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Soil climate and pedology of the Transylvanian Plain, Romania

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SOIL CLIMATE AND PEDOLOGY OF THE TRANSYLVANIAN PLAIN, ROMANIA

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ABSTRACT

The Transylvanian Plain (TP) is a 395,000 ha region located in north-central Romania and is an area of agronomic importance in the region. The TP is characterized by hilly terrain, dissected by the Someş and Mureş Rivers. The terrain creates a unique situation when assessing pedology and soil temperature. Soils can change quickly across the landscape in the TP due to the terrain. To account for these differences, soil temperature was measured to predict soil temperatures as well as to evaluate growing conditions. Twenty stations were installed for a long-term temperature and pedology study. Pedons were described for morphological characterization at each location. Pedon descriptions were then classified using both *US Soil Taxonomy (USST)* and *Sistemul Roman De Taxonomie A Solurilor (Romanian System of Soil Taxonomy- RSST)*. The two soil classification systems aligned for all 20 stations. Morphological descriptions showed that there were 10 Mollisols (Cernisoluri), 4 Alfisols (Luvisoluri), and 6 Inceptisols (Cambisoluri) according to *USST (RSST)*. All locations had sufficient organic carbon to classify as mollic epipedons. However, other requirements such as: color and depth of epipedon were not met. Soil temperature is identified at the family level in *USST* and is not present in *RSST.* In addition to morphological characterization at the 20 locations, soil and air temperatures were measured via a data logging system. Soil temperature is a vital property when evaluating crop growth due to its influence on germination and root growth. Growing degree days (GDD) were evaluated for the summer of 2009 using air temperature for the TP. Craiesti and Filpisu Mare were significantly warmer than Matei and Zoreni and gained sufficient GDD for tasseling 21 days earlier. Mean annual soil temperature (MAST) was predicted using a multiple regression model and Landsat 7 ETM+. Landsat provided a better linear relationship to *in situ* MAST values with a coefficient of determination value (R^2) of 0.63 compared to the multiple regression with an R^2 of 0.42. Significant differences were found in MAST values

between agricultural and urban land covers. The use of Landsat ETM+ could reduce the time and expense of large *in situ* field studies.

CHAPTER 1. INTRODUCTION/LITERATURE REVIEW

1.1 THE TRANSYLVANIAN PLAIN, ROMANIA

Romania covers 238,391 sq km, of which 36 percent is comprised of highlands and hill country. The Transylvanian Plain (TP) is a highly dissected basin located in the Northwest region of Romania and is a feature within the Transylvanian Basin (TB). Transylvania in Latin translates to "The land beyond the forest" (Bodea and Candea, 1982). The TB is ~2,000,000 ha and is surrounded by the Carpathian mountain range to the east and the south. The TP is approximately 395,000 ha; two rivers enclose the TP, with the Someş River to the north and the Mureş River to the south. The Mureş River is the longest river in Romania and flows 718 km (Posea and Velcea, 1975). The two rivers which are draining in a westward direction have strongly dissected the TP (Foldvary, 2009). The southwestern portion of the plain is the driest portion of the TP. Part of the reason that this portion of the TP is warmer is due to Foehn winds (Nicolescu *et al.*, 2002; Ando, 1995). Foehn winds are a warm, dry wind which travels down the leeward side of mountain ranges causing temperatures to rise; these are also referred to as austru winds in Romania (Defant, 1951). In Romania, regions that are typically considered plains are referred to as tablelands. In the hilly regions of Romania landslides are of concern, because of the potential loss of life, structures, and agricultural land. Motoc (1982) estimated that the TP lost 4.5 t ha^{-1} yr^{-1} of soil to landslide events. Large, deep seated landslides occur in the TP with enough frequency that they are locally referred to as *Glimee*. In the TP the predominant sediments where landslides occur are Sarmatian clays and marls, which have a thick mantle of Pleistocene and Holocene deposits (Morariu *et al.*, 1964). The TB is part of a larger feature still, known as the Pannonian Basins (Sclater *et al.*, 1980). Of the Pannonian Basins, the TB is the

highest in elevation, because of uplift which occurred during the Quaternary (Sclater *et al.*, 1980). However, due to the difference in elevation and a thicker continental crust, some research has stated that the TB is a separate feature from the Pannonian Basins (Horvath, 1993; Sanders *et al.*, 2002). The sediment layers which are present in the TB are a result of the gradual disappearance of the Pannonian Sea (Foldvary, 2009). Large salt deposits are also present throughout the TB as a result of the Pannonian Sea. According to Ichim and Sandulescu (1997), the major geomorphological attributes in the hilly plains such as those found in the TP were formed during the Pliocene and through the Quaternary. By contrast, the Romanian and Crisano-Banato Plains are Quaternary formations with primarily Holocene deposits. The geologic time periods discussed above are shown in Figure 1.1.

1.2 HISTORY AND AGRICULTURE OF THE TRANSYLVANIAN PLAIN, ROMANIA

Romania has long been an agriculturally productive area in Eastern Europe. Paleolithic people settled in this region of Romania, selected areas close to the Someş River plain and the hills of the TP. The Transylvanian region of Romania has experienced a large amount of turmoil since the First World War. Transylvania was given to Romania after WWI, and then Hitler gave Transylvania back to Hungary during WWII in 1940 (Zagoroff, 1955). After WWII in 1945 Transylvania was given back to Romania. The instability in the region has made it hard for successful agriculture practices to be implemented in the TP. In the 1970s 63 percent of Romania's land was being used in agricultural production of which 91 percent was owned by state farms and co-operatives and consisted of 95.4 percent of the arable land (Posea and Velcea, 1975).

Agriculture is the foundation of societies. During the communist regime (1945-1989) agriculture depended on state run farms (Drager and Jaksch, 2001). The TP farmers depend on

agriculture, not for economic gain entirely but for sustaining their families. Drager and Jaksch (2001), stated that many families had been forced into farming even though they had previously been urban residents, merely to produce enough food for their family. In 1998, land ownership had changed dramatically from the state owned system from the socialist era, to 72 percent of farm land and 84 percent arable land being owned by private entities (Drager and Jaksch, 2001). The amount of farming and animal production by the privatized portion of Romania was 63 and 37 percent, respectively. The TP is located within Bistrita Nassaud, Cluj, and Mureş, counties in northern Romania where, in 1995, the percent of the population employed in agriculture was 15.6, 26.8, and 36.5, respectively (European Commission, 2002).

In 2009, corn (*Zea mays* L.) was the predominate crop in the TP for all three counties. Mureş, Bistrita-Nasaud, and Cluj contained 27.8, 24.6, and 17.1 percent arable land planted in corn, respectively. The top six crops grown (not in descending order for all counties) for 2009 were corn, wheat (*Triticum aestivum* L.), barley (*Hordeum vulgare* L.), oats (*Avena sativa* L.), potatoes (*Solanum tuberosum* L.), and sunflower (*Helianthus annuus* L.) (Table 1.1). Corn is grown in every county of Romania and is important for feed, human consumption, and fuel (Drager and Jaksch, 2001). Due to the importance of corn, proper planting dates are vital for maximum yield. In the TP, most planting dates are based on historical precedent from previous generations (H. Cacovean, personal communication, 2009). This can work reasonably well, however some years will feature a warmer spring, whereby farmers could plant their crops earlier. One planting-based folk tradition is linked to the flowering of the sloe tree (*Prunus spinosa* L.) “when the sloe tree is white as a sheet, sow your barley whether it be dry or wet” (Swainson, 1873). These traditions notwithstanding, numerical methods of calculating planting dates are available and should be used to obtain maximum return for farmers in the TP.

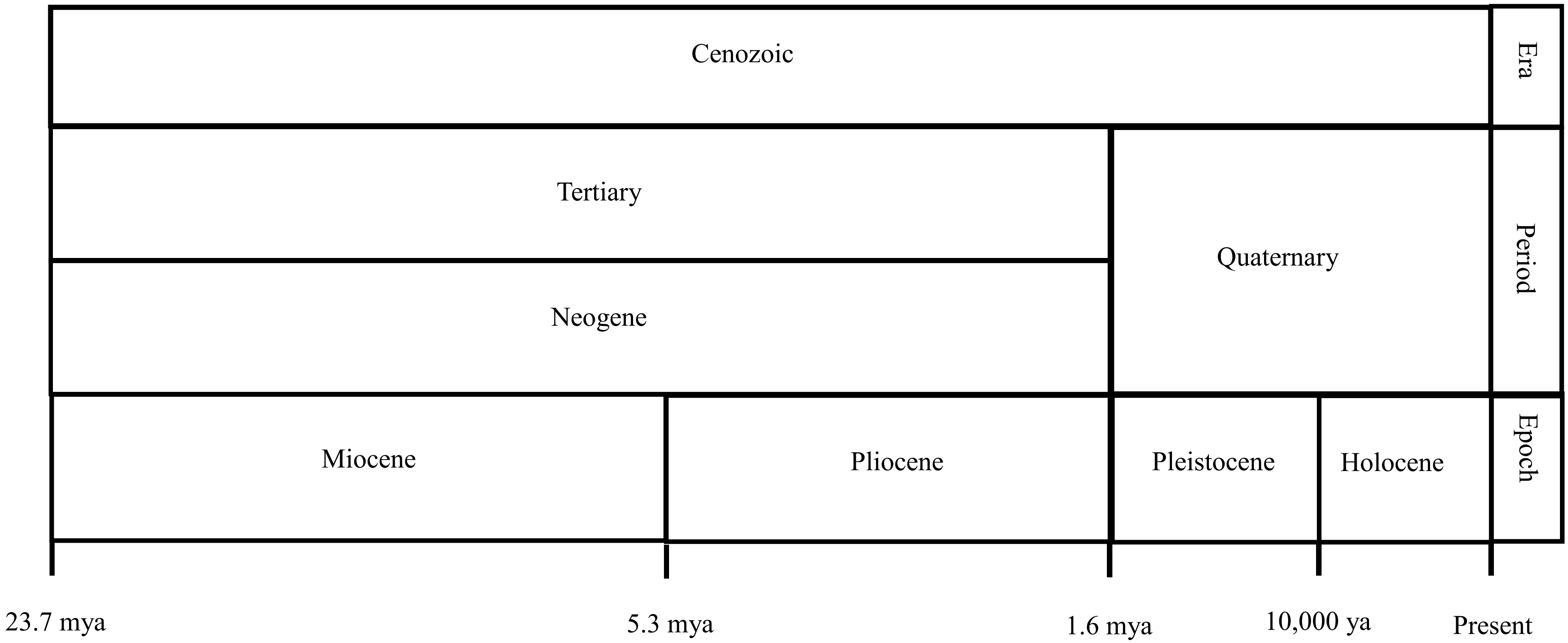

Figure 1.1. Geologic timeline for periods which were important for the development of the Transylvanian Plain, Romania.

Table 1.1. Agriculture production for Mureş, Bistrita-Nasaud, and Cluj Counties in 2009 (Anuarul Statistic al Romaniei, 2009).

---Mureş---				--- Bistrita-Nasaud ---				---Cluj---			
Crop	Area ha	Yield kg/ha	Arable Land %	Crop	Area ha	Yield kg/ha	Arable Land %	Crop	Area Ha	Yield kg/ha	Arable Land %
Maize	61685	4043	27.84	Maize	25141	2926	24.65	Maize	31270	3557	17.11
Wheat	31124	2857	14.05	Potatoes	9891	15994	9.70	Wheat	12187	2551	6.67
Barley	11214	1633	5.06	Wheat	5160	2174	5.06	Barley	11398	1595	6.24
Oats	10354	1561	4.67	Oats	4830	1555	4.74	Potatoes	6823	17411	3.73
Potatoes	7283	16040	3.29	Barley	2986	1427	2.93	Oats	4319	1558	2.36
Sunflower	3066	1408	1.38	Sunflower	712	1412	0.70	Sunflower	2535	1736	1.39
Sugar Beet	1606	45323	0.72	Cabbage	569	20844	0.56	Beans	1216	1762	0.67
Tomatoes	1300	15000	0.59	Dry Onion	529	11085	0.52	Sugar Beet	1212	36496	0.66
Cabbage	1296	19899	0.58	Tomatoes	432	14373	0.42	Cabbage	1153	25442	0.63
Dry Onion	1199	13997	0.54	Beans	93	1215	0.09	Dry Onion	926	10374	0.51
Soy Beans	492	1616	0.22	Sugar Beet	21	38381	0.02	Tomatoes	891	19411	0.49
Peas	226	2699	0.10	Tobacco	20	1000	0.02	Rye	839	2460	0.46
Melons	160	19969	0.07	Rye	-	-	-	Soy Beans	527	1545	0.29
Rye	75	2667	0.03	Peas	-	-	-	Peas	314	1971	0.17
Tobacco	58	1552	0.03	Soy Beans	-	-	-	Melons	20	13400	0.01
Beans	29	1000	0.01	Melons	-	-	-	Tobacco	3	2000	0.00
Total	131167		59.20		50384		49.39		75633		41.39

1.3 UNITED STATES AND ROMANIAN SOIL TAXONOMIES

Soils found in the TP are dynamic due to geomorphic processes shaping the landscape. The ability to accurately assess and identify agronomically important and structurally sound soils is important for farmers and residents in the region. By means of well-constructed classification systems it is possible to determine suitable localities in the TP. Soil classification has been an important part of society. The importance of soil classification extends beyond agriculture to suitability for structures (drainage and shrink-swell), land appraisals, roadway suitability, drainage (flood zones), and structural integrity for city needs (dump sites, waste water treatment facilities, and power plants) (Karlen *et al.*, 1997). In early civilizations the main purpose of classification would have been for the purpose of agricultural production (Brevik and Hartemink, 2010). The region which was selected by the Mesopotamians led to their demise, due to flooding from over irrigation with salty water (Hillel, 1991). Egyptian civilization centered on the Nile River and the frequent flooding provided enriching nutrients to the prepared fields (Krupenikov, 1992). The Chinese developed their first soil classification system around 4000 BP which assessed color, texture, moisture, vegetation, and soil fertility (Li and Cao, 1990). In the Americas the Aztecs also developed a soil classification system based on fertility, texture, moisture, genesis, topographic location, and farmer practices (Williams, 2006).

