MOST SUITABLE AREAS FOR THE CULTIVATION OF HERBACEOUS ENERGY CROPS IN UMBRIA REGION (ITALY) AND BIOMASS PRODUCTION EVALUATION

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ABSTRACT: Nowadays arable land in Umbria Region (Italy) is occupied mainly by winter wheat, sunflower, forages, sugar beet and tobacco. Considering changes coming from new European Union Agricultural Policy some of this crops will bring reduced incomes to the farmers that could switch to energy crops. To this aim it is important to find out which are the most promising areas for herbaceous energy crops cultivation, such as sorghum, miscanthus, giant reed, corn, sunflower, cardoon. Most suitable areas can be found through pedoclimatic indexes and will be defined as the areas in which environmental variables meet physiological requirements of the energetic crop. The biomass yield from suitable areas depends on energetic crop genetic characteristics and on the influence of environment. Experimental studies have been performed at the Biomass Research Centre to assess and predict productivity of herbaceous energy crops in different environments. Three experimental fields are under study in the Umbria region and the data coming from these are used to predict productivity in the different suitable areas. Eventually by introducing state of art efficiencies for thermal and electric conversion a preliminary assessment of the energy potential from herbaceous crops is then available.
Keywords: Pedoclimatic conditions, energy crops, suitability

1 INTRODUCTION AND OBJECTIVE OF THE STUDY

Umbria Region represents 1,46% of the Italian population occupying 2,8% of the global surface and is the 9th region in Italy for energy demand pro-capita; each inhabitant consumes around 6,7 MWh of electricity and the pro-capita energy requirement in civil buildings is about 1 MWh [1].

Figure 1: Umbria Region (Italy)

The Regional Energy Master Plan requires both actions on energy demand (such as energy savings in industrial and civil buildings) and on energy production; especially energy from renewable sources may contribute to power and heat generation on small plants located throughout the Region, such as minihydraulic powerstations, that actually produce around 500 MWel, and photovoltaic power stations with 200 kW installed. Concerning biomass an increase of about 300.000 ton/year is expected [1] from CHP plants and from heating boilers using energy crops, straw, wine industry residues, olive husk and other residues [1].

In this study the attention is focused on herbaceous energy crops (maize, sunflower, sorghum, rapeseed,) and perennial ones (giant reed, miscanthus, cardoon). At the moment Umbria Region cultivates less then 1000 ha of poplar, but no herbaceous crop is dedicated to energy production. The objective of the study is to build a tool that calculates the yield of biomass obtainable from different crops in areas previously defined as suitable for that particular crop. The methodology is tested on Umbria Region to define different scenarios of plantation to reach the 300,000 ton/year target outlined in the Regional Energy Master Plan.

There are several works in the Literature that deal with this problem, such as:

- crop area planning [2];
- models of species' distribution [3];
- definition of agroclimatic regions [3];
- development of suitability indexes [4];
- land evaluation method [5-6].

Land evaluation was deeply promoted by FAO framework [7] and its subsequent guidelines for application to diverse types of land uses and land areas. The most important mechanism to find suitability, according to land evaluation method requires the match of areas with land uses to determine the relative suitability of each land area for each land use. Typically land evaluation is based both on physical suitability and economic suitability while this study focuses only on environmental suitability. For economic evaluation of different crops [8] can be considered.

For the Italian scenario interesting approaches are proposed in [9] and [10]. The first study describes the influence of climatic changes on agricultural production and classifies national territory from the point of view of agricultural potential, referring to soil-climate interactions. A pedoclimatic atlas of Italy describing rain, frost risk, mean, maximum and minimum temperature interpolations, is produced.

The second study defines bioclimatic indexes used to define the suitability of an area for the cultivation of energy crops. In [10] three bioclimatic indexes are individuated:

- Growing Degree Days (GDD, defined as the thermal degrees that are necessary to bring the crop to complete development, and calculated as the daily sum of the difference between mean temperature and base temperature, that is fixed);
- Water deficit (defined as the difference between global rain and evapotraspiration);
- Frost risk (defined as the days in which

temperature decreases below zero).

