Using the EPIC model to estimate soil moisture and temperature regimes and to assess the desertification risk.

Edoardo A.C. Costantini[1], Fabio Castelli[2], Giovanni L'Abate[1]*
[1]*Istituto Sperimentale per lo Studio e la Difesa del Suolo, 50121 Firenze Italy*
[2]*Istituto Sperimentale per il Tabacco, 37151 Bovolone (VR), Italy*
**Corresponding author (costantini@issds.it)*

Abstract

The desertification risk is estimated at a global level using the aridity index, that is the ratio of annual precipitation to potential evapotranspiration. The aridity index is often also used at the regional, national and local scale, although the scaling down of the evaluation should imply a more precise evaluation and delimitation of the areas. This can be obtained considering soil moisture and temperature regimes. Soil moisture and temperature regimes can be estimated by means of the EPIC (Erosion-Productivity Impact Calculator) model. EPIC estimates quantitative water content of each soil layer, works on a daily time step, and permits the simulation of time periods longer than the available meteorological data. Aim of this work was a new pedoclimatic classification method, targeted at assessing the desertification risk by means of processing the EPIC outputs. This methodology provides, besides pedoclimatic classification, a set of parameters useful to qualify the soil and furnishes, for each year, the standard deviation of the soil temperature and the number of days in which the control section is dry, moist or wet.

Keywords: pedoclimate, desertification risk, EPIC model, Italy.

Introduction

The assessment of areas with a potential desertification risk has utmost relevance in policy planning and the financing of mitigation measures. The United Nations Secretariat of the Convention to Combat Desertification (UNCCD) has stated that desertification means "land degradation in arid, semi-arid and dry sub-humid areas resulting from various factors, including climatic variations and human activities". In this definition, arid, semi-arid and dry sub-humid areas are the territories, other than polar and sub-polar regions, in which the aridity index, that is the ratio of annual precipitation to potential evapotranspiration, falls within the range from 0.05 to 0.65. This classification system takes into account only two climatic parameters, which are moreover rather common, yet is nevertheless a good approximation for the evaluations at a global or continental scale. The reliability of that criteria when used at a regional level, that is at Mediterranean, national, or local scale, is a questionable topic (DIS/MED, 2002). In fact, the scaling down needs a more precise evaluation, and a more detailed delimitation of the areas susceptible to desertification. Since soil is able to store water and mitigate drought, this can be obtained considering soil characteristics as well as temperature excursions.

Soil Taxonomy (Soil Survey Staff, 1999) classification considers soil moisture and temperature regimes. Soil moisture regime classification is based on a yearly assessment of the number of days in which the soil moisture control section is either moist, partially dry, or completely dry, while soil temperature regime classification refers to mean annual temperature at 0.50 m depth.

The soil moisture regimes "aridic", "xeric" and "ustic" can be used to characterize areas with a more or less strong desertification risk (Eswaran and Reich, 1998). In addition to Soil Taxonomy classes, Van Wambeke (1986) proposed the "dry xeric" soil moisture regimes for a more detailed qualification of the drier climates in the Mediterranean environment.

Similarly, we can use Soil Taxonomy criteria to single out areas with "thermic" and "iperthermic" soil temperature regimes, that is the lands where the mean annual soil temperature at 0.5 m depth is higher than 15 °C in the first case or 22 °C in the second one. The organic matter of these soils can be rapidly consumed, especially in agricultural land use, with a consequent increase of the potential desertification risk.

Pedoclimatic classification needs data collected over a long period of time, that is ten years or more. Since in most cases these data were not available, in our research work we used the EPIC mathematical model to simulate moisture and temperature soil conditions. EPIC (Erosion-Productivity Impact Calculator) model (Sharpley and Williams, 1990) estimates quantitative water content of each soil layer, works on a daily time step, can be calibrated with several climatic, soil and crop parameters, and permits the simulation of time periods longer than the available meteorological data. The daily soil outputs might be used for soil moisture and temperature regime classifications. The methodology has already been applied on experimental fields, in particular for soil moisture regime (Costantini et al., 2002), following which we needed to use it at a national scale, to ascertain its ability in assessing the desertification risk.

This work tests the use of EPIC outputs to classify both soil moisture and temperature regimes and to assess the desertification risk.