Prior to soil classification in the United States, Russian scientists were shaping soil genesis and classification. Since soil science is a younger science, early influential scientists had varied backgrounds which were from chemistry, physics, geography, geology, and biology. Dokuchaev was a geologist who is now known as the father of pedology for his study of Chernozems in 1883 (Mollisols- US or Cernisoluri-Romanian) (Simonson, 1989). Dokuchaev's initial study of Chernozems provided him with the perfect setting to study soil formation and

defend that soils were not directly related to the geologic parent material, but a dynamic system influenced by water, air, and vegetation (Buol et al, 2003).

1.3.1 Soil Taxonomy in the United States

Soil classification in the United States has evolved since its inception in 1899 (Simonson, 1989). Under instruction from the U.S. Department of Agriculture (USDA) Milton Whitney (1900) conducted four surveys which collectively were the first report for the Division of Soils. An early classification scheme by Marbut in 1913 consisted of three categories: 1) Soil provinces or geographic units; 2) Soil series- units related to parent material; and 3) Soil types- soil series subdivisions based on texture of the entire soil profile (Cline, 1979). During the 1930s as part of the New Deal the Soil Erosion Service was initiated. The service was later transferred to the USDA and renamed the Soil Conservation Service (SCS) (Simonson, 1989). Today, the agency has evolved into the Natural Resources Conservation Service (NRCS). In 1935, Marbut presented a new classification scheme which was composed of six categories. The categories from narrow to broad are as follows: 1) Soil units- types and phases of soil series; 2) Soil series; 3) Family groups- i.e. mature soils, swamp soils, immature soils on slopes, etc.; 4) Great soil groups- environmental groups i.e. tundra, chernozems, podzols, etc.; 5) Inorganic constituents- whether physically or chemically weathered; and 6) Solum composition- Pedalfers and Pedocals. During this period Marbut championed the idea of “normal” and “abnormal” soils, which were the same concepts as zonal and azonal soils. In this scheme a normal or zonal soil is located on a well-drained, hillslope geomorphic position and was classified. Abnormal or azonal soils were typically in lowland, poorly drained locations and were omitted from the 1935 classification system (Buol *et al.*, 2003). The zonal and intrazonal soils were fully elucidated in the 1938 classification system. The 1938 system was published in the *1938 USDA Yearbook of*

Agriculture - Soils and Men (Baldwin *et al.*, 1938). In the 1950s, after Marbut's influential term at the USDA, Guy D. Smith became the new soil classification project leader (Cline, 1979). Smith's approximations were the foundation of the current *United States Soil Taxonomy* (*USST*) (Soil Survey Staff, 1999) used for classification (Buol *et al.*, 2003; Cline, 1979).

Soil Taxonomy is a hierarchical classification system with 12 soil orders at the highest level followed by suborders, great groups, subgroups, families, and series. There are eight attributes which *USST* is intended to represent (Soil Survey Staff, 1999). First, all users of *USST* should be able to reach the same taxonomic classification based on the properties of the soil. As such, specific quantifiable classes must be used. It is cumbersome for a pedologist to classify a certain soil based on high pH, when in a different region of the U.S. the same pH may not be considered high. Second, *USST* must be multicategorical because of the diverse situations in which soil classification is needed. With over 2000 subgroups in *USST,* higher categories are essential to understanding how the soils compare with one another. Third, it is understood that the combinations of soil properties which could exist in nature are not all known. As such, *USST* should not be a reference of every possible combination but that of soils known to exist. Also, as with any taxonomic classification it should always be able to be modified as new classifications are needed. Fourth, differentiating characteristics should be present via *in situ* investigation or by reproducible laboratory analysis. Fifth, *USST* should be able to incorporate new information without compromising the integrity of the system. Sixth, soils which are the same should as much as possible classify the same whether a virgin profile or a soil under agricultural production. For this reason, diagnostic horizons extend beyond the upper surface which is disproportionately affected by anthropogenic activities. Seventh, *USST* must be able to account for all soil bodies which reside within the landscape for mapping to be possible. Eighth, there is

an unavoidable bias toward well studied regions in *USST*; however it should provide enough of a base for an inclusive classification system to be constructed in the future.

1.3.2 Soil Taxonomy in Romania

As many countries have soil classification systems, it is important for concepts to be discussed so that no system becomes static or obsolete. In Romania, the *Romanian System of Soil Taxonomy* (*RSST*) (Florea and Munteanu, 2003) is the national system used. The *RSST* is also a hierarchical system consisting of (from broad to narrow) 12 classes, types, sub-types, varieties, species, families, and variants. The main objective of *RSST* is the identification, grouping, and naming of soils in Romania with a hierarchical system based on intrinsic characteristics of the soil (Florea and Munteanu, 2003). The *RSST* also has attributes which are the foundation of the classification system (Florea and Munteanu, 2003). First, *RSST* is intrinsically Romanian with the Romanian school of thought reflected throughout. Second, while it was important to preserve the heritage of the Romanian system, some terms reflect those found in international classification schemes for the purpose of correlation with other systems. Third, *RSST* is a multi-categorical genetic classification system. Fourth, the categories reflect real bodies which occupy portions of the landscape resultant from pedogenesis. Fifth, the differentiating characteristics should result from properties seen in the field or based on a combination of soil science with other disciplines (i.e. mineralogy or geology). The system also uses laboratory information. Sixth, specific soil properties in the system may develop independently of one another. Seventh, elements were chosen so as to not change after low intensity human disturbance as long as diagnostic horizons have not disappeared. Eighth, to ensure that all soil systems known in Romania are identified an information base was used to develop *RSST*. Ninth, as new knowledge

is discovered the classification system will be amended without the disturbance of the general structure.

There are some very similar attributes for both *USST* and *RSST*. They are both multi-categorical systems which allow for the classification of thousands of individual soil bodies. Taxa should be based on real soils that exist in nature. Anthropogenic disturbance should not change the classification of a soil as long as the diagnostic horizons remain. Modification to the system should be feasible without disrupting the entire classification system.

1.3.3 Soil Orders (*USST*) or Classes (*RSST*)

Both *USST* and *RSST* have 12 categories for their broadest classification (Table 1.2). All of the soil orders are not synonymous. Because *RSST* is a national classification system and not an international classification system, there are some orders/classes present in *USST* which are not found in Romania. For example, Oxisols are tropical soils which have been highly leached due to copious amounts of rain; these soils would not be found in the country of Romania and therefore are not found in *RSST*. Conversely, in *USST* soils with natric horizons are separated out at the Great Group level while salic horizons are separated at the Suborder and Great Group levels. Antrisoluri is a newer soil Class in *RSST*. These soils show high amounts of anthropogenic modification, with two types noted in *RSST*: 1) Erodosol a soil where the surface has been lost due to strong or uncovering erosion, resulting in a surface < 20 cm thick and 2) Antrosol other Antrisoluri with anthropogenic horizons at least 50 cm thick. Taxonomies serve to classify soils based on the needs determined by the authors. Since *RSST* does not have a need to classify all soils worldwide, other Orders/Classes have been created as needed (Salsodisoluri, Hidrisoluri, Umbrisoluri, and Antrisoluri).

Table 1.2. Approximate relationship between Soil Orders (*USST*) and Classes (*RSST*).

Main Concept	United States	Romanian
Dark colored, high organic matter, and Mollic epipedon	Mollisols	Cernisoluri
Lighter soils with an Argillic, Kandic, or Natric horizon	Alfisols	Luvisoluri
Other soils with some development	Inceptisols	Cambisoluri
Andic properties in 30 cm or more of the surface	Andisols	Andisoluri
30% or more clay throughout and cracking	Vertisols	Pelisoluri
Greater than 30% organic matter	Histosols	Histisoluri
Other soils	Entisols	Protisoluri
Spodic horizon within 200 cm	Spodosols	Spodisoluri
Permafrost within 100 cm	Gelisols†	---------------
Highly weathered Fe and Al rich	Oxisols†	---------------
Base saturation < 35%	Ultisols†	---------------
Aridic soil moisture regime	Aridisols†	---------------
Presence of a Sodic or Natric Horizon	---------------	Salsodisoluri‡
Highly gleyed horizon in the upper 50 cm	---------------	Hidrisoluri‡
Dark colored, with an Umbric epipedon	---------------	Umbrisoluri‡
Anthropogenically modified soils	---------------	Antrisoluri‡

†These orders are not found in *RSST* because they are not found in Romania.
‡The main concepts of these orders are found in lower levels of *USST*.

1.4 SOIL TEMPERATURE

In *RSST*, soil temperature is not used as a differentiating property. However, soil temperature is an important characteristic which is unique to each pedon depending on the constituents found in the soil. Climate has played an important role in soil science since classification and taxonomy started in the late 1800's. Dokuchaev and Sibirtsev produced their original systems of soil classification using a zoned system. The zones were predominately based on climate and vegetation. This zonal system was inclusive of: 1) Zonal: normally developed soils which occur in specific geographical zones (climatic separation), 2) Intrazonal: soils of intermediate development which are noticeably influenced by one of the factors of soil formation, and 3) Azonal: soils which are not systematically found in separate geographic zones. The five factors of soil formation which were fully elaborated by Jenny (1994) were initially

recognized by Dokuchaev (Cline, 1979). The zonal system did not continue to be part of *USST* after the 1938 system because it was difficult to relate to soil properties (Smith, 1983).

For years many scientists felt that soil temperature should not be part of *USST*. This stemmed from many soil scientists discounting soil temperature as a property of the soil (Buol, 1984). It was known that temperature influences the formation of soils, but some felt climate to be a transient property. Guy Smith fought for this mindset to change when he joined the Soil Conservation Service. In a 1952 memo attached to the November 1951 revisions to the 1st Approximation Smith made the following comment (from Cline, 1979: 41):

> I cannot say this feature was controversial, because there was near unanimity of comment [Rejection of soil temperature as a soil feature]. I am still convinced that soil temperature or some substitute for it must be brought into the classification scheme. I do not see that it matters much whether it is at the Great Soil Group level, above that level, or even below, in the realm of what we now consider the family field. Without them you cannot make management recommendations.

Smith (1981) noted that if soil climate was not used in *USST,* pedologists would overlook soil temperature when describing soil profiles. It is important to note that Guy Smith did not always believe that soil temperature should be part of the soil classification system. In 1952 he wrote the following (from Cline, 1979: 20):

> I am omitting such criteria as soil temperature and soil moisture because I cannot conceive of them as genetic characteristics. To be sure, they are the effects of environment in the same sense that roots of plants are a part of the soil and their distribution is a genetic characteristic which is ever changing.

It cannot be fully known if Smith made the above statement solely due to insufficient data at the time, because in 1951 temperature was proposed for the first time in the 1st Approximation (Cline, 1979). Another important moment when Smith was trying to emphasize temperature as a

property was in the early 1950s when he was on a soils tour in tropical Africa. Once the group had returned to Europe they examined a soil profile identical to the soil profile Africa. None of the scientists could identify any measurable differences between the two soil profiles. At this moment Guy Smith placed his hand on the soil profile and stated that there was a measurable soil difference: soil temperature (S. Buol, personal communication, 2011).

The first set of temperature classes recognized by USDA-SCS was in the 2nd Supplement to the 7th Approximation (Soil Survey Staff, 1964). This original scheme varied slightly from today with different temperature differences denoting “iso-“ and by the lack of a Hyperthermic class. There were other proposed breaks in earlier soil taxonomy approximations. In 1952, the following comments were made by European soil scientists regarding soil temperature classes: a) Cold soils are below -1.1 °C with no chance of being suitable for agricultural production, b) Cool soils are between -1.1–7.2 °C with short growing seasons primarily capable of summer wheat, c) Temperate soils have temperatures between 7.2 – 21.1 °C and the capability of growing a wide variety of crops, and d) Tropical soils have temperatures >21.1 °C (Cline, 1979). Both historical and contemporary temperature classes are presented in Table 1.3.