This three indexes are considered also in the present work (and also soil texture is introduced).

Concerning productivity modeling interesting approaches are proposed [11] and [12] on miscanthus. In [11] an interesting experimental methodology to simulate productivity on territorial basis (through GIS calculation) is presented. The basis of these are the following:

- Leaf Area Index measuring; (LAI), through leaf area planimeter;
- incident radiation (I_0) measuring, that is measurements of incident and transmitted PAR (400-700 nm) above and at the base of the canopy;
- radiation extinction coefficient calculation, through the following equation:

$$k= (\exp(ei-1))/LAI \quad (1.1)$$

where ei is radiation interception efficiency.

- intercepted radiation calculation (IRAD) through Monsi-Saeki equation:

$$IRAD= I_0e^{-kLAI} \quad (1.2)$$

- biomass production calculation through Monteith equation [13]:

$$W=RUE*IRAD \quad (1.3)$$

Where W is biomass weight, RUE is Radiation Use Efficiency (expressed in g/MJ) and IRAD is intercepted radiation, given by the Monsi-Saeki equation [14]. This approach will be followed also in this study.

2 METHODOLOGY

2.1 Introduction

The aim of this work is to classify the regional territory in suitable areas for energy crop cultivation and to evaluate the resulting biomass production and expected energy yield. The information is important for decision making and may suggests how to allocate arable land between different energy crops.

The logical paths that brings from the individuation of suitable areas to the calculation of productivity (and then of energy) is explained in figure 2 and consists of five steps in which from meteorological statistics and/or meteorological databases are inputted together with DTM model into an interpolation method (based on Cokriging) to find through specific constraints suitable areas for a specified energy crop. Those areas are then redistributed, and it is supposed that just only 10% of the surface is actually converted. Productivity is calculated based on simple biomass models [13] once the interpolation of intercepted solar radiation has been calculated. Knowing the resulting productivity for each kind of biomass, depending also on its composition a technology of energy conversion was chosen and then the resulting heat or electricity (or both in case of CHP) were calculated, considering biomass LHV and the efficiency of the adopted conversion system.

2.2 Most suitable areas determination

The steps that bring to the individuation of the most suitable areas for the cultivation of certain crops are outlined in the following:

1) climatic and pedologic data collection;
2) interpolation of climatic and pedologic characteristics to obtain maps that describe how they change through out the territory (pedoclimatic indexes);
3) individuate precise needs of the crops under analysis;
4) individuate by querying which are the areas that satisfy crop requirements, these are defined as optimal areas.
5) intersecting optimal areas, most suitable areas are found.
6) intersection of most suitable areas with actual cultivated fields (CORINE LANDCOVER);
7) surface distribution among crops under study.

The pedoclimatic indexes taken into account in this study are: GDD, global rain, soil texture and frost risk. GDD, Global Rain and frost risk have to be referred to the vegetative period of each plant under study, because a meteorological event that happens out of this period has no effect on the growth of the crop, and on biomass production which is the parameter of interest. So for each pedoclimatic index (but soil texture) 7 maps were produced (one for each crop studied) the total of the maps were 21 maps for meteorological parameters and 1 map for soil texture.

For each crop the map were produced according to the specific requirements of the culture in terms of temperature and rain etc. Then optimal areas were intersected to determine the final most suitable area that could contain also non agricultural land. A final most suitable area was then obtained through an intersection with CORINE LANDCOVER MAP to focus the attention on fields.

Hereafter the example of sorghum is presented. In figure 1 the optimal areas for: GDD, RAIN, and SOIL TEXTURE are reported.