The method was applied to some benchmark soils in Italy, to check its reliability at the national and sub-national scales.

Methods

The methodology relies on a water content simulation attained by means of the EPIC model (version 3090) run on a daily step. Daily climatic inputs to the EPIC model's weather generator were minimum and maximum air temperatures, relative humidity, rainfall, and solar radiation. The Priestley-Taylor method (1972) was used to estimate potential evapotranspiration. The weather generator of the EPIC uses monthly mean values and some statistics obtained from daily values (standard deviation, skewness, probability of wet day after dry or wet day, average number days of rain per month) to simulate a 50-year period. In our simulations, monthly means came from long-term series of data (30 or more years) and daily statistics from the same long-term or a limited number (5 - 10) of recent years. In some cases, long term means were applied with the statistics of the nearest useful meteorological station.

The reference crop was a stable meadow, cultivated without irrigation, and maintained at a height of about 0.2 m. Optimal temperature for plant growth was set at 20 °C for warmest climate ("Mediterranean to subtropic" and "Mediterranen subcontinental to continental" climatic region, Finke et al., 1998) and 15 °C for the others. The model was also used for forest stands, with an original calibration for beech, based upon the information found in literature (Scarascia Mugnozza, 1999).

Soil layer input data included horizon depth, texture, rock fragments, measured or estimated bulk density, water content at field capacity and wilting point, and organic carbon. In cases where estimation was required, the Baumer's methodology, implemented in EPIC, was used.

Since EPIC estimates water content at different depths, according to the given soil horizons, we structured the input data to include four layers corresponding to the moisture control section of each studied soil. A suitable spreadsheet was created to estimate the limits of the soil moisture control section. The EPIC model was initialized at field capacity, then, using the weather generator, EPIC ran for a 50-year period of time. A specific software was worked out to fit the climatic data to the EPIC input format, and also to extract the daily soil moisture and temperature data from the EPIC output file. A set of spreadsheets were used to elaborate the daily data previously obtained, and to classify the soil moisture regimes of each of the 50 years simulated, according to Soil Taxonomy and Van Wambeke requirements (table 1). Soil Taxonomy requirements were modified, so as to be mutually exclusive and easily calculated using a worksheet. The dry xeric soil moisture regime was added to draw attention to the areas, like some part of Sicily and Sardinia, where fallow is widespread, the cultivation of a summer crop without irrigation isn't possible, and winter species sometimes need emergency irrigation (Raimondi et al., 1996). The same set of spreadsheet produced the average number of days per year when the moisture control section is in dry (water content equal or below wilting point), moist (water content between wilting point and field capacity), or wet (water content above field capacity) conditions.

EPIC is also able to estimate soil temperature of a single soil layer, working again on a daily time step. Unfortunately, the model provides solely the temperature of the second layer of the soil profile. Therefore, we needed to modify the actual depth of the upper layers to turn the selected depth (0.5 m in our case) into the second layer of the model input dataset. Chemical and physical parameters of this artificial layer were calculated as weighted means of the original values of the layers included as far as the selected soil depth. Besides long term mean, we calculated also the standard deviation and the number of days when soil temperature at 0.5 m is less than 7 °C. The last is at the same time a requirement envisaged by Soil Taxonomy, and an information that can be related to the period of biological inactivity and vegetative stasis in wintertime.

The methodology was applied matching a set of meteorological stations, representative of the different European climates of Italy (Righini et al., 2001), with benchmark soils, defined as the reference profiles of soil series that occupy a significant part of the land surrounding the meteorological stations (fig. 1).

Results

The sites examined were allocated in the soil and climatic regions to which they belong and then arranged, in descending order, according to the long term rainfall/evapotranspiration rate values (table 2a). The dry sub-humid conditions, that is R/ETP < 0.65, are rarely present in the Po Plain region, whereas they appear frequently in the plains and hilly areas of Central and Southern Italy. Semi arid conditions (R/ETP < 0.50) are sporadic in Po Plain, but are quite frequent along the coasts of Central and Southern Italy and also in the inner part of Apulia, Calabria, Sicily and Sardinia, where the lowest values of the R/ETP ratio were also found.