When MAST classes were originally divided the Soil Conservation Service tried to split as few soil series as possible. The MAST regime lines were drawn where major cropping systems existed in the United States. Due to the availability of air temperature records, part of the initial investigation concerned the relationship of soil temperature to air temperature. This method worked, but only on smaller regional scales (Smith, 1964). Whereby, mean annual air temperature did not allow for a nationwide adjustment for MAST. After field work was completed and soil temperature isolines were determined, the temperature classes were divided based upon cropping regions. The current soil temperature regimes are as follows: hyperthermic

>22℃, thermic 15-22℃, mesic 8-15℃, frigid < 8℃, cryic < 8℃ with no permafrost, and gelic < 0℃ with permafrost (Soil Survey Staff, 1999). The crops used to divide soil temperature regimes were cotton and corn. The cooler limit of the cotton belt was approximately 15℃ which is also the lower limit of the thermic class.

Table 1.3. Mean annual soil temperature class differences from 1951 to present in the United States.

Classification System	Temperature ℃
1951 - 2nd Approximation	
Cold	< 1.7
Cool	1.7 - 7.2
Warm	7.2 - 21.1
Hot	> 21.1
1952 - European Conference	
Cold	< -1.1
Cool	-1.1 - 7.2
Temperate	7.2 - 21.1
Tropical	> 21.1
1964 – 2nd supplement to 7th Approximation	
Frigid	< 8.3
Mesic	8.3 - 15
Thermic	>15
1999 - Soil Taxonomy	
Gelic	< 0
Cryic	< 8
Frigid	< 8
Mesic	8-15
Thermic	15-22
Hyperthermic	>22

The lowest temperature range for the corn belt was approximately 8℃ which is the lower limit of the mesic temperature regime (Smith, 1983). One reason for dividing soil temperature classes in

this manner was to avoid splitting soil series which existed. Inherently, most soil series did not cross soil temperature regimes since divisions were made based on crop tolerances.

United State Soil Taxonomy uses mean annual soil temperature (MAST) to describe the thermal climate of soils. Mean annual soil temperature (MAST) is measured at 50 cm and consists of an overall average from two seasonal means: summer (June, July, and August) and winter (December, January, and February) (Soil Survey Staff, 1999). Mean annual soil temperature can also be estimated by taking the temperature of well water at a depth of 10 to 20 m (Soil Survey Staff, 1999). Soil temperature is mentioned in *RSST* but it is not used in the taxonomic scheme.

1.4.1 Soil Temperature Quantification

Soil temperature has been measured in a number of different ways. Early soil temperature measurements were made using a standard soil thermometer (mercury filled). There was typically a metal or wooden pipe inserted into the soil where the thermometer could be inserted to be read (Connell, 1923). Contemporary thermometers are extremely advanced compared to early mercury filled glass thermometers. Furthermore, the dynamic range of thermometers is important as soil temperature can range from -40 to 60 °C (Livingston, 1993). The most common type of thermometers used are electrical sensors. These consist of thermocouples, semiconductor thermometers (thermistors), and resistance thermometers. Thermocouple thermometers are built using two different metals, the voltage difference between the reference metal and the other metal is then used for measuring the temperature (Novak, 2005). The most common metal combinations are chromel/constantan or copper/constantan (Kleinhans *et al.*, 2010). Resistance thermometers are typically a singular metal in which temperature resistance is measured (Novak, 2005). The resistance thermometer is less cost effective than other thermometers. Semiconductor

thermometers or thermistors are widely available for soil temperature studies. They are cost effective, relatively small, and they produce large signals, meaning less expensive data loggers can also be used (Novak, 2005). In the case of thermistors, the voltage to temperature relationship is non-linear but fits a polynomial function. Another method to measure soil temperature is with a radiative sensor, but this sensor can only measure the soil surface (Hillell, 2004; Novak, 2005).

1.4.2 Pedogenic Gains and Losses

Pedogenesis is markedly influenced by gains and losses. The types and amounts of losses and gains will depend on the location of the developing pedon. A soil found in a backslope position might gain soil from its parent material in the form of residuum; however losses are possible in the form of colluvium which then provides a gain for a pedon in a lower slope position. This process does not exist only for hill slope positions; in alluvial areas a terrace may lose soil in the form of sheet erosion. Further down in the river system if there is a flood a gain will have occurred on the floodplain. In the TP there are massive losses in the forms of landslides, which in turn create a gain at lower slope positions.

Not all gains and losses concern soil parent material, as those aforementioned. Others come in the form of energy, in the terrestrial system the source of energy is solar radiation. Energy is not always transferred into the soil system; at night when the air temperature is lower than the soil temperature, heat is lost from the soil to the atmosphere. Equation 1.1 shows this energy balance in physical systems (Hillel, 2004).

$$R_n = S + A + LE \qquad (1.1)$$

Where:

R_n = Net radiation (cal cm^{-2} day^{-1})

S = Soil heat flux (Down into the soil [W m^{-2}])

A = Sensible heat flux (Up into the air [W m^{-2}])

LE = Energy used in evapotranspiration (cal g^{-1})

Important terms for the above equation are sensible heat and latent heat. Both of these terms are define energy changes. Sensible heat is an actual change in temperature value. Conversely, latent heat is a process where there is not a change in temperature when the system changes (i.e. when ice melts and becomes water). In the soil system, the latent heat process occurs during evaporation and transpiration, and latent heat is the most predominant form of heat transfer in an agricultural system (Hillel, 2004). Part of the radiation in the aforementioned equation is reflected at the soil surface and returns to the atmosphere; this is known as the albedo. Light colored surfaces have higher albedos than dark colored surfaces. However, water surfaces typically have a lower albedo than soil or crops (Jury *et al.*, 1991). Some research has shown that by changing the surface color of the soil by the addition of fertilizers or mulches can reduce soil temperature (Stanhill, 1965). It is possible to calculate the amount of radiant energy received from the sun via the Stephan-Boltzmann equation (Equation 1.2).

$$\Sigma = \epsilon\sigma T^4 \qquad (1.2)$$

Where:

Σ= Energy flux (W m^{-2})

σ = Stephan-Boltzmann constant (5.67 x 10^{-8} W m^{-2} K^{-4})

ϵ = Emmisivity (1 for a blackbody)

Soil heat flux is an important parameter in the soil as this determines how fast or slow an individual pedon will warm or cool throughout seasons (Jury and Horton, 2004; Sauer and Horton, 2005). Heat flux is the amount of thermal energy which moves through a unit of time in an area of soil. Fourier's Law is used to demonstrate heat flow through a solid material (Equation 1.3).

$$G = -\lambda \partial T / \partial z \quad (1.3)$$

Where:

G= Heat flux (W m^{-2})

λ= Thermal conductivity (W m^{-1} K^{-1})

∂T= Change in temperature (K)

∂z= Change in depth (m)

Thermal conductivity depends on the soil constituents including the mineralogy, moisture content, organic matter, and the bulk density (Sauer and Horton, 2005). Since air and water have greatly different thermal conductivities, the influence of soil moisture on heat flux is immense. The thermal conductivities of air and water are 0.025 and 0.57 W m^{-1} K^{-1}, respectively (Sauer and Horton, 2005). As aforementioned, the driving force behind heat transfer in the soil is solar radiation. This causes variability in the soil due to the diurnal and annual cycles of the sun as well as irregular temperature fluctuations due to weather (i.e. clouds, rain, and heavy winds).

1.4.3 Effect on Crop Production

In the TP, crop production is important for the livelihood of subsistence farmers. Soil temperature is crucial for the life cycle of crops. All plants have a biologic zero or a point at

which growth ceases. For many plants the biologic zero is 5°C. Soil temperature is important for seedbed preparation due to its effect on germination. Seedbed temperature can be controlled by the use of mulch (Dahiya, 2007; Papendick, 1973). It can be difficult to weigh the benefits of mulching considering the following. If mulch is left on top of the soil it will conserve soil moisture, conversely solar radiation will not be able to penetrate through the mulch well and the soil will not warm as quickly in the spring. This can be beneficial if a producer does not have irrigation and is worried about the seedbed being too dry. However it can be devastating if the producer must delay planting because the warming soil temperatures are delayed. In northern states (Ohio, Wisconsin, and Iowa) Allmaras *et al.* (1964) found a negative effect on corn yield due to the addition of mulch.

Knowing the soil temperature is imperative for planting dates since the seed used could potentially rot if planted too early in the spring, preventing germination. The soil temperature which required for germination is crop specific. For sugar beets (*Beta vulgaris* L.), germination occurs in soil temperatures which range from 18-24℃ (Blunt *et al.*, 1991). Corn (*Zea Mays* L.) begins germinating at 4.5-5℃ (Clifton-Brown *et al.* 2011). Wheat (*Triticum aestivum* L.) starts to germinate at a base temperature of 2℃ (Seefeldt *et al.*, 2002).

One method of determining proper planting dates is the use of growing degree days (GDD). Growing degree days are useful for the study of annual plant cycle events or phenology. Different growth stages of corn have been linked to known accumulated GDD. Figure 1.2 shows the different growth stages of corn.

Corn emergence begins with soil temperatures greater than 8℃ (Buol *et al.*, 2003). Growing degree days are calculated from a minimum and maximum air temperature. For most GDD calculations 10℃ is considered the base air temperature, which defines the lowest

temperature at which growth will occur in the plant. The maximum temperature of 30℃ is where growth is curtailed due to stress experienced by the plant. The minimum and maximum temperatures used in GDD calculations to predict plant growth based on air temperature. Common methods for calculating GDD include: single-sine, averaging, double-sine, and single-triangle (Arnold, 1960; Baskerville and Emin, 1969; Allen, 1976; Lindsey and Newman, 1956). The single-sine and averaging methods were the two techniques employed in this research project and will be further defined.

The single-sine method resembles the trend seen in diurnal air temperatures. Equation 1.4 defines GDD calculation with the single-sine method, where BT (°C) is the base temperature in all equations, AVG is the average of the minimum and maximum daily air temperature, and MT (°C) is the maximum temperature. The average (AVG) (°C) is typically the minimum and the maximum of the daily air temperature for each day of the growing season that has occurred at the time of calculation. However, if temperatures are recorded more often, averages can also be utilized from the more comprehensive dataset.

$$GDD_{Single\text{-}sine} = \{[W * \cos(A2)] - [(BT - AVG) * ((\pi/2) - A2)]\}/\pi \qquad (1.4.a)$$

$$A2 = \text{Arcsine}\,[(BT - AVG)/W] \qquad (1.4.b.1)$$

$$W = (MT - BT)/2 \qquad (1.4.b.2)$$

The averaging method is a simpler determination of GDD. Here, the minimum and maximum temperatures are averaged and then the BT is subtracted to obtain the $GDD_{Averaging}$ (Equation 1.5).

$$GDD_{Averaging} = AVG - BT \qquad (1.5)$$

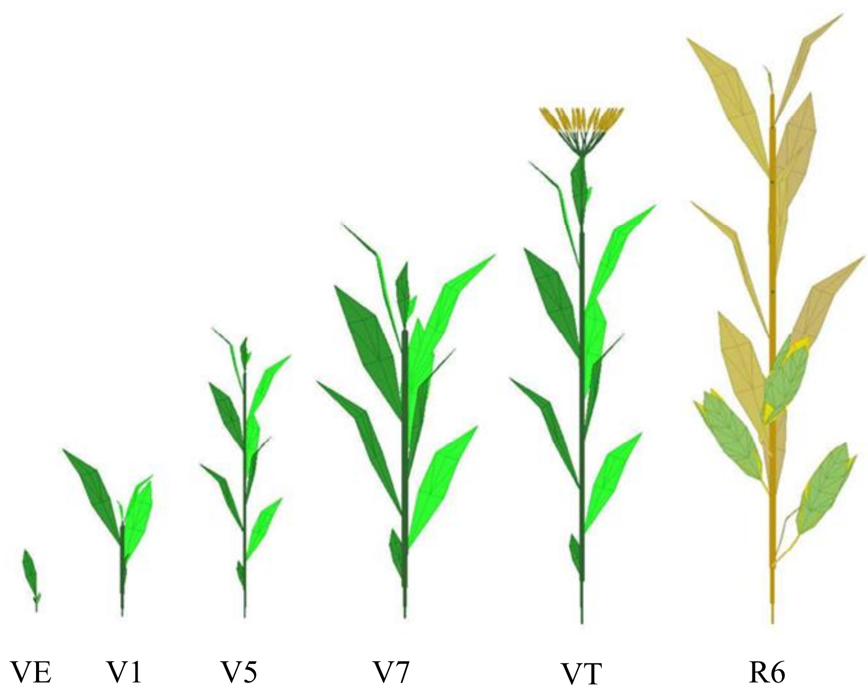

Figure 1.2. Growth stages of corn, VE: emergence, V1: First visible leaf collar, V5: Internode elongation and tassel starts to form, V7: Rapid growth stage, VT: Tassel emerges, and R6: Maturity.

Throughout the growing season, GDD are calculated starting the day after planting. This facilitates the determination of when certain growth stages will be reached. Growing degree days required for certain corn growth cycles are found in Table 1.4. The GDD will vary from the following values depending on maturity days required for different varieties of corn.

Table 1.4. Growing degree days (GDD) based on 100 day corn for selected growth stages of corn (*Zea Mays* L.) (Neild and Newman, 1987).