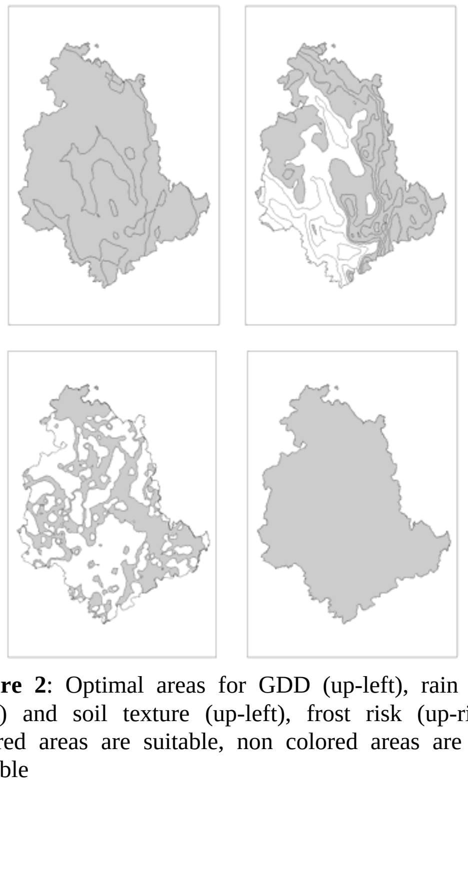

Figure 2: Optimal areas for GDD (up-left), rain (up-right) and soil texture (up-left), frost risk (up-right) colored areas are suitable, non colored areas are non suitable

Optimal areas are given by the selection of the surfaces that satisfy crop requests. Those are presented in table 1.

Table 1: Crop needs (* indicates that the needs have been estimated based on experimental measurements)

Specie	Base t (°C)	GDD (°C)	Water (mm/ha)	Soil
Corn	8 [15]	1300 [15]	500-600 [16]	All [16]
Giant reed	10*	1500*	700*	All [17]
Miscanthus	10 [11]	800 [11]	625-780[18]	All [17]
Sunflower	6 [15]	1550 [15]	300-400 [16]	Clay-loam [16]
Sorghum	8 [15]	1450 [15]	300-350 [16]	Clay-loam [16]
Rapeseed	5 [19]	850 [19]	450-500 [20]	Clay-loam [16]
Cardoon	7*	750*	400 [21]	Clay-loam [21]

Intersecting optimal areas, most suitable areas are found. These have to be intersected with actually cultivated areas – reported in CORINE LANDCOVER- (see figure 1).

Figure 3: Sorghum most suitable area.

In the case of sorghum it can be seen as there are areas in which global rain falling during the whole vegetative period is sufficient to grant the growth of the crop; for maize, miscanthus and giant reed there is not enough availability of water, so it has been supposed that they will be planted in surfaces that are very close to rivers or lake to grant irrigation water.
Giving that the aim of this work is to find most suitable areas to convert them from conventional crops to energy crops, once the 7 surfaces have been founded it has to be checked that they do not overlay each other.
Once the most suitable area of maize, miscanthus and giant reed are fixed, the other surfaces are derived in the following way:

- cardoon= cardoon – (sunflower + miscanthus + giant reed + sorghum).
- sunflower= sunflower- (maize + miscanthus + giant reed);
- sorghum= sorghum-(sunflower-maize + miscanthus + giant reed)
- rapeseed = rapeseed- (maize+miscanthus+giant reed+cardoon);

The resulting surfaces are the following.

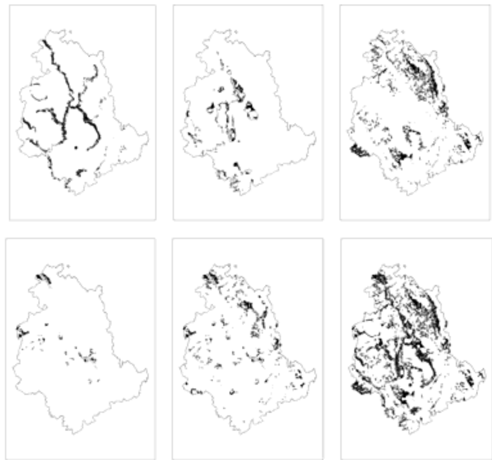

Figure 4: Allocated most suitable area: maize + miscanthus + giant reed (up-left), cardoon (up-center), sunflower(up-right), sorghum (down-left), rapeseed (down-center), union (down right)

The extension of each most suitable area is proposed in table 2 (where it is also compared with the actual cultivated areas in Umbria Region).