Soil moisture regimes

The udic class dominates in the Alps, while ustic and udic take over in the Po Plain (table 2b). In the mountainous areas of Central and Southern Italy the udic regime prevails, whereas the ustic is sporadic. Dominant xeric pedoclimate is frequent in Southern Italy and islands, as well as along the Tirrenian sea in Central Italy.

Soil moisture regime only partially reflects aridity conditions. In particular, the xeric and dry xeric pedoclimates can differentiate sites with similar aridity conditions. The sites of Cirò and Calangianus, for instance, both have an aridity index of 0.53, and a dominant dry xeric soil moisture regime, whereas Albidona and Vasto, with an aridity index of 0.52, result prevalently ustic.

The role played by soil characteristics in the pedoclimate classification was highlighted through the EPIC simulation of different soils using the same meteorological dataset. At Minoprio, for instance, the four elaborations obtained by the model produced two possible dominant soil moisture regimes, ustic or udic, according to the different wilting point.

The number of days when the soil moisture control section is, on average, completely dry, moist, or wet, provides further information, useful for characterizing soils and environments. Taking Minoprio's soils as reference, the two soils classified as udic show equal humidity conditions. On the contrary, the two soils with ustic regime show one as having twice as many dry days in the control section than the other. The elaboration points out a pedo-environment where cultivations are much more difficult to manage, because of lack or excess of water in the profile. Another significant example is that of the localities which have more than a hundred days when the soil moisture control section is dry, and wet days are only 1 or zero. A result which emphasizes a possible risk of salinization threatening these soils.

Soil temperature regimes.

Only two classes, mesic and thermic, characterize the studied soils (table 2b). However, we did not elaborated sites placed on the highest elevations. The mesic soil temperature regime is common in the temperate climatic regions, while the thermic one is diffused in the Mediterranean sub-tropical and subcontinental climates.

The influence of soil type on pedoclimate is well put in light by EPIC, especially where different soils are referred to the same meteorological station but, as a whole, EPIC estimates a long term soil temperature at 0.5 m not much different from air temperature. This contrasts with Soil Taxonomy indications, as well as with some of our field measurements obtained in the past (Costantini et al., 2001), and suggests caution in the interpretation of the results.

The standard deviation of soil temperature reflects both the continentality of the climate, similarly to the difference between summer and winter air temperature, and soil characteristics, in particular the water holding capacity.

The water content at field capacity is also one of the main soil factor controlling the number of days when soil temperature at 0.5 m is less than 7 °C. At Voghera, for instance, the two examined soils have 39 or 78 days when the temperature at 0.5 m is below the considered threshold. At Lavis, where the annual air and soil temperatures have mean values similar to that of Voghera, the soil with a lower field capacity has 87 cold days.

Conclusions

This experience highlights the amount of information which can be added to the aridity index suggested by the UNCCD to assess the desertification risk, by using the Soil Taxonomy pedoclimatic classification, in different soil and climatic regions of Italy. Soil Taxonomy classes, however, had to be slightly modified and integrated with the dry xeric soil moisture regime, so as to single out areas, where local experts have verified a higher drought risk.

The use of a somewhat sophisticated model, like EPIC, to calculate the soil moisture and temperature regimes, is justified by the extensive outputs, which can be further elaborated, as well as by the possibility of reproducing long term pedoclimate and coping with limited meteorological inputs.

The reliability of EPIC in simulating the soil moisture regime can be confirmed at the national scale, but its consistency with the soil temperature regime is not clear, and must be validated.

Nevertheless, the information obtained from EPIC outputs can be relevant to get more accurate qualification of every single soil typological unit. This can be useful to better delineate areas with more critical conditions, where financial investments for the mitigation of the desertification risk must have priority.

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References

Costantini E.A.C., Castelli F., Iori M., Magini S., Lorenzoni P., Raimondi S. (2001): Regime termico del suolo in alcuni campi sperimentali del nord, centro e sud Italia. Atti convegno SISS, Gressoney Saint Jean, 1999, (CD-ROM computer file), ISNP, Roma.

Costantini E.A.C., Castelli F., Lorenzoni P., Raimondi S. (2002): Assessing soil moisture regimes with traditional and new methods. Soil Sci. Soc. Am. J. Soil Sci. Soc. Am. J., 66, 6, 1889-1896.