Growth Stage	GDD ℃
Emergence	93
Tasseling	613
Maturity	1480

1.5 ESTIMATING SOIL TEMPERATURE

Previous estimates of soil temperature in the TP have been based on air temperature. This method is viable, but does not allow for microclimates which exist in a region the size of the TP at 395,000 ha. The ability to estimate soil temperature is beneficial for understanding the thermal system for different soils. The following terms are needed to evaluate thermal regimes: thermal conductivity, volumetric heat capacity, and thermal diffusivity. The aforementioned terms are also known as the thermal properties of soil (Hillel, 2004). The volumetric heat capacity (C) is the amount of heat needed to change the temperature of a unit of soil. The units are typically cal/cm^3 K. In 1975, de Vries produced a table which illustrates specific heat capacity and thermal conductivity of soil constituents (Table 1.5). Thermal conductivity (κ) is the amount of heat which moves through a unit area in a unit of time, and has the following unit of measurement cal/cm sec K. Soil constituent's thermal conductivities are ranked as follows: sand > loam > clay > peat. It is important to note that the thermal conductivity of a soil relies heavily on the compaction (bulk density) and the moisture content of the soil (Jury *et al.*, 1991). Thermal diffusivity is defined as the ratio of soil conductivity to the product of the soils specific heat and bulk density (Hillel, 2004). Based on the values established in Table 1.3, the heat capacity of a soil can be estimated via (Equation 1.6). Normally air is included in Eq. 1.6; however it has a negligible effect on the heat capacity and is usually excluded.

Table 1.5. Thermal properties of soil constituents as determined by de Vries (1975).

Constituent†	Density $g\ m^{-3}$	Thermal Conductivity (κ) $W\ m^{-1}\ K^{-1}$	Specific Heat Capacity (C) $cal\ cm^{-3}\ K$
Quartz	2.66	8.8	0.48
Other minerals	2.65	2.9	0.48
Organic matter	1.3	0.25	0.6
Water	1.0	0.57	1.00

†The temperature is at 10℃ for all constituents.

$$C = \Sigma(f_m C_m + f_w C_w + f_o C_o) \quad (1.6)$$

Where:

$f_{(m,\ w,\ or\ o)}$ = The volume phase of each constituent ($m^{-3}\ m^{-3}$)

$C_{(m,\ w,\ or\ o)}$= Product of density and specific heat for each constituent (cal cm^{-3} K)

m = Mineral

w = Water

o = Organic matter

Since soil temperature is largely controlled by solar radiation, the resulting pattern in soil temperature is a sinusoidal fluctuation (Wang *et al.*, 2010; YongJun *et al.*, 2011). The resulting oscillating patterns have either daily (24 h) or annual (365 d) periods. Equation 1.7 is commonly used to predict soil temperature (Scott, 2000). The use of this equation is only valid on clear days (Hillel, 2004).

$$T(z, t) = T_a + A_0 e^{-z/d} \sin[\omega(t-t_0) - z/d] \quad (1.7)$$

$$\omega = 2\pi/t_p \quad (1.7.1)$$

Where:

T_a= Average temperature at the soil surface (°C)

A_0= Amplitude at the soil surface (°C)

d= Damping depth (m)

ω= Radial frequency (radians)

t= Starting time (hours)

t_0= Time of average temperature (hours)

t_p= Period of the cycle (Typically 24 h for a day)

z= Depth (m)

Mahrer (1980) accurately predicted soil temperature under different mulches using air temperature, humidity, wind speed, and radiation. Due to the importance of soil temperature in understanding soil-plant-atmospheric interactions, Tyagi and Satyanarayana (2010) predicted soil temperature and heat flux using the Fourier equation (1.3) to provide soil temperature data to obtain missing data.

Because of the relationship between soil temperature and solar radiation, soil temperature has also been predicted by using elevation and latitude in the form of a multiple regression (Carter and Ciolkosz, 1980; Schmidlin *et al.*, 1983). Latitude effectively represents solar incidence for the prediction of soil temperature. Smith (1964) found that soil temperature decreased 1 °C for every 300 m increase in elevation. This method must be evaluated *in situ* for the multiple regression to be valid.

In addition to *in-situ* studies, remote sensing has been shown to accurately predict and measure soil temperature. The simplest form of remote sensing is through infrared thermometry. This type of sensor can be as simplistic as the Extech 1832F Infrared Thermometer (Extech Instruments, Waltham, Massachusetts) with a range of -50-1000 °C or as advanced as band-6 on the Landsat 7 ETM+ satellite. This type of sensor is based upon principles from the Stephan-Boltzmann equation where Σ is the energy flux or the amount of radiation which is being emitted by the surface (Scott, 2000). The sensor measures Σ and can be used to calculate temperature based upon Eq. 1.2. This type of sensor typically measures between 8-10 μm in the electromagnetic scale (Figure 1.3).

Landsat 7 ETM+ is a remote sensing satellite platform maintained by the United States Geological Service (USGS, 2011). The satellite platform scans the earth's surface on a 16 day repetitive cycle with a swath width of 185 km. The satellite has seven bands which are sensing in the visible and thermal IR wavelengths and one panchromatic band. Bands 1-4 are visible, bands 5 and 7 are near infrared and band 6 is the thermal infrared band which is used for land surface temperature. Band 6 is measured between 10.4 to 12.5 μm and has 60 m spatial resolution.

The sensed thermal IR images from Landsat 7 ETM+ must be converted from a digital number to Kelvin. A digital number is a term used by USGS (2011) to denote the raster data prior to processing. This conversion is achieved with the use of equations 1.8 and 1.9.

$$L_{\lambda} = ((LMAX_{\lambda} - LMIN_{\lambda})/(QCMAX - QCMIN)) * (DN-QCMIN) + LMIN_{\lambda} \qquad (1.8)$$

Where:

$LMAX\lambda$ = Maximum value of spectral radiance (W (m^{-2} $ster^{-1}$ m^{-2}))

LMINλ = Minimum value of spectral radiance (W (m^{-2} $ster^{-1}$ m^{-2}))

QCMAX = The maximum pixel or digital number in the image

QCMIN = The minimum pixel or digital number in the image

L_λ = Spectral radiance (W (m^{-2} $ster^{-1}$ m^{-2}))

$$T = ((K2)/\ln((K1/L_\lambda)+ 1) \tag{1.9}$$

Where:

K1 = 666.09 (W (m^{-2} $ster^{-1}$ m^{-2}))

K2 = 1282.71 (Kelvin)

L_λ = Spectral radiance (W (m^{-2} $ster^{-1}$ m^{-2}))

Once the digital number has been converted to temperature values the data can be validated with *in situ* measurements at geo-referenced points in the study region.

Landsat platforms 5 and 7 have been successfully used to measure land surface temperature (LST) (Schott *et al*., 2001; Thomas *et al*., 2002). The measurement of water temperature is important for weather as well as habitat preservation. Landsat thermal band data has been used to study surface water temperature in bays, oceans, and lakes (Schott *et al.*, 2001; Thomas *et al.*, 2002; Wloczyk *et al.*, 2006). Land surface temperatures are important for boundary layer conditions, urban heat island research, agriculture, and modeling soil moisture (e.g., Li *et al.*, 2004; Suga *et al.*, 2003; Srivastava *et al.*, 2010; Giraldo *et al.*, 2009).

1.6 OBJECTIVES

The overall objectives of this project were to: 1) Determine differences between *USST* and *RSST*, 2) Evaluate agronomic growing conditions within the TP, and 3) Predict soil temperatures in the TP.

1.7 REFERENCES

Anuarul Statistic al Romaniei 2009. 2010. Badea, D., editor, National Institute of Statistics. Bucharest.

Arnold, C.Y. 1960. Maximum-minimum temperatures as a basis for computing heat units. Am. Soc. Hort. Sci. 76:682-692.

Ando, M. 1995. The geography of the river Mureş and its river system. In: J. Hamar and A. Sarkany-Kiss, editors, The Maros/Mureş River Valley: A study of the geography, hydrobiology and ecology of the river and its environment – TISCIA monograph series. Tisza Klub, Szolnok, Hungary, p. 7-23.

Baldwin, M., Kellog, C.E., and J. Thorp. 1938. Soil Classification. In Soils and Men. USDA Yearbook of Agriculture, 1938. p. 979-1001. U.S. Govt. Printing Office, Washington, DC.

Baskerville, G.L. and P. Emin. 1969. Rapid estimation of heat accumulation from maximum and minimum temperatures. Ecology. 50:514-517.

Blunt, S.J., M.J.C. Asher, and C.A. Gilligan. 1991. Infection of sugar beet by *Polymyxa betae* in relation to soil temperature. Plant Pathology 40:257-267.

Bodea, C. and V. Candea. 1982. Transylvania in the history of the Romanians – East European Monographs. Columbia Univ. Press, New York.

Brevik, E.C. and A.E. Hartemink. 2010. Early soil knowledge and the birth and development of soil science. Catena 83:23-33.

Buol, S.W., R.J. Southard, R.C. Graham, and P.A. McDaniel. 2003. Soil genesis and classification, 5th edition. Blackwell Publishing, Ames, IA, USA.

Buol, S.W. 1984. Use of soil temperature regimes in soil taxonomy. Proc. of the Int. Soil Classification Workshop, 6th, Chile and Ecuador. 9-20 Jan. 1984. Sociedad Chilena de la Ciencia del Suelo, Santiago, Chile.

Carter, B.J. and E.J. Ciolkosz. 1980. Soil temperature regimes of the central Appalachians. Soil Sci. Soc. Am. J., 44: 1052-1058.

Clifton-Brown, J., P. Robson, R. Sanderson, A. Hastings, J. Valentine, I. Donnison. 2011. Thermal requirements for seed germination in *Miscanthus* compared with switchgrass (*Panicum virgatum*), reed canary grass (*Phalaris arundinaceae*), maize (*Zea mays*), and perennial ryegrass (*Lolium perenne*). GCB Bioenergy 3:375-386.

Cline, M.G. 1979. Soil classification in the United States. Dep. of Agron. Mimeo No. 79-12. Cornell Univ., Ithaca, NY.

Connell, A.B. 1923. Measuring soil temperature by standard thermometer suspended in iron pipe. Ecology 4:313-316.

Dahiya, R., J. Ingwersen, and T. Streck. 2007. The effect of mulching and tillage on the water and temperature regimes of a loess soil: Experimental findings and modeling. Soil and Tillage Research 96:52-63.

Defant, F. 1951. Local winds. In: T.F. Malone, editor, Compendium of Meteorology. American Meteorological Soc. Boston, p. 655-672.

De Vries, D.A. 1975. Heat transfer in soils. In: D.A. de Vries and N.H. Afgan, editors, Heat and Mass Transfer in the Biosphere: 1. Transfer processes in the plant environment. Scripta Book Co., Washington, DC.

Drager, D. and T. Jaksch. 2001. Romania. In: S.J. Goetz *et al.*, editors, Agricultural Transformation and Land Use in Central and Eastern Europe. Ashgate, Aldershot, England, p. 269-290.

European Commission. 2002. Volume 11: Portrait of the regions – Romania. Office for Official Publications of the European Communities, Luxembourg.

Florea, N. and I. Munteanu. 2003. Sistemul Roman de taxonomie a solurilor. Estifalia. Bucuresti, Romania.

Foldvary, G. Z. 2009. The Carpathian Mountain range and the enclosed interior. Cent. Eur. J. Geosci. 1:291-302.

Giraldo, M.A., D. Bosch, M. Madden, L. Usery, and M. Finn. 2009. Ground and surface temperature variability for remote sensing of soil moisture in a heterogeneous landscape. J. of Hydrology 368:214-223.

Hillel, D. 1991. Out of the Earth: Civilization and the life of the soil. Univ. of California Press, Berkeley, CA.

Hillel, D. 2004. Introduction to environmental soil physics. Elsevier, Amsterdam.

Horvath, F. 1993. Towards a mechanical model for the formation of the Pannonian basin. Tectonophysics 226:333-357.

Ichim, I. and M. Sandulescu. 1997. Romania. In: E.M. Moores and R.W. Fairbridge, editors, Encyclopedia of European and Asian regional geology. Chapman and Hall, London.

Jenny, H. 1994. Factors of Soil Formation: A System of Quantitative Pedology. Dover Publications, Inc. New York.

Jury, W.A., W.R. Gardner, and W.H. Gardner. 1991. Soil Physics. John Wiley and Sons, Inc. Hoboken, NJ. p. 159-191.

Jury, W.A. and R. Horton. 2004. Soil Physics. 6th ed. John Wiley and Sons, Hoboken, New Jersey.

Karlen, D.L., M.J. Mausbach, J.W. Doran, R.G. Cline, R.F. Harris, and G.E. Schuman. 1997. Soil Quality: A concept, definition, and framework for evaluation (A Guest Editorial). Soil Sci. Soc. Am. J. 61:4-10.

Kleinhans, F.W., S. Seki, and P. Mazur. 2010. Simple, inexpensive attainment and measurement of very high cooling and warming rates. Cryobiology 61:231-233.

Krupenikov, I.A. 1992. History of soil science from its inception to the present. Oxonian Press, New Delhi.

Li, C. and S. Cao. 1990. History of soil science in China. Transactions of the 14th International Congress of Soil Science 5:197-202.