Table 2: Summary of most suitable areas for the crops under study

Specie	Suitable area (ha)	Actually cultivated area (ha)	Difference
Corn	15.372	16.000	-628
Miscanthus	15.372	/	15.372
Giant Reed	15.372	/	15372
Sunflower	75.584	40.000	35.584
Sorghum	10.134	419	9.715
Rapeseed	39.656	103	39.553
Cardoon	26.731	/	26.731

The only hearbaceous crop actually cultivated in the region is sunflower, but this is used for food purposes.
Only 10% of the most suitable areas reported in table was considered possible to be converted into biomass production.

2.2 Productivity determination

Once most suitable areas have been individuated, then it has to be calculated how much biomass this areas can produce. This can be done using data of global radiation taken from PVGIS Project [22]: Geographical Assessment of Solar Energy Resource and Photovoltaic Technology. Then from the values of global radiation referred to the growing period of different crops (see table 3) the intercepted radiation has to be calculated, using formulas 1.1, 1.2 and Monsi Saeki equation (1.3). RUE (Radiation Use Efficiency) and LAI (Leaf Area Index) have been measured experimentally (as it will be explained later), according to the methodology cited in [11]. Once the intercepted radiation has been calculated it can be interpolated through out Umbria territory and then multiplied for RUE to obtain biomass production. The mean production multiplied for the interested surface gives total production.

Table 3: Crop sowing and harvesting dates

Crop	Sowing day (1-365)	Harvesting day (1-365)
Corn	150	254
Miscanthus	150	285
Giant Reed	150	285
Sunflower	75	245
Sorghum	120	250
Rapeseed	274	170
Cardoon	100	244

2.3 Energy scenarios

Once the total biomass produced yearly by the potentially cultivable areas found before have been calculated it has been supposed how this biomass will be used. An example is proposed in the following table.

Table 4: Energy conversion scenarios

Specie	Final use	Efficiency
Corn	Biogas (electricity)	0,3
Miscanthus	heat	0,9
Giant Reed	heat	0,9
Sunflower	Biofuel	/
Sorghum	electricity	0,3
Rapeseed	Biofuel	
Cardoon	70% electricity	0,2
	30% heat	0,9

3 DATA CONTROL

3.1 Most suitable areas determination: pedoclimatic atlas.

The interpolations of: mean temperature, global rain, soil texture and frost (related to the mean year) were compared with data presented in the Atlas (that are referred to the Italian territory, so they are less detailed). Here the maps are proposed. Errors are calculated in 5 points situated in the center, north, west, east and south of Umbria (the coordinates are expressed in the reference system ED_1950_UTM _ZONE_32N). In figure 5 the comparison of mean temperature maps is proposed.

Table 5: Yearly mean temperature: error calculation

Point	Coordinates (ED_1950_UTM _ZONE_32N	Inter polation (°C)	Atlas (°C) [9]	Error (%)
Center	782588-4778358	14,0	12,0	14
North	764692-4821812	14,2	12,8	9
West	742647-4761895	14,2	12,7	10
East	816319-4773954	13,8	12,3	10
South	795405-4701224	14,0	14,3	2

The average error between interpolated mean temperature and [9] data is about 2°C (see table 5), while [23] data, presented in figure 6, are more similar.
In figure 7 the comparison of global rain interpolations maps is proposed.
Rain interpolation differ in some cases from control data, anyway the general trend is similar (see table 6).
In figure 8 the comparison of soil texture interpolation maps is proposed. In figure 9 the comparison of frost risk interpolation maps is proposed.