DIS/MED Desertification Information System to Support National Action Programs in the Mediterranean (2002): Italian Country Report. Technical Workshop on thematic and sensitivity mapping on desertification and drought February 27 - March 2, 2002, Djerba (Tunisia), pp. 7.

Eswaran H. and Reich P. (1998): Desertification: A global assessment and risk to sustainability. In: Proc. Of 16th Int. Congr. Soil Science, Montpellier, France. CD ROM.

Finke, P., R. Hartwich, R. Dudal, J. Ibanez, M. Jamagne, D. King, L. Montanarella, and Yassoglu N. (1998): Georeferenced soil database for Europe. EUR 18092, Ispra, Italy.

Priestley, C.H.B., and Taylor R.J. (1972): On the assessment of surface heat flux and evaporation using large scale parameters. Mon. Weath. Rev. 100:81-82.

Raimondi S., Poma I. and Frenda A.S. (1996): Il pedoclima come fattore di sensibilità ambientale: esempio di metodologia applicata all'agro di Sparacia-Cammarata (AG). In "Il Pedoclima e applicazioni Tassonomiche". Palermo, Italia, 29-40.

Righini G., Costantini E.A.C., and Sulli L. (2001): La banca dati delle regioni pedologiche italiane. Boll. Soc. It. Scienza del Suolo, 50, Suppl., 261-271.

Scarascia Mugnozza G. (1999): Ecologia strutturale e funzionale di faggete italiane. Ed agricole, Bologna, 372 pp.

Sharpley, A.N., and Williams J.R. (1990): EPIC-Erosion/Productivity Impact Calculator. USDA Tech. Bull. 1768.

Soil Survey Staff (1999): Soil Taxonomy: A basic system of soil classification for making and interpreting soil surveys. 2nd ed. USDA-NRCS Agric. Handb. 436. U.S. Gov. Print. Office, Washington, DC.

Van Wambeke, A. (1986): Newhall simulation model, a basic program for the IBM PC [floppy disk computer file]. Dep. of Agron., Cornell University, Ithaca, NY.

Table 1 - Soil water and temperature regimes conditions by year.

Soil moisture:

Aridic: i) the Soil Moisture Control Section is completely dry for more than 180 d; ii) the SMCS is completely moist for less than 45 d in the 4 months following the winter solstice.

Dry xeric: i) exclusive of aridic conditions; ii) the SMCS is completely dry for more than 89 d; iii) the SMCS is completely moist for more than 44 d in the 4 months following the winter solstice.

Xeric: i) exclusive of aridic and dry xeric conditions; ii) the SMCS is completely dry for at least 45 d in the 4 months following the summer solstice, iii) the SMCS is completely moist for more than 44 d in the 4 months following the winter solstice.

Ustic: i) exclusive of aridic, dry xeric and xeric conditions; ii) one or more layers of the SMCS are dry for more than 89 d.

Udic: remaining conditions.

Soil temperature at 0.5 m depth:

Cryic: the annual mean soil temperature is lower than 8 °C and the summer temperature is lower than 15 °C

Frigid: the annual mean soil temperature is lower than 8 °C

Mesic: the annual mean soil temperature is between 8 and 22°C

Thermic: the annual mean soil temperature is between 15 and 22°C

Hyperthermic: the annual mean soil temperature is higher than 22 °C

The Iso prefix is added when mean summer and winter soil temperatures differ less than 6 °C.

Figure 1 - Meteorological stations and climatic regions of Italy.