Li, F., T.J. Jackson, W.P. Kustas, T.J. Schmugge, A.N. French, M.H. Cosh, and R. Bindlish. 2004. Deriving land surface temperature from Landsat 5 and 7 during SMEX02/SMACEX. Remote Sensing of Environment 92:521-534.

Livingston, N.J. 1993. Soil temperature. In: M.R. Carter, editor, Soil sampling and methods of analysis. Canadian Soc. Of Soil Sci. Lewis Publishers, Boca Raton, FL.

Morariu, T., B. Diaconeasa, and V. Garbacea. 1964. Age of landslides in the Transylvanian tableland. Revue Roum. Geol. Geophys. Geogr., Ser. Geogr, 8:149-157.

Motoc, M. 1982. Ritmul mediu de degradare erozionala a teritoriului Romaniei. Bulletin Informativ Academia de Stiinte Agricole Silvice, Bucuresti, 11:47-65.

Nicolescu, G., A. Vladimirescu, and O. Ciolpan. 2002. The distribution of mosquitoes in Romania (Diptera: Culicidae). Part I: *Anopheles*, *Aedes* and *Culex*. J. of the European Mosquito Control Association 13:17-26.

Neild, R.E. and J.E. Newman. 1987. Growing season characteristics and requirements in the corn belt: NCH-40. National Corn Handbook. Purdue Univ. Cooperative Extension Service, West Lafayette, IN.

Novak, M. 2005. Soil Temperature. In: M.K. Viney, J.L. Hatfield, and J.M. Baker, editors, Micrometeorology in Agricultural Systems – Agronomy Monograph No. 47. ASA-CSSA-SSSA, Madison, WI.

Papendick, R.I., M.J. Lindstrom, and V.L. Cochran. 1973. Soil mulch effects on seedbed temperature and water during fallow in eastern Washington. Soil Sci. Soc. Amer. Proc. 37:307-314.

Posea, G. and I. Velcea. 1975. The socialist republic of Romania – geographical characteristics. Geoforum 6:15-19.

Sanders C., R. Huismans, J.D. van Wees, and P. Andriessen. 2002. The Neogene history of the Transylvanian basin in relation to its surrounding mountains. EGU Stephan Mueller Special Publication Series 3:121-133.

Sauer, T.J. and R. Horton. 2005. Soil heat flux. In: M.K. Viney, J.L. Hatfield, and J.M. Baker, editors, Micrometeorology in Agricultural Systems – Agronomy Monograph No. 47. ASA-CSSA-SSSA, Madison, WI.

Schott, J.R., J.A. Barsi, B.L. Nordgren, N.G. Raqueno, and D. de Alwis. 2001. Calibration of Landsat thermal data and application to water resource studies. Remote Sensing of the Environment 78:108-117.

Scott, H.D. 2000. Soil physics: Agricultural and environmental applications. Iowa State University Press, Ames, IA.

Sclater, J.G., L. Royden, F. Horvath, B.C. Burchifiel, S. Semken, and L. Stegena. 1980. The formation of the Intra-Carpathian basins as determined by subsidence data. Earth and Planetary Science Letters 51:139-162.

Seefeldt, S.S., K.K. Kidwell, and J.E. Waller. 2002. Base growth temperatures, germination rates and growth response of contemporary spring wheat (*Triticum aestivum* L.) cultivars from the US Pacific Northwest. Field Crops Research 75:47-52.

Simonson, R.W. 1989. Historical highlights of soil survey and soil classification with emphasis on the United States, 1899-1970. Technical Paper 18. ISRIC, The Netherlands.

Srivastava, P.K., T.J. Majumdar, and A.K. Bhattacharya. 2010. Study of land surface temperature and spectral emissivity using multi-sensor satellite data. J. Earth Syst. Sci. 119:67-74.

Smith, G. 1981. Soil climate in Soil Taxonomy. p. 1-10. In: S.A. Ferrari *et al.*, editors, Proc. of 3rd Int. Soil Classification Workshop, Syria and Lebanon. 14-23 April 1980. The Arab Center for the Studies of Arid Zones and Dry Lands.

Smith, G.D. 1983. Historical developments of Soil Taxonomy – background. In: L.P. Wilding *et al.,* editors, Pedogenesis and Soil Taxonomy. I. Concepts and Interactions. Elsevier, Amsterdam.

Soil Survey Staff. 1999. Soil Taxonomy: A basic system of soil classification for making and interpreting soil surveys. 2nd ed. USDA-Soil Conservation Service, Agricultural Handbook #436, US Gov. Print. Office, Washington DC.

Soil Survey Staff. 1964. Soil Classification: A comprehensive system, 7th Approximation. USDA-Soil Conservation Service, US Gov. Print. Office, Washington DC.

Stanhill, G. 1965. Observations on the reduction of soil temperature. Agric. Meteorol. 2:197-203.

Swainson, C. 1873. A handbook of weather folk-lore. W. Blackwood and Sons, Edinburg.

Thomas, A., D. Byrne, and R. Weatherbee. 2002. Coastal sea surface temperature variability from Landsat infrared data. Remote Sensing of the Environment 81:262-272.

Tyagi, B., and A.N.V. Satyanarayana. 2010. Modeling of soil surface temperature and heat flux during pre-monsoon season at two tropical stations. J. of Atmospheric and Solar-Terrestrial Physics 72:224-233.

United States Geological Survey. 2011. Landsat 7 science data users handbook. http://landsathandbook.gsfc.nasa.gov/ (accessed 5 Jun. 2011).

Wang, J., R.L. Bras, G. Sivandran, and R.G. Knox. 2010. A simple method for the estimation of thermal inertia. Geophysical Research Letters 37:L05404.

Williams, B.J. 2006. Aztec knowledge soils: classes, management ecology. In: B.P. Warkentin, editor, Footprints in the Soil: People and Ideas in Soil History. Elsevier, New York, p. 17-42.

Whitney, M. 1900. Field operations of the Division of Soils, 1889. USDA Report No. 64, p. 13-35.

Wloczyk, C., R. Richter, E. Borg, and W. Neubert. 2006. Sea and lake surface temperature retrieval from Landsat thermal data in Northern Germany. International J. of Remote Sensing 27:2489-2502.

YongJun, P., W. Bing, C. BuFeng, C. Jin, S. Xin, and L. HanQiang. 2011. Characteristics of soil temperature in short-rotation Eucalyptus plantation. Forest Research 24:404-409.

Zagoroff, S.D. 1955. Agriculture and food in Rumania during World War II. In: S.D. Zagoroff, J. Vegh and A.D. Bilimovich, editors, The Agricultural Economy of the Danubian Countries 1935-45. Stanford Univ. Press, Stanford, CA.

CHAPTER 2. SOIL CLASSIFICATION IN THE TRANSYLVANIAN PLAIN, ROMANIA

2.1 INTRODUCTION

Soil classification has occurred throughout history for varying purposes such as land quality evaluation for taxation, public use and development, or agriculture suitability (Brevik and Hartemink, 2010; Buol *et al.*, 2003). Since countries developed their soil classification systems separately, philosophical differences concerning classification concepts have presented themselves. For example, early versions of *Romanian Soil Taxonomy* did not recognize the accumulation of secondary calcium carbonate in subsoils as a feature of pedogenesis (N. Florea, personal communication, 2011).

Throughout history wars have stifled the transfer of soil classification information between countries during formative periods of taxonomy. As a result, the development of soil classification produced two main groups; genetic and taxonomic systems (Bockheim and Gennadiyev, 2000). Given Romania's location in South-Central Eastern Europe, the Russian/Dokuchaev school of thought influenced their philosophical approach to soil morphology and classification, but the *World Reference Base (WRB) for Soil Resources* (FAO, 2006) proved to be the most influential external system. The genetic system of soil classification has been most influential on Romanian soil classification.

The Transylvanian Plain (TP) is a hilly region located in north central Romania, an area with historical and cultural importance. Paleo-lithic people who originally settled in this region selected areas near the Someş River plain and some hills throughout the TP.

The settlement of the TP changed with different societies. The Roman Empire settlements were around the edge of the TP, which is where the two main rivers are located. During the Austrian-Hungarian period settlements moved to the hilly interior of the TP. This location transition led to large amounts of deforestation of the TP, which resulted in the forest "islands" found today (Baciu *et al.*, 2010). These forests are located on summits across the TP. Conflict and turmoil in the TP during its settlement have resulted in hardships which have stifled agricultural productivity. Much of the conflict in this region has stemmed from historical changes in power (Roman Empire, Austrian-Hungarian Empire, and Soviet Union Communism). In the 1970s, 63% of Romanian land was in agricultural production, of which 91% was owned by co-operatives and state farms. After the fall of communism in 1989, land ownership drastically changed. By 1998, 72% of farm land was owned by private entities (Drager and Jaksch, 2001). As land transitioned from state farms to individual farms, lack of modern farming equipment proved a formidable constraint. Farming equipment once owned by the state was suitable for large scale farms, while family farms averaged only 2.5 ha. Some cooperatives were formed by multiple families to combine their land and purchase a tractor for use by all. Nonetheless, the lack of available farming equipment has resulted in the wide-spread use of manual and horse drawn methods of agricultural production to this day (Figure 2.1).

Figure 2.1. Traditional horse drawn agriculture prevalent in the Transylvanian Plain, Romania.

The TP is located within contemporary Bistrita Nassaud, Cluj, and Mureş counties. In 1995, the population employed in agriculture for the three aforementioned counties was 15.6%, 26.8%, and 36.5%, respectively (European Commission, 2002). The TP is a smaller feature (395,000 ha) within the larger Transylvanian Basin (TB) (2,000,000 ha). The TB is part of an even larger system of Pannonian Basins in the Carpathian arc. The TP is surrounded by the Eastern Carpathian, Southern Carpathian, and Apuseni Mountains (Figure 2.2). The TP is composed of Miocene marine sediments which were periodically dissected beginning in the Pliocene (Ichim and Sandulescu, 1997; Sclater *et al.*, 1980).

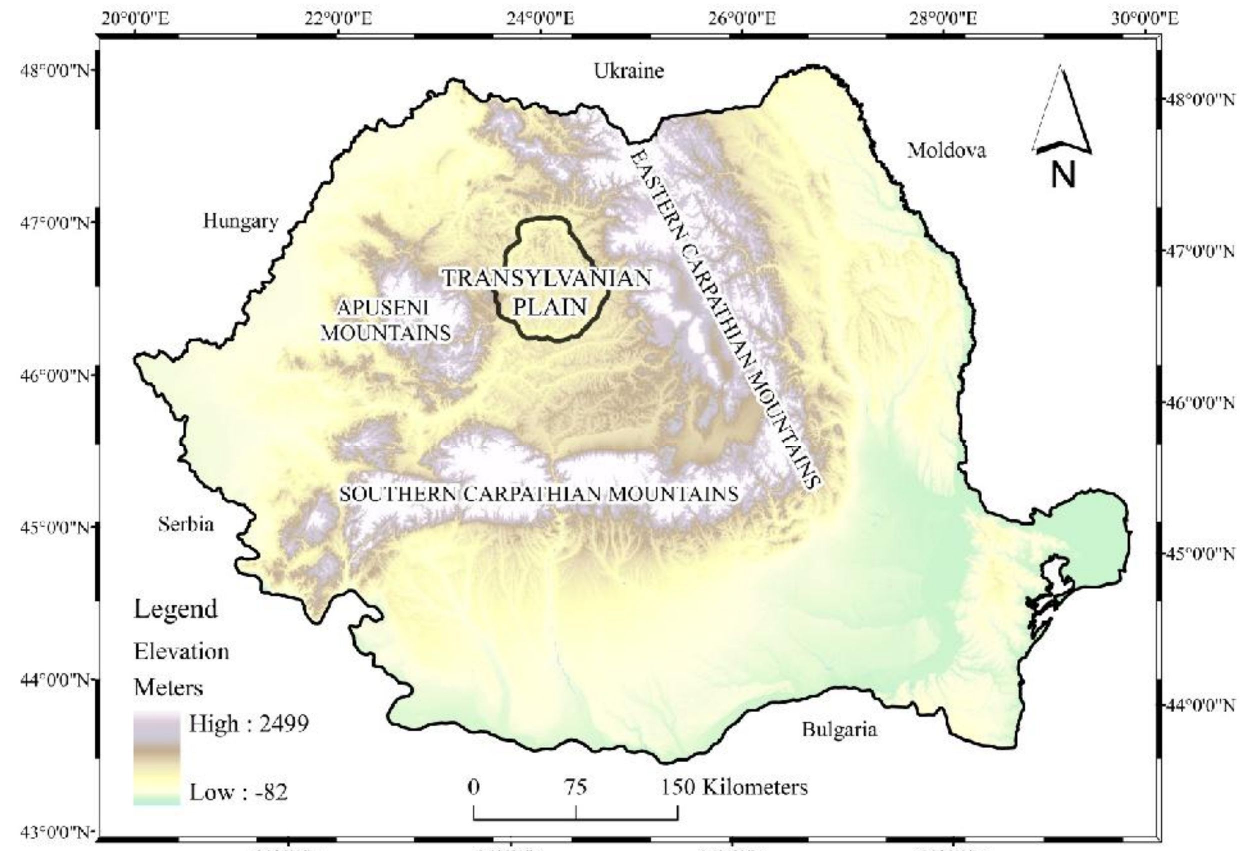

Figure 2.2. Digital elevation model of Romania with the Transylvanian Plain outlined.