Table 6: Yearly global rain: error calculation

Point	Coordinates (ED_1950_UTM _ZONE_32N)	Inter polation (mm/ha)	Atlas (mm/ ha) [9]	Error (%)
Center	782588-4778358	696	802	15
North	764692-4821812	816	802	2
West	742647-4761895	737	752	2
East	816319-4773954	1088	848	22
South	795405-4701224	1224	850	30

Table 7: Soil texture: values comparison

Point	Coordinates ED_1950_UTM_ ZONE_32N	Inter polation	Atlas [9]
Center	782588-4778353	Clay-loam	Clay-loam-silty
Nord	764692-4821812	Clay-loam	Clay-loam
West	742647-4761895	Clay-loam	Clay-loam
East	816319-4773954	Clay-loam	/
South	794505-4701224	Clay-loam	Clay-loam

With respect to the other interpolations frost risk refers to a period and it is not referred to the whole year. CRB interpolation is referred to sorghum vegetative period, while pedoclimatic Atlas refers to the period comprised between the beginning of growth season and 31st july. Growth season is defined as the period in the year in which temperature is always over a thermal threshold (that in this case is set to 10°C).
Spring frost risk is very close to zero. While winter frost risk is higher, but the only winter crop considered in the study is rapeseed.

3.2 Productivity determination: experimental fields network

As above said Radiation Use Efficiency and Leaf Area Index growing trend were measured experimentally for the crops under study. RUE was measured sampling at the end of the growing season the produced biomass, measuring its dry weight and referring it to intercepted radiation (calculated using LAI). The trend of LAI during sorghum growing season is proposed in figure 10

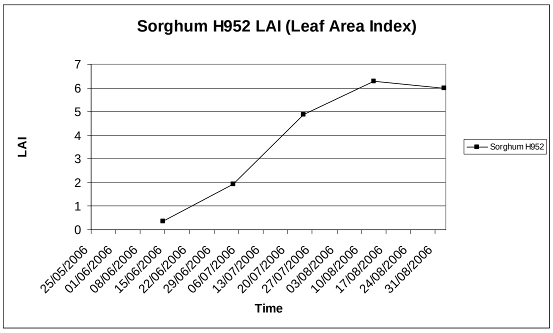

Figure 10: Sorghum LAI trend during time

Figure 11: LAI measurements

The measures interested 5 experimental fields situated in different sites through out Umbria territory:

- Trestina, field established in collaboration with private farmer (sorghum, hemp, kenaf);

Figure 12: Trestina experimental field

- Pietrafitta field, established in collaboration with local agency (Black locust)[24] [25];

Figure 13: Pietrafitta experimental field

- Beroide field, established in collaboration with private farmer (poplar clones);

Figure 14: Beroide experimental field

- Montelabate field, established in collaboration with private farmer (jerusalem artichoke, black locust, poplar clones).

Figure 15: Montelabate experimental field

- Casalina field, established in collaboration with Perugia University experimental farm.

Figure 16: Casalina experimental field

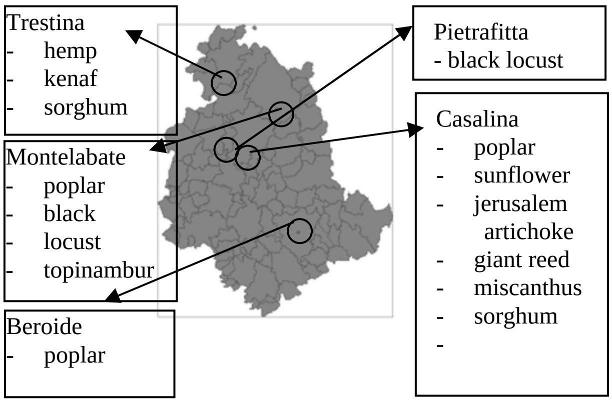

Figure17: Fields monitoring network

Also meteorological parameters, CO2 assumption and physico-chemical properties of biomass were measured.