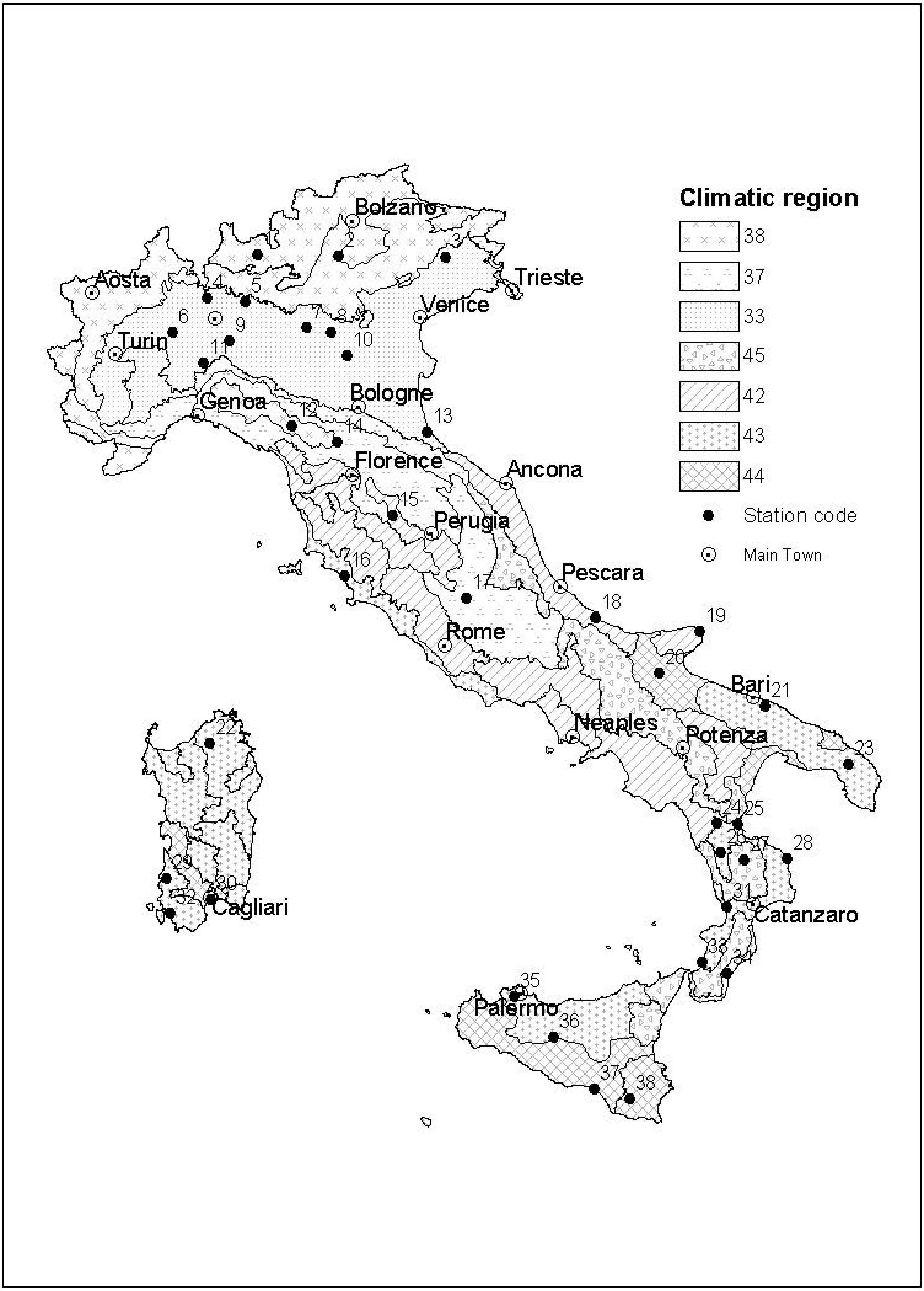

Table 2 – Pedoclimate of benchmark soils in the soil and climatic regions of Italy:
a) site characteristics.