The TB is the highest of the Pannonian basins due to Quaternary uplift which did not occur in the other basins (Sclater *et al.*, 1980). Currently, two main river systems bound the TP; the Mureş River to the South and the Someş River to the North. The TP is essentially divided by the drainage basins of these two rivers. It is noteworthy that the TP is a manmade geographic region; a fact emphasized since it encompasses portions of two distinct watersheds. The marl and sandstone marine sediments found throughout the TP have led to a phenomenon which occurs predominately on southern slopes, whereby glimee landslides occur. Glimee landslides are a large scale, deep seated form of mass wasting (Figure 2.3). The sediments of the TP are of marine origin and consist mainly of marl, clay marl, sand, and sandy clay complexes (Jakab, 2007).

Figure 2.3. Glimee landslides in the Southern Transylvanian Plain, Romania.

The *Sistemul Roman De Taxonomie A Solurilor (Romanian System of Soil Taxonomy - RSST)* has as its main objective the identification, grouping, and naming of Romanian soils with hierarchical attributes on the basis of intrinsic characteristics which the soil expresses to prevent redundancy and emphasize specific features (Florea and Munteanu, 2003). Table 2.1 shows the relationships between the top three levels of *RSST* and *US Soil Taxonomy (USST).*

Table 2.1. Comparison of the higher levels of United States Soil Taxonomy and the Romanian System of Soil Taxonomy (Secu *et al.*, 2008; Soil Survey Staff, 2011; Soil Survey Staff, 1999).

United States Soil Taxonomy			Romanian System of Soil Taxonomy		
Level		Example	Level		Example
Order	12	Alfisol	Class	12	Luvisoluri
Sub-order	64	Hapludalf	Type	32	Preluvosol
Great group	300	Typic Hapludalf	Sub-type	245	Tipic Preluvosol

However, Romania is the only country which uses *RSST*. As such, its use fosters isolationism when compared to other widely used systems such as *WRB* and/or *USST*. A clear translation of the *RSST* soil classification in relation to *WRB* and *USST* would be useful for more effective communication among pedologists.

The TP is predominately Mollisols (Cernisoluri) 40%, followed by Alfisols (Luvisoluri) 22% and Entisols (Protisoluri, Antrisoluri, and Hidrisoluri) 25% (Figures 2.4 and 2.5). The Mollisols occur primarily in the southern portion of the TP where the plain has less drastic changes in relief providing slightly more stable lands. The northern TP contains the highest relief features (628 m) and is dominated by Alfisols. The mean elevations for these Mollisols and Alfisols are 389 m and 417 m, respectively.

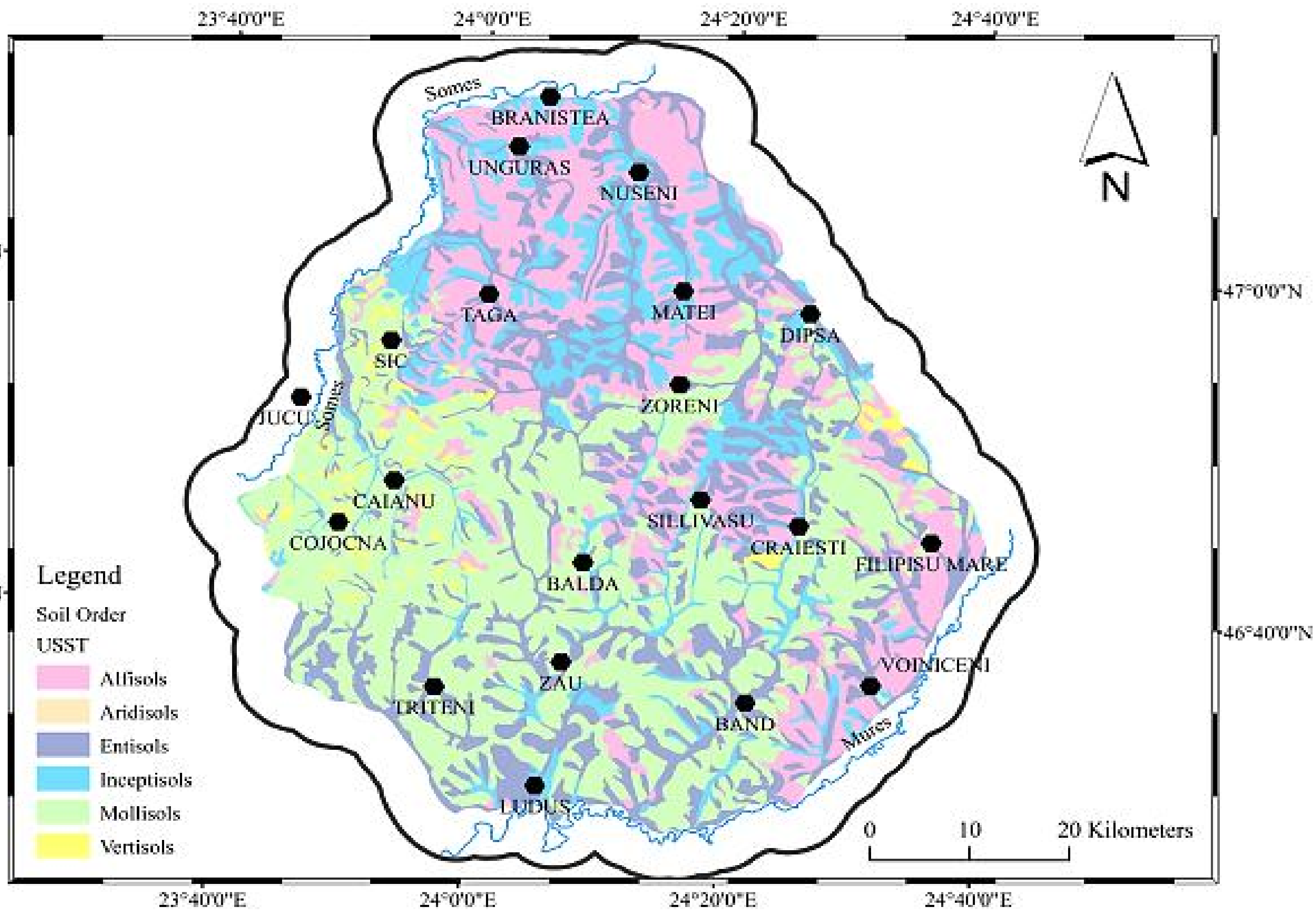

Figure 2.4. Soil map of the Transylvanian Plain, Romania based upon *US Soil Taxonomy* (Soil Survey Staff, 1999).

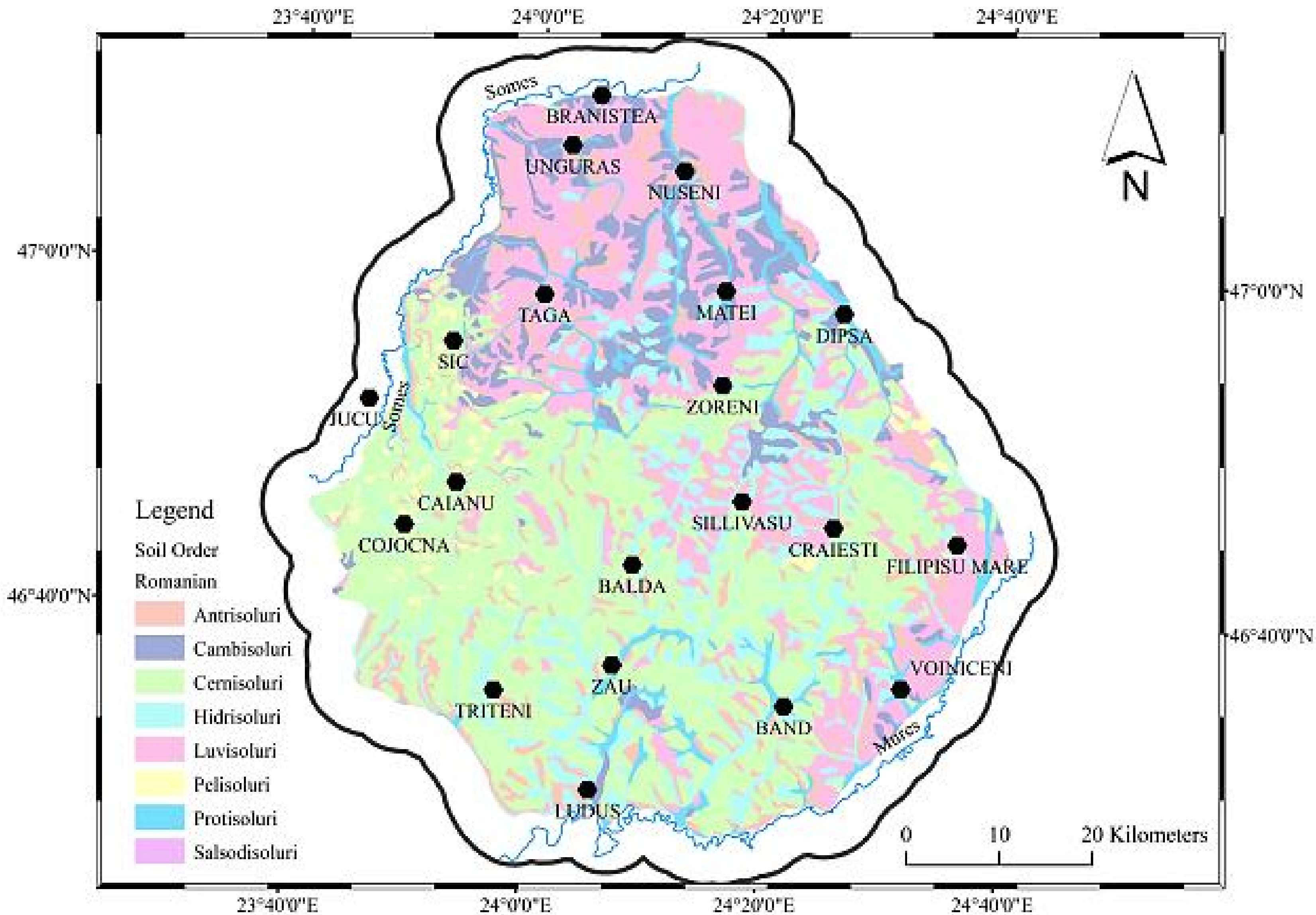

Figure 2.5. Soil map of the Transylvanian Plain, Romania based upon *Romanian System of Soil Taxonomy*.

In recognition of the TP's agricultural importance, clearly established translational soil classification between *RSST* and other widely accepted systems of taxonomy (*USST* and *WRB*) would be beneficial for future land use planning and agricultural development. As such, the objectives of this study were to: 1) characterize select soils in the Transylvanian Plain, Romania, and 2) compare *RSST* soil classifications with *USST*.

2.2 MATERIALS AND METHODS

Twenty pedons were morphologically described in the Transylvanian Plain (TP) per Soil Survey Staff (2002). The sites were selected as part of an established soil temperature study in the TP (Haggard *et al.*, 2010; Haggard *et al.*, 2012). Each site was georeferenced using a Garmin eTrex Vista (Olathe, KS, USA) handheld global positioning system device. Profiles were morphologically described to 50 cm in a soil pit and core samples were taken near the pit to a depth of 100 cm for particle size, organic carbon, and calcium carbonate equivalent. Soil core samples were oven dried at 40^{o}C and ground to pass a 2 mm sieve in Romania, then shipped to the Louisiana State University Agricultural Center in Baton Rouge, LA, USA for lab analysis. Samples were stored in sealed plastic bags for transport. Particle size was assessed using a modified hydrometer method with a 24 hr clay reading (Gee and Bauder, 1986). Due to the carbonates present in the TP samples were run at 400°C for 16 h for loss on ignition (LOI) organic matter analysis (Ben-Dor and Banin, 1989). Calcium carbonate equivalent was measured via the pressure calcimeter method (Loeppert and Suarez, 1996) to aid in Cernoziom confirmation in the TP. Cation exchange capacity and base saturation percentage were measured via the NH_4OAc method (Chapman, 1965). Map processing was performed using ArcGIS 9.3 (ESRI, 2009). Differences in organic carbon percentage (OC) were analyzed using Proc Mixed; an analysis of variance procedure in SAS 9.3 (SAS Institute, 2010). The *WRB* (FAO, 2006) was

used to assist in determining the correct *RSST* classification in some instances. Since *RSST* is only available in Romanian, some classifications were first made using *WRB,* then converted to *RSST* and adjusted as needed to reflect differences from *WRB*. Finally, comparative soil taxonomic classifications were made between *USST* and *RSST* (Soil Survey Staff, 1999; Munteanu and Florea, 2002; Florea and Munteanu, 2003).