3.3 Energy scenarios: Regional Energy Plan

For each crop an energy conversion scenario was chosen (table 4), using the values of LHV measured in CRB Laboratory (see table 8) and hypotetical conversion efficiencies it is possible to calculate the energy yield. The obtained values were compared then with those reported in the Regional Energy Plan (that is a yearly consumption of 449 ktoe electricity and 667 ktoe methane).

Table 8: Biomass LHV, and biofuel conversion ratio

	Energy yield [22]	
Specie	LHV(MJ/kg)	Kg biodiesel / kg biomass
Corn	17,80	
Giant reed	16,70	
Miscanthus	16,90	
Sunflower		0,45
Sorghum	15,80	
Rapeseed		0,28
Cardoon	14,1	

4 RESULTS

Giving the surfaces proposed in table 2 the productivity was calculated referring to 10% of the final most suitable area.

Table 9: Potential yearly productivity of biomass

Specie	10% suitable area (ha/year)	Productivity (t/year)
Corn	1.537	32.277
Giant reed	1.537	39.962
Miscanthus	1.537	52.258
Sunflower	7.558	10.203
Sorghum	1.013	26.338
Rapeseed	3.965	7.930
Cardoon	2.673	72.171
Total	19.820	241139
Expected from Regional Energy Master Plan		333.851

Table 9 shows the available biomass from energy crops if 10% of the suitable areas were cultivated. Therefore to meet the target set by the Regional Energy Master Plan the contribution required from poliennal SRF has to be around 92.712 ton/year.

The deriving energy production is proposed in table 10, and related also to the actual consumption.

Table 10: Potential yearly productivity of energy, compared to yearly energy demand

		Specie	Bioenergy Offer (ktoe)	Energy Demand (ktoe)	Contri bution (%)
Heat		Giant reed	14,3		
		Miscanthus	19,0		
		Cardoon	6,6		
		Total	40,0	667	6,0%
CHP	El.	Sorghum	0,6		
		Corn	2,5		
		Cardoon	3,4		
		Total	6,5	449	1,4%
	Heat	Sorghum	1,2		
		Corn	5,0		
		Cardoon	6,8		
		Total	8,5	667	1,3%

5 CONCLUSIONS

The most suitable areas for cultivation of hearbaceous crops such as giant reed miscanthus, sorghum, sunflower, cardoon, maize, rapeseed were individuated. Then the potential productivity obtainable has been estimated and assuming certain forms of energy conversion the potential contribution of biomass from herbaceous crops to the energy consumption in Umbria region was calculated. It has been seen as :

- miscanthus, giant reed and cardoon if cultivated in a surface equal to 10% of the suitable area, can avoid the consumption of 6,0% of the methane consumed yearly in the region;

- sorghum, corn, cardoon if cultivated in a surface equal to 10% of the suitable area, can produce 1,4% of the electricity required and (in the hypothesis of cogeneration) can avoid the consumption 1,3% of the methane consumed yearly in the region.

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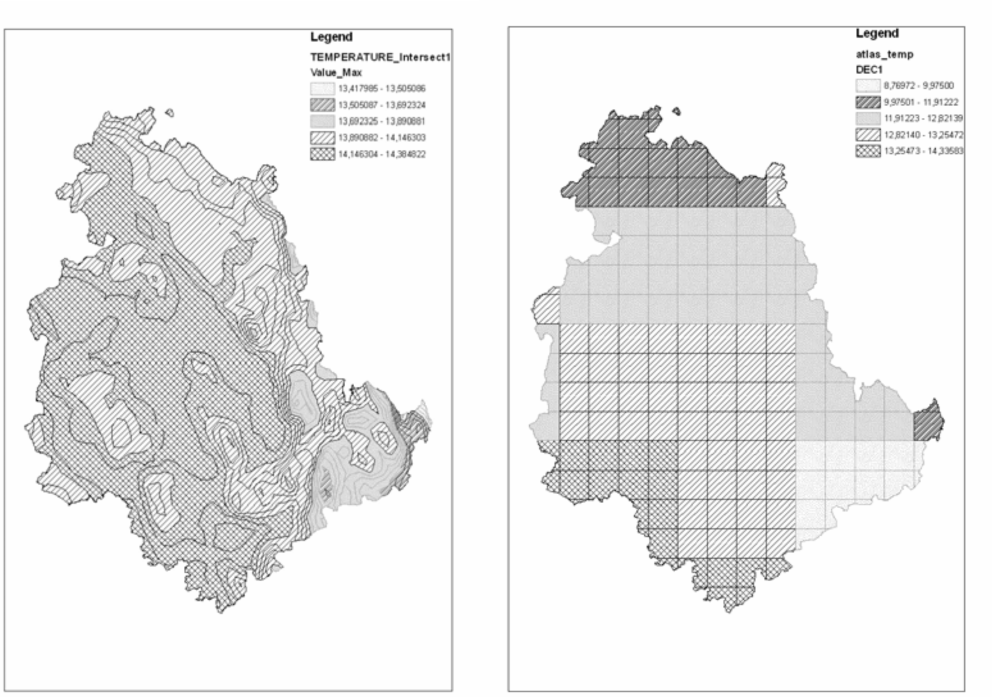