Map	Site	Soil region	Climatic region	Annual rainfall	Annual evapotranspiration	Aridity index	Land use	Slope
code	name	code‡	code#	mm	mm	R/ETP	code¶	%
1	Sondrio	37.1	38	1023	894	1.14	25	0.1
1	Sondrio	37.1	38	1023	894	1.14	25	0.1
2	Lavis	34.3	38	894	1345	0.67	25	0.1
3	Vivaro	18.8	33	1582	1218	1.30	25	0.1
5	Bergamo	18.8	33	1177	1337	0.88	25	0.1
4	Minoprio	18.8	33	1149	1426	0.81	25	0.1
4	Minoprio	18.8	33	1149	1426	0.81	25	0.1
4	Minoprio	18.8	33	1149	1426	0.81	25	0.1
4	Minoprio	18.8	33	1149	1426	0.81	25	0.1
12	Cesenatico	18.8	33	740	1227	0.60	25	0.1
6	Confienza	18.8	33	805	1404	0.57	25	0.1
6	Confienza	18.8	33	805	1404	0.57	25	0.1
9	S.Angelo L.	18.8	33	768	1351	0.57	25	0.1
9	S.Angelo L.	18.8	33	768	1351	0.57	25	0.1
9	S.Angelo L.	18.8	33	768	1351	0.57	25	0.1
7	Cavriana	18.8	33	799	1428	0.56	25	0.1
7	Cavriana	18.8	33	799	1428	0.56	25	0.1
11	Voghera	18.8	33	744	1367	0.54	25	0.1
11	Voghera	18.8	33	744	1367	0.54	25	0.1
10	Borgofranco Po	18.8	33	656	1535	0.43	25	0.1
10	Borgofranco Po	18.8	33	656	1535	0.43	25	0.1
10	Borgofranco Po	18.8	33	656	1535	0.43	25	0.1
10	Borgofranco Po	18.8	33	656	1535	0.43	25	0.1
8	Bovolone	18.8	33	684	1129	0.61	25	0.1
12	Ligonchio	35.7	38	1727	1071	1.61	25	0.1
14	Camugnano	78.2	37	966	1465	0.66	25	0.1
14	Camugnano	78.2	37	966	1458	0.66	25	14.0
15	Cesa	64.4	42	743	647	1.15	25	0.1
17	Rieti	16.4	37	1027	1432	0.72	25	0.1
16	Alberese	60.7		682	2088	0.33	24	42.0
18	Vasto Marina	61.3	42	641	1228	0.52	25	0.1
19	Vieste	72.3	42	602	1417	0.42	24	0.1
20	Foggia	62.1	44	481	1416	0.34	24	0.1
23	Monteroni	72.2	43	475	1296	0.37	24	0.1
21	Rutigliano	72.2	43	623	2847	0.22	24	0.1
24	Montegiordano	61.1	45	824	1489	0.55	28	0.1
24	Albidona	61.1	45	824	1576	0.52	25	4.5
33	S.Cristina	62.3	43	983	1391	0.71	28	0.1
34	Melissa	62.3	43	952	1352	0.70	24	0.1
31	Lamezia Terme	62.3	43	1007	1547	0.65	24	0.1
35	Palermo	62.3	43	718	1326	0.54	24	0.1
28	Ciro'	62.3	43	789	1497	0.53	24	0.1
26	Tarsia	62.3	43	817	1644	0.50	24	0.1

26	Torano Castello	62.3	43	817	1654	0.49	25	0.1
25	Cassano Ionio	62.3	43	522	1550	0.34	24	0.1
36	Cammarata	62.3	43	591	1307	0.45	24	0.1
27	Cecita	66.5	45	930	1484	0.63	28	0.1
38	Ragusa	59.9	44	704	1368	0.51	24	0.1
37	Gela	62.2	44	373	1401	0.27	24	0.1
22	Calangianus	59.2	43	806	1534	0.53	24	0.1
29	Antas	67.4	44	732	1573	0.47	24	0.1
32	Palmas	76.1	43	553	1607	0.34	24	10.0
30	Cagliari	59.1	44	434	1509	0.29	24	0.1

‡ 37.1: Leptosols with Podzols and Cambisols of the Central Alps, partly with glaciers or permanent snow cover; 18.8: Cambisols - Luvisols of Po Plain; 35.7: Cambisols - Leptosols with Podzols and Regosols in the high northern Apennine; 78.2: Regosols - Cambisols of the Middle Apennine; 16.4: Cambisols - Leptosols with Luvisols of the Central Apennines; 64.4: Cambisols - Fluvisols with Luvisols and Vertisols of rivers e costal plains in Central Italy; 60.7: Cambisols with Luvisols and Fluvisols of Tirrenian coast of Central Italy; 61.3: Cambisols - Regosols with Vertisols of Central and Southern Italy; 72.3: Luvisols - Cambisols of Gargano (Apulia, Italy); 62.1: Cambisols - Vertisols - Luvisols, with Fluvisols, of the coast of Southern Italy; 72.2: Luvisols - Regosols - Cambisols of south-east Italy; 61.1: Cambisols - Regosols, with Luvisols of south-eastern part of the Apennine; 62.3: Cambisols - Vertisols - Luvisols of Southern Italy; 66.5: Cambisols - Leptosols of Sila and Nebrodi Mts. (Southern Italy); 59.9: Cambisols - Leptosols with Andosols of south-east Sicily; 62.2: Cambisols - Luvisols - Vertisols with Leptosols and Regosols of Southern Sicily; 67.4: Leptosols - Cambisols, with Luvisols, of Sardinia; 59.2: Cambisols - Leptosols with Luvisols of east Sardinia; 59.1: Cambisols - Leptosols with Vertisols, Phaeozems, and Calcisols, of Sardinia.