2.3 RESULTS AND DISCUSSION

Of the twenty pedons described, there were 6 Inceptisols, 4 Alfisols, and 10 Mollisols (Table 2.2). Mollisols (*USST*) or Cernisoluri (*RSST*) was the dominant soil order or class in the TP occupying 156,311 ha (Table 2.3). A representative site for each classification based on the great group (*USST*) / sub-type (*RSST*) level will be discussed. The *RSST* contains some slight differences regarding subordinate horizons which are shown in Table 2.4. In *RSST*, a subordinate horizon is only used when the respective diagnostic horizon is present. Consider a horizon that shows illuviated silicate clays in the form of clay films, with a clay increase relative to the overlying horizon from 43 to 46 percent. In *USST*, this horizon would be designated as a Bt horizon. In *RSST* it would be designated as a Bv horizon as it is clearly not argillic (still cambic based on pedogenesis). Epipedons provide important information regarding surface characteristics of a soil pedon. In *RSST* epipedons are identified as lower case letters in conjunction with A or O horizons. For example, an ochric epipedon would be noted as Ao according to *RSST*. This method allows for a quick and easy notation of an epipedon.

A point of divergence in pedologic ideology between *USST* and *RSST* concerns the movement of calcium carbonate through the soil profile. Two forms of calcium carbonate movement in the soil are known.

Table 2.2. Soil Classification of 20 sites located in the Transylvanian Plain, Romania.

Station	*USST*†	*RSST*‡	Slope Position	Elevation m
Filpisu Mare	Typic Dystrudept	Tipic Districambosol	Backslope	375
Silivasu	Typic Humudept	Molic Eutricambosol	Footslope	463
Unguras	Typic Eutrudept	Tipic Eutricambosol	Footslope	291
Branistea	Typic Eutrudept	Tipic Eutricambosol	Terrace	266
Zau	Typic Eutrudept	Tipic Eutricambosol	Backslope	320
Matei	Typic Eutrudept	Tipic Eutricambosol	Floodplain	322
Taga	Typic Hapludalf	Tipic Preluvosol	Backslope	316
Sic	Typic Hapludalf	Tipic Preluvosol	Backslope	363
Nuseni	Typic Hapludalf	Tipic Preluvosol	Backslope	296
Zoreni	Typic Hapludalf	Tipic Preluvosol	Backslope	445
Caianu	Typic Calciudoll	Calcaric Cernoziom	Backslope	469
Balda	Typic Hapludoll	Cambic Faeoziom	Backslope	361
Triteni	Typic Hapludoll	Cambic Faeoziom	Backslope	342
Band	Typic Argiudoll	Argic Faeoziom	Floodplain	319
Craiesti	Typic Argiudoll	Argic Faeoziom	Terrace	375
Dipsa	Typic Argiudoll	Argic Faeoziom	Floodplain	356
Cojocna	Typic Argiudoll	Argic Faeoziom	Backslope	579
Jucu	Entic Hapludoll	Tipic Faeoziom	Footslope	326
Voinceni	Entic Hapludoll	Tipic Faeoziom	Floodplain	345
Ludus	Entic Hapludoll	Tipic Faeoziom	Toeslope	293

†United States Soil Taxonomy - Classification
‡Romanian System of Soil Taxonomy – Classification

Table 2.3. Area of all soil orders (classes) in the Transylvanian Plain, Romania.

Romanian	Area ---ha---	*USST*	Area ---ha---
Antrisoluri	39,200	Alfisols	86,410
Cambisoluri	35,679	Aridisols	236
Cernisoluri	156,311	Entisols	98,180
Hidrisoluri	51,090	Inceptisols	47,742
Luvisoluri	86,410	Mollisols	156,311
Pelisoluri	6,737	Vertisols	6737
Protisoluri	19,909		
Salsodisoluri	280		

Table 2.4. A comparison of some subordinate horizon and epipedon nomenclature in United States Soil Taxonomy (*USST*) and Romanian Soil Taxonomy (*RSST*).

USST	*RSST*	Feature
w	v	Pedogenic development
t	t	Accumulation of silicate clay
n	na	Accumulation of sodium
p	p	Mechanical disturbance
g	g	Reduced soil color
k	ca	Calcium carbonate accumulation
-	Am	Mollic epipedon
-	Ao	Ochric epipedon
-	Au	Umbric epipedon

The first being that calcium carbonate is wind deposited or weathered in place from calcareous parent material, dissolved and slowly translocated through the soil profile in chemical solution by water, then precipitated in the subsoil as masses, films, or similar features (Gunal and Ransom, 2006). The second form of movement is through upward movement of carbonates due to a high water table or higher evapotranspiration than precipitation during the summer months (Knuteson *et al.*, 1989). However, in *RSST* the only movement acknowledged is from the subsoil toward the surface in response to evaporative demand or capillary action (N. Florea, personal communication, 2011). Thus, carbonate rich parent material loses carbonates through upward water movement in the soil profile. Carbonates within the soil profile have an important role in *RSST* with regards to classification of the Cernisoluri class (order). Within this class there are four soil types: Kastanozem, Cernoziom, Phaeozem, and Rendzina. Previously, it was thought that Cernozioms were not present in the TP. The area is hilly with tree covered summits. There have been different theories concerning deforestation within the TP and whether or not enough time has elapsed for the formation of a true Cernoziom (Baciu *et al.*, 2010). However, the Caianu pedon shows a fully developed Cernoziom (Figure 2.6, Table 2.5).

In *RSST* a Cernoziom is defined as follows:

> Other Cernisoluri with an Am (where Am denotes a mollic epipedon) horizon with chroma equal to or less than 2 and Cca horizon of secondary carbonate concentrations in the top 125 cm (for Cernisoluri with coarser textures, chroma of the A horizon can be 3 or less, and residual carbonates may occur up to 200 cm).

In comparison a Phaeozem must meet the following requirements according to *RSST*:

> Soils having an Am horizon with the value and chroma both equal to or less than 3.5. No secondary carbonate accumulations within the top 125 cm of the profile. These soils are exclusively formed on calcareous parent material.

The Caianu pedon is a Typic Calciudoll (*USST*) or Calcaric Cernoziom (*RSST*) located in a backslope position on a 15% slope. Carbonate concentrations start at 20 cm with diameters which range from 0.5 to 1.5 cm.

Another important difference between *USST* and *RSST* concerns the role of secondary carbonates in pedogenesis. In *RSST*, secondary calcium carbonate movement is not seen as pedogenesis according to the current system. Therefore if secondary carbonates are the only pedogenic development observed, the horizon would still be described by a C master horizon. This would change the classification from Bk1, Bk2, and Ck to Cca1, Cca2, and Cca3 at the Caianu site. However, given strong international recognition of secondary carbonates as a pedogenic feature, changes to *RSST* to recognize a pedogenic Bk horizon are planned (N. Florea, personal communication, 2011).

The Branistea pedon was classified as a Typic Dystrudept (*USST*) or Tipic Districambosol (*RSST*). The site is located on a Someş River terrace in the northern portion of the TP. The profile is characterized by an ochric epipedon and a cambic horizon (Table 2.5). The Branistea pedon contains free carbonates throughout the profile as well as rounded siliceous gravels.

Figure 2.6. The Caianu pedon and landscape position in the Transylvanian Plain, Romania.

Table 2.5. Pedon descriptions at five locations in the Transylvanian Plain, Romania.

USST†	*RSST*‡	Depth cm	Clay --%--	Texture	$CaCO_3$ ---%---	Hue	Value	Chroma
				Caianu				
Ap	Ap	5	47	Silty Clay	17	10 YR	3	2
Bw	Bv	18	47	Silty Clay	5	10 YR	3	2
Bk1	Cca1	30	44	Silty Clay	15	10 YR	5	3
Bk2	Cca2	60	47	Silty Clay	16	10 YR	6	3
Ck	Cca3	100+	49	Silty Clay	68	10 YR	6	3
				Branistea				
Ap	Ap	12	24	Loam	3	2.5Y	4	1
Bw1	Bv1	26	25	Loam	5	2.5Y	5	3
Bw2	Bv2	40	31	Silty Clay Loam	3	2.5Y	5	3
Bw3	Bv3	100+	37	Silty Clay Loam	4	2.5Y	5	3
				Jucu				
Ap	Ap	9	48	Silty Clay	6	10YR	3	2
Bw1	Bt1	34	52	Silty Clay	2	10YR	3	2
Bw2	Bt2	55	54	Silty Clay	12	10YR	3	2
C	C	100+	36	Silty Clay Loam	6	10YR	4	2
				Cojocna				
Ap	Ap	13	28	Silty Clay Loam	-	10YR	3	2
Bt1	Bt1	35	32	Silty Clay Loam	-	10YR	3	2
Bt2	Bt2	50	40	Silty Clay Loam	-	10YR	3	2
Bt3	Bt3	100+	45	Clay	-	10YR	3	2
				Sic				
Ap	Ap	12	39	Clay Loam	12	2.5Y	4	2
Bt	Bt	22	42	Clay	3	2.5Y	4	2
Btkg1	Btg1	40	39	Clay Loam	16	2.5Y	6	4
Btkg2	Btg2	100+	36	Clay Loam	16	2.5Y	6	4

†United States Soil Taxonomy - Horizonation
‡Romanian System of Soil Taxonomy - Horizonation

The site was the lowest elevated of all of the pedons described in the TP. The Bw1 horizon contains 22% gravels making the horizon a gravelly sandy clay loam. Of the 20 sites, this is the only one with a horizon containing a large amount of siliceous gravels.

The Jucu pedon was classified as an Entic Hapludoll (*USST*) or Tipic Faeoziom (*RSST*). The site is located near the Someş River on a footslope position at 326 m. Jucu has a mollic epipedon with a cambic diagnostic subsurface horizon (Table 5).

The Cojocna pedon classified as a Typic Argiudoll (*USST*) or Argic Faeoziom (*RSST*). The Cojocna site is on a backslope position at 579 m with an argillic diagnostic subsurface horizon (Table 2.5). Of the 20 sites, there were four Typic Argiudolls (*USST*) classified. The pedon was characterized by strong angular blocky structure in the Bt1 horizon (Figure 2.7). The Cojocna site was at the highest elevation described in this study throughout the TP.

The Sic pedon was one of four Alfisols identified across the 20 sites. The Sic pedon was classified as Typic Hapludalf (*USST*) or Tipic Preluvosol (*RSST*). The site is located on a backslope at 363 m and has an ochric epipedon (Table 2.5). The Sic pedon contains calcium carbonate as well as illuviated silicate clays. However, the classifications are slightly different between *USST* and *RSST*. The k subordinate is not shown in the *RSST* classification since the Sic pedon does not qualify as a calcic horizon. The *Romanian System of Soil Taxonomy* (*RSST*) differs from *USST* concerning calcic and argillic horizons. In *USST*, a Bt horizon can be described without having an argillic horizon. Similarly, a Bk horizon is possible without the presence of a calcic horizon. In both circumstances, the non-calcic Bk and non-argillic Bt qualify as cambic horizons representing intermediate soil pedogenesis. However, in *RSST* Bt or Cca horizons are not described in the absence of an argillic or calcic horizon.

Figure 2.7. The Cojocna pedon and landscape position in the Transylvanian Plain, Romania.

This may infer the absence of clay or carbonate accumulation in the subsoil, when in fact some may have occurred; just not to the level required to form diagnostic subsurface horizons.

Organic carbon (OC) percentages at all of the pedons were sufficient for a mollic epipedon (>0.6%); though other factors such as color precluded such a designation at some sites. There were significant differences between the sites when OC was evaluated. The Cojocna site had the highest OC and was significantly different than all other sites except Triteni, Silivasu, Dipsa, Ludus, and Craiesti. The sites with the lowest OC were Zau de Campie, Unguras, Branistea, and Voinceni. The aforementioned sites were significantly different than Cojocna and Triteni (Table 2.6).

Table 2.6. Analysis of variance of soil organic carbon in the Transylvanian Plain, Romania.

Site	Organic Carbon ---%---
Cojocna	5.9[a†‡]
Triteni	4.7[ab]
Silivasu	3.6[abc]
Dipsa	3.5[abc]
Ludus	3.5[abc]
Craiesti	3.4[abc]
Caianu	3.2[bc]
Nuseni	3.1[bc]
Jucu	3.0[bc]
Zoreni	2.9[bc]
Balda	2.8[bc]
Matei	2.7[bc]
Sic	2.7[bc]
Taga	2.7[bc]
Band	2.5[bc]
Filpisu Mare	2.5[bc]
Zau	2.0[c]
Unguras	1.7[c]
Branistea	1.5[c]
Voinceni	1.5[c]

†Different letters in the same column are significantly different (p=0.05).
‡Standard error was 0.45.

2.4 CONCLUSIONS

Twenty pedons were described in the Transylvanian Plain, Romania according to both *USST* and *RSST*. Classification showed that Mollisols (*USST*) or Cernisoluri (*RSST*) were the most prevalent soil order, documented at 10 out of the 20 sites. A philosophical difference between *USST* and *RSST* concerns the movement of carbonates through the soil profile. Dissolution and subsequent movement down through the pedon is one of the processes advocated by *USST* while *RSST* argues that the only process is through evapotranspiration and capillary action move carbonates from the subsoil upward toward the surface. Free secondary carbonates found in some of the profiles changed the classification from a Typic Dystrudept to a Typic Eutrudept (*USST*). Furthermore, the secondary carbonates present at the Caianu site, along with other features, clearly establish the presence of Cernozioms (*RSST*) in the TP. Organic carbon percentages (OC) were found to differ significantly between sites, with the Cojocna and Voinceni sites containing the highest and lowest OC at 5.85 and 1.45%, respectively. Continued pedological studies will strengthen the correlation between *RSST* and other widely accepted systems of soil classification and elucidate important philosophical concepts germane to global soil classification.

