὅσον καὶ μεταξὺ ἐπιφανείας γυμνοῦ ἐδάφους καὶ 10 ἐκ. ὑπεράνω αὐτοῦ, κατὰ τὴν ψυχρὰν περίοδον. Μία δὲ ἀναστροφή διατηρουμένη καθ' ὅλην τὴν διάρκειαν τοῦ ἔτους, μεταξὺ ἐπιφανείας 10 ἐκ. ὑπεράνω γυμνοῦ ἐδάφους, καὶ ἐπιφανείας 1,5 μ. ὑπεράνω αὐτοῦ.

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