38: Temperate mountain; 33: Temperate suboceanic; 37: warm Temperate sub-continental; 42: Mediterranean sub-oceanic; 44: Mediterranean sub-tropical; 43: Mediterranean sub-continental; 45: Mediterranean mountain.

¶ 24: meadow in Mediterranean sub-tropical and subcontinental climates, 25: meadow, 28: beech forest, pine forest

b) soil moisture regimes.

Map	**Site**	**Field capacity**	**Wilting point**	**Soil Moisture Regime**				**Soil Moisture Control Section**		
				dry-xeric	**xeric**	**ustic**	**udic**	**dry**	**moist**	**wet**
code	name	m^3/m^3	m^3/m^3	%	%	%	%	days	days	days
1	Sondrio	0.230	0.091	0	0	14	86	20	342	3
1	Sondrio	0.098	0.047	0	8	34	58	55	297	13
2	Lavis	0.264	0.079	0	4	56	40	43	321	1
3	Vivaro	0.327	0.149	0	0	4	96	19	343	3
5	Bergamo	0.260	0.117	0	0	34	66	38	324	3
4	Minoprio	0.230	0.091	0	0	56	44	45	316	4
4	Minoprio	0.290	0.141	0	0	38	62	39	323	3
4	Minoprio	0.260	0.117	0	0	36	64	39	323	3
4	Minoprio	0.098	0.047	2	16	68	14	90	262	13
12	Cesenatico	0.094	0.027	0	4	96	0	89	276	0

6	Confienza	0.230	0.091	0	6	80	14	68	295	2
6	Confienza	0.290	0.141	0	2	68	30	59	305	1
9	S.Angelo L.	0.230	0.091	0	6	74	20	57	306	2
9	S.Angelo L.	0.290	0.141	0	2	72	26	54	310	1
9	S.Angelo L.	0.353	0.176	0	8	54	38	51	312	2
7	Cavriana	0.353	0.176	0	2	60	38	50	313	2
7	Cavriana	0.260	0.117	0	0	70	30	56	308	1
11	Voghera	0.353	0.176	0	10	78	12	69	294	2
11	Voghera	0.465	0.284	0	12	76	12	73	288	4
10	Borgofranco Po	0.230	0.091	0	4	86	10	75	289	1
10	Borgofranco Po	0.290	0.141	0	2	76	22	61	303	1
10	Borgofranco Po	0.353	0.176	0	4	66	30	59	305	1
10	Borgofranco Po	0.465	0.284	0	4	62	34	61	302	2
8	Bovolone	0.247	0.088	0	0	62	38	41	323	1
12	Ligonchio	0.177	0.091	0	2	38	60	44	311	10
14	Camugnano	0.289	0.107	0	6	84	10	71	292	2
14	Camugnano	0.381	0.237	0	8	84	8	80	200	85
15	Cesa	0.338	0.184	0	2	18	80	26	337	2
17	Rieti	0.235	0.121	0	14	84	2	85	273	7
16	Alberese	0.160	0.101	34	56	10	0	136	176	53
18	Vasto Marina	0.418	0.241	0	8	70	22	67	296	2
19	Vieste	0.333	0.247	38	36	26	0	128	236	1
20	Foggia	0.512	0.321	82	18	0	0	203	162	0
23	Monteroni	0.187	0.081	50	34	16	0	137	227	1
21	Rutigliano	0.378	0.218	36	24	40	0	149	216	0
24	Montegiordano	0.371	0.215	0	4	0	96	4	321	40
24	Albidona	0.307	0.175	6	40	54	0	109	208	48
33	S.Cristina	0.283	0.137	0	2	2	96	3	357	5
34	Melissa	0.332	0.181	12	54	34	0	101	261	3
31	Lamezia Terme	0.347	0.214	10	44	44	2	105	257	3
35	Palermo	0.234	0.138	62	36	2	0	134	231	0
28	Ciro'	0.328	0.185	42	26	32	0	124	239	2
26	Tarsia	0.370	0.174	46	50	4	0	125	237	3
26	Torano Castello	0.241	0.089	8	32	60	0	107	256	2
25	Cassano Ionio	0.338	0.207	58	30	12	0	142	221	2
36	Cammarata	0.223	0.135	34	52	14	0	121	242	2
27	Cecita	0.238	0.085	0	2	0	98	4	357	4
38	Ragusa	0.176	0.085	40	50	10	0	134	229	2
37	Gela	0.225	0.138	80	20	0	0	160	191	14
22	Calangianus	0.014	0.005	100	0	0	0	168	184	13
29	Antas	0.252	0.137	14	16	70	0	136	229	0
32	Palmas	0.078	0.025	100	0	0	0	196	166	3
30	Cagliari	0.055	0.084	8	44	48	0	164	201	0