Figure 5: Comparison between mean temperature interpolations; CRB interpolation (left) control interpolation (right);

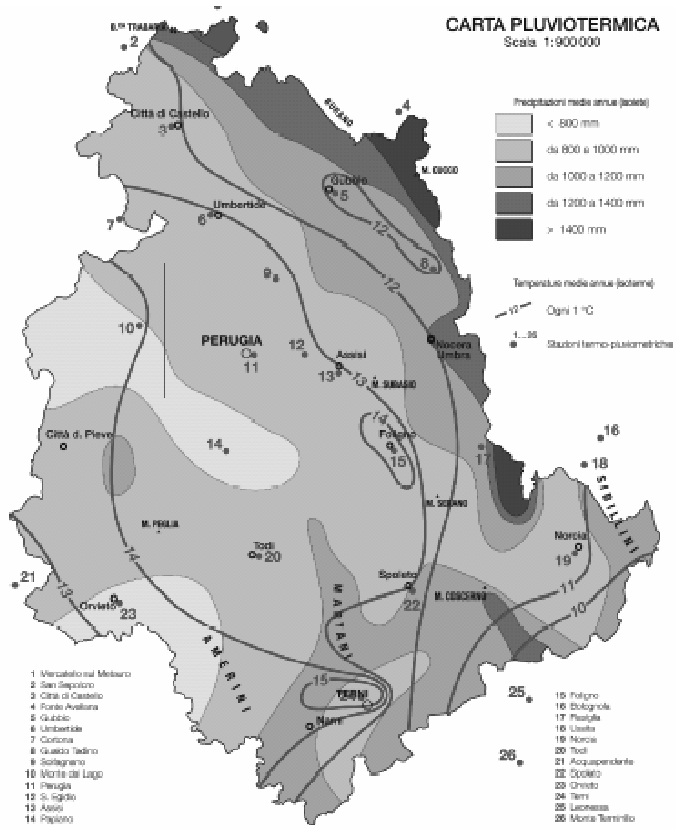

Figure 6: Mean yearly temperature and global annual rain

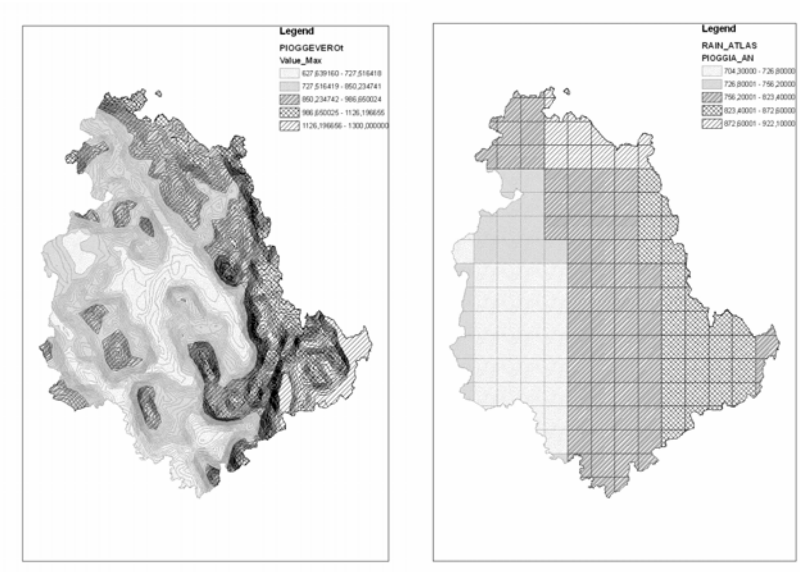

Figure 7: Comparison between global rain interpolation; CRB interpolation (left) control interpolation (right);