c) soil temperature regimes.

Map	Site	Field capacity	Mean Annual air	Mean Summer air	Mean Winter air	Classification	Mean Annual soil	Standard Deviation	Soil temperature <7

							0.5 m		
code	name	m^3/m^3	°C	°C	°C	class	°C	°C	d/year
2	Lavis	0.264	12.2	20.9	2.0	mesic	11.8	4.5	87
4	Minoprio	0.098	13.5	22.6	4.7	mesic	13.0	3.1	3
10	Borgofranco Po	0.230	14.2	24.2	4.1	mesic	14.6	6.1	44
10	Borgofranco Po	0.290	14.2	24.2	4.1	mesic	13.8	5.4	47
11	Voghera	0.353	12.0	21.5	1.9	mesic	11.7	4.9	78
11	Voghera	0.465	12.0	21.5	1.9	mesic	11.8	3.7	39
12	Ligonchio	0.177	8.7	16.7	1.2	mesic	8.7	3.6	127
8	Bovolone	0.247	13.0	22.5	3.1	mesic	12.7	5.1	63
12	Cesenatico	0.094	14.2	22.4	5.3	mesic	13.4	4.5	35
14	Camugnano	0.289	12.0	20.6	3.4	mesic	11.9	4.2	51
14	Camugnano	0.381	12.0	20.6	3.4	mesic	11.6	4.4	67
15	Cesa	0.338	13.1	21.0	4.9	mesic	14.7	4.1	23
16	Alberese	0.160	14.5	21.8	7.6	thermic	15.1	4.4	7
17	Rieti	0.235	12.2	20.3	4.1	mesic	12.1	3.7	27
18	Vasto Marina	0.418	15.7	23.2	8.6	thermic	15.2	3.5	0
19	Vieste	0.333	16.2	24.0	9.0	thermic	15.7	3.6	0
20	Foggia	0.512	15.6	24.3	7.9	thermic	15.3	3.8	0
21	Rutigliano	0.378	15.2	23.3	7.9	thermic	15.0	3.9	0
22	Calangianus	0.014	13.8	21.4	6.8	mesic	13.2	2.8	2
23	Monteroni	0.187	16.7	22.5	10.8	thermic	16.2	3.4	0
26	Torano Castello	0.241	16.5	24.1	9.4	thermic	16.2	4.3	0
29	Antas	0.252	16.1	22.5	10.1	thermic	16.2	3.9	0
31	Lamezia Terme	0.347	17.5	24.1	11.3	thermic	17.2	3.2	0
35	Palermo	0.234	17.1	23.7	11.1	thermic	16.5	3.5	0
36	Cammarata	0.223	15.1	23.0	8.3	mesic	14.6	4.2	3
37	Gela	0.225	19.5	25.6	13.6	thermic	19.1	3.0	0
38	Ragusa	0.176	16.7	25.2	9.2	thermic	16.0	4.1	1