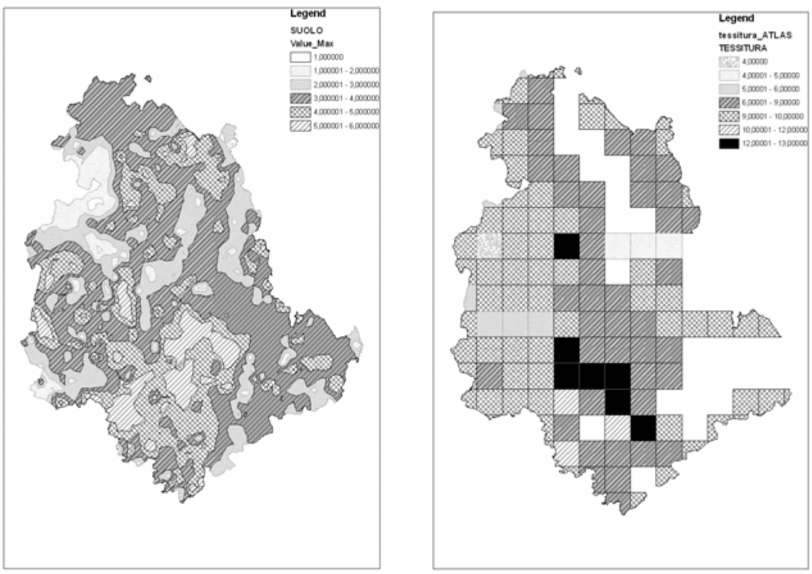

Figure 8: Comparison between soil texture interpolations; CRB interpolation (left) control interpolation (right);

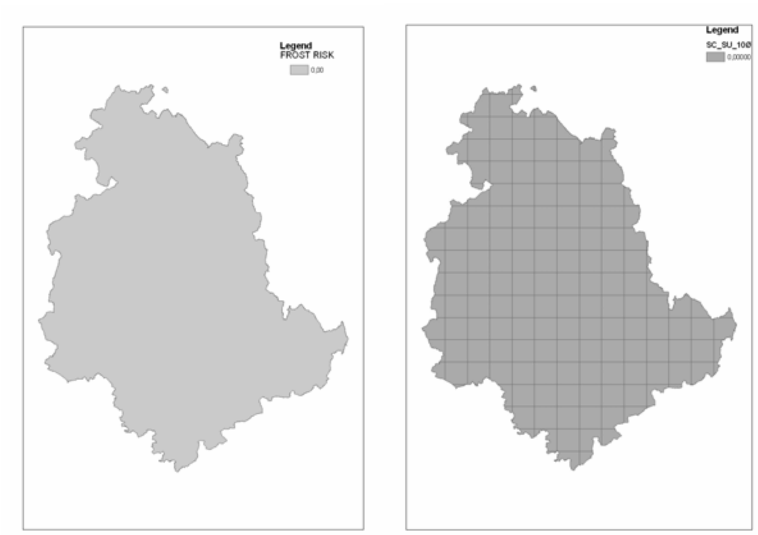

Figure 9: Comparison between frost risk interpolations; CRB interpolation (left) control interpolation (right);

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