2.5 REFERENCES

Baciu, N., C. Stanescu, O.L. Muntean, R. Mihaiescu, and T. Mihaiescu. 2010. Geo-systems and types of geo-facets in the Transylvanian plain – Tools for defining cultural landscapes. Present Environment and Sustainable Development 4:255-262.

Ben-Dor, E., and A. Banin. 1989. Determination of organic matter content in arid-zone soils using simple “loss-on-ignition” method. Commun. Soil Sci. Plant Anal. 20:1675-1695.

Bockheim, J.G., and A.N. Gennadiyev. 2000. The role of soil-forming processes in the definition of taxa in Soil Taxonomy and the World Soil Reference Base. Geoderma 95:53-72.

Buol, S.W., R.J. Southard, R.C. Graham, and P.A. McDaniel. 2003. Soil Genesis and Classification. 5th ed. Blackwell Publishing, Ames, IA, USA.

Brevik, E.C., and A.E. Hartemink. 2010. Early soil knowledge and the birth and development of soil science. Catena 83:23-33.

Chapman, H.D. 1965. Cation-exchange capacity. In: Black, C.A., editor, Methods of soil analysis- chemical and microbiological properties. Agronomy 9:891-901.

Drager, D., and T. Jaksch. 2001. Romania. In: S.J. Goetz *et al.* (editors) Agricultural Transformation and Land Use in Central and Eastern Europe. Ashgate, Aldershot, England, p. 269-290.

European Commission. 2002. Volume 11: Portrait of the regions – Romania. Office for Official Publications of the European Communities, Luxembourg.

Food and Agriculture Organization of the United Nations. 2006. World reference base for soil resources 2006: A framework for international classification, correlation and communication. FAO. Rome, Italy.

Florea, N., and I. Munteanu. 2003. Sistemul Roman de taxonomie a solurilor. Estifalia. Bucuresti, Romania.

Gee, G.W., and J.W. Bauder. 1986. Particle size analysis. In: J.M. Bigham, editor, Methods of soil analysis: Part 1- physical and mineralogical methods. SSSA-ASA. Madison, WI.

Gunal, H., and M.D. Ransom. 2006. Clay illuviation and calcium carbonate accumulation along a precipitation gradient in Kansas. Catena 68:59-69.

Haggard, B.J., D. Weindorf, H. Cacovean, T. Rusu, J. Lofton. 2010. Analysis of growing degree days in the Transylvanian Plain, Romania. Studia Universitatis Babeş-Bolyai, Geographia, Anul LV, nr. 2/2010 (pp. 13-20).

Haggard, B., D.C. Weindorf, and A.L. Hiscox. 2012. Evaluation of the predictive capabilities of Landsat 7 ETM+ on 50 cm mean annual soil temperature in the Transylvanian Plain, Romania. Eur. J. Soil Sci. In Press.

Ichim, I., and M. Sandulescu. 1997. Romania. In: E.M. Moores and R.W. Fairbridge (editors) Encyclopedia of European and Asian regional geology. Chapman , and Hall, London.

Jakab, S. 2007. Chrono-toposequences of soils on the river terraces in Transylvania (Romania). Catena 71:406-410.

Knuteson, J.A., J.L. Richardson, D.D. Patterson, L. Prunty. 1989. Pedogenic carbonates in a Calciaquoll associated with recharge wetland. Soil Sci. Soc. Am. J. 53:495-499.

Loeppert, R.H., and D.L. Suarez. 1996. Carbonate and gypsum. In: J.M. Bigham, editor, Methods of soil analysis: Part 2- chemical methods. SSSA-ASA. Madison, WI.

Munteanu, I, and N. Florea. 2002. Present-day status of soil classification in Romania. P. 55-62. In: E. Micheli, F.O. Nachtergaele, and R.J.A. Jones (editors) Soil Classification 2001. European Soil Bureau –research report number 7. Office for Official Publications of the European Communites, Luxembourg.

SAS Institute. 2010. The SAS system for Windows. Release 9.3. SAS Institute Inc., Cary, NC, USA.

Sclater, J.G., L. Royden, F. Horvath, B.C. Burchifiel, S. Semken, and L. Stegena. 1980. The formation of the Intra-Carpathian basins as determined by subsidence data. Earth and Planetary Science Letters 51:139-162.

Secu, C.V., C. Patriche, and I. Vasiliniuc. 2008. Aspects regarding the correlation of the Romanian Soil Taxonomy System (2003) with WRB (2006). Ґрунмознавсмво (Ukrainian for Soil Science) 9:56-62.

Soil Survey Staff. 1999. Soil taxonomy: A basis system of soil classification for making and interpreting soil surveys. 2nd ed. USDA-NRCS. US Gov. Print. Off. Washington, DC.

Soil Survey Staff. 2011. Soil education – Soil formation and classification [Online]. Available at http://soils.usda.gov/education/facts/formation.html (verified 14 Dec. 2011).

Soil Survey Staff. 2002. Field book for describing and sampling soils, Version 2.0. NRCS-NSSC, Lincoln, NE.

CHAPTER 3. GROWING DEGREE DAYS[1]

3.1 INTRODUCTION

The TP is a geographical region located in north-central Romania and is bordered by large rivers to the north and south, the Someşul Mare and the Mureş, respectively. The TP is ~395,000 ha and ranges from 200-600 m in elevation, with some of the highest elevations occurring in the NW region. Contrary to the name, the TP consists of rolling hills with patches of forests located mainly on the tops of hills. The region is a major agricultural zone with major crops of corn, sugar beet, wheat, sunflower, and forages.

With a more proficient method of crop growth estimation, fertilization and harvesting could be achieved more effectively in farming operations of the Transylvanian Plain (TP), Romania. Growing degree days (GDDs) have been used for many years as a method of rating the maturity of crops. Two GDD calculations are most commonly used: single-sine (BE) and averaging method [rectangular] (AM) (Arnold, 1960; Baskerville and Emin, 1969). There are other more complicated methods that have been introduced, but they have not shown a significant improvement over the aforementioned methods (Roltsch *et al.*, 1999). The basis of growing degree days is that every crop has a base temperature (BT) at which plant growth takes place. When air temperature rises above BT, GDDs are accumulated. For example the BT for corn is usually set at 10 ^{o}C. If the average temperature for a certain day was 17 ^{o}C, then 7 GDDs were accumulated (Arnold, 1960). This process is conducted for the growing period of the crop, until maturity is reached. It is considered more accurate than calendar days because it can account for air temperature anomalies throughout the current growing season. All GDDs mentioned are based on ^{o}C air temperatures.

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Cereals and oilseeds require ~1200 GDDs with a 5 ^{o}C BT (Ash *et al.*, 1999). Depending on the corn hybrid, the GDDs needed for silage may range from 1100 to 1200 GDDs, while grain corn could take 1100-1600 GDDs with a 10 ^{o}C BT (Ash *et al.*, 1999; Cox, 2006). Cox (2006) found that 96 to 100 calendar day corn started to tassel at around 694 GDDs in Aurora, NY. This is similar to the GDDs for some of the DeKalb® 100 day corn hybrids (Monsanto Company, 2009).

Growing degree days are normally calculated using only the minimum and maximum temperatures for each day. The objectives of this study were to: (i) compare two different GDD calculation methods to serve as an initial starting point for comparing GDDs to the maturity rates of corn at twenty locations in the TP, (ii) determine if there is a need for different planting dates across the TP to maximize the use of GDD for corn, and (iii) evaluate available corn hybrids that could be planted in the TP based on GDDs.

3.2 MATERIALS AND METHODS

For this study, GDDs were run from approximately day of year (DOY) 110 to 199 to use available data from twenty datalogging stations to evaluate the mid-pollination GDDs of corn cultivars available from DeKalb®. The BE and AM were calculated using 24 h temperature values collected at each station (BE-Full and AM-Full) and then recalculated using only the minimum and maximum values for each day (BE-M/M and AM-M/M), giving four different values; (1) BE-Full, (2) BE-M/M, (3) AM-Full, (4) AM-M/M. Baskerville-Emin was calculated using equation 3.1.a for 24 h data and equation 3.1.b for the minimum and maximum of each day. To calculate BE, equations 3.1.c.1, 3.1.c.2, and 3.1.c.3 must be evaluated and the values placed in equations 3.1.a and 3.1.b (Baskerville and Emin, 1969). The AM was calculated by equation 3.2 (Arnold, 1960).

$$BE\text{-}Full = \{[W * Cos(A1)] - [(BT - AVG_F) * ((3.14/2) - A1)]\}/3.14 \quad (3.1.a)$$

$$BE\text{-}M/M = \{[W * Cos(A2)] - [(BT - AVG_{MM}) * ((3.14/2) - A2)]\}/3.14 \quad (3.1.b)$$

$$A1 = Arcsine\ [(BT - AVG_F)/W] \quad (3.1.c.1)$$

$$A2 = Arcsine\ [(BT - AVG_{MM})/W] \quad (3.1.c.2)$$

$$W = (MT - BT)/2 \quad (3.1.c.3)$$

$$AMGDD = AVG - BT \quad (3.2)$$

Where AVG_F = the average temperature using the full days' worth of temperature readings, AVG_{MM} = the average temperature using the minimum and maximum for the day, BT= base temperature, and MT= maximum temperature. The lower threshold was set at 10^oC, and the upper threshold was set at 30^oC, in case either the BT or MT was below or above, respectively. Outside of this temperature range, crop growth is limited.

In 2009, temperature values were recorded at twenty datalogging stations by two different sensors. Ten stations without rain gauges (rain-) recorded air temperature using a 12-Bit Temperature Smart Sensor, while the other 10 (rain+) have a HOBO® Data Logging Rain Gauge (Onset Computer Corporation, Bourne, MA, USA). At the rain+ stations, temperature was recorded once every hour, while at the rain- stations, temperature was read every 2 min and a 10 min average was recorded. Table 3.1 shows the station configuration. Both temperature sensors are within .5 m of the surface, which removes errors that could occur due to higher elevated air temperatures not accurately describing the vegetative microclimates (Roltsch *et al.*, 1999). The temperature data was processed in Microsoft Access 2007 to produce the minimum, maximum,

and average temperature for 110-199 DOY. The temperature values were then moved to Microsoft Excel 2007 to calculate the GDDs, using the above equations.

Table 3.1. Station configuration in the Transylvanian Plain, Romania.

Station number	Station name	Latitude	Elevation	Rain gauge
			m	
1	Balda	46.717002	360	No
2	Triteni	46.59116	342	No
3	Ludus†	46.497812	293	Yes
4	Band	46.584881	318	No
5	Jucu	46.868676	325	Yes
6	Craiesti	46.758798	375	No
7	Silivasu	46.781705	463	Yes
8	Dipsa	46.966299	356	Yes
9	Taga	46.975769	316	No
10	Caianu	46.790873	469	Yes
11	Cojocna	46.748059	604	Yes
12	Unguras	47.120853	318	Yes
13	Branistea	47.17046	291	Yes
14	Voinceni	46.60518	377	Yes
15	Zau	46.61924	350	Yes
16	Sic†	46.92737	397	No
17	Nuseni	47.09947	324	No
18	Matei†	46.984869	352	No
19	Zoreni†	46.893457	487	No
20	Filpisu Mare	46.746178	410	No

† Stations have incomplete data, and are not used in the interpolation maps.

The accumulated growing degree days (AGDDs) of the four methods were analyzed to find the approximate day of tasseling based on a 694 AGDDs tassel date. The data was analyzed in SAS software (SAS Institute, 2008) using the LSD test to identify any differences between sites located across the TP. Finally, the data was georeferenced to station locations in ArcMap 9.2 (ESRI, Redlands, CA, USA) to create spline interpolation maps showing the GDD trend across the TP.

3.3 RESULTS

The TP has shown some growing season variability from initial GDDs data. Table 3.2 shows the LSD results for the DOY that 694 AGDDs were reached at 16 sites. Three sites failed to reach 694 AGDDs by 199 DOY; the last day of data currently available. Site 3 had no air temperature data due to data logger error.

Table 3.2. Least significant difference test of the day of year each site reached 694 accumulated growing degree days, Transylvanian Plain, Romania.

Site	Mean†
1	189.25
2	189.50
4	184.50
5	188.00
6	180.50
7	190.00
8	190.75
9	183.75
10	189.75
11	187.50
12	188.50
13	184.50
14	190.75
15	184.50
17	185.75
20	181.00

†LSD = 1.966

It was found that 694 AGGD were reached at 177 DOY while some sites had not reached the AGDD needed by 199 DOY. As such, sites 6 and 20 would tassel an entire month sooner than sites 8 and 14 on the plain, even with the same planting date. A slice was performed in ArcMap 9.2 (ESRI, 2006) with the same data that was evaluated in SAS using LSD, and split into 6 equal intervals (Figure 3.1). The DOY when each site reached 694 AGDDs for BE-F and AM-F was interpolated using spline (Figures 3.2 and 3.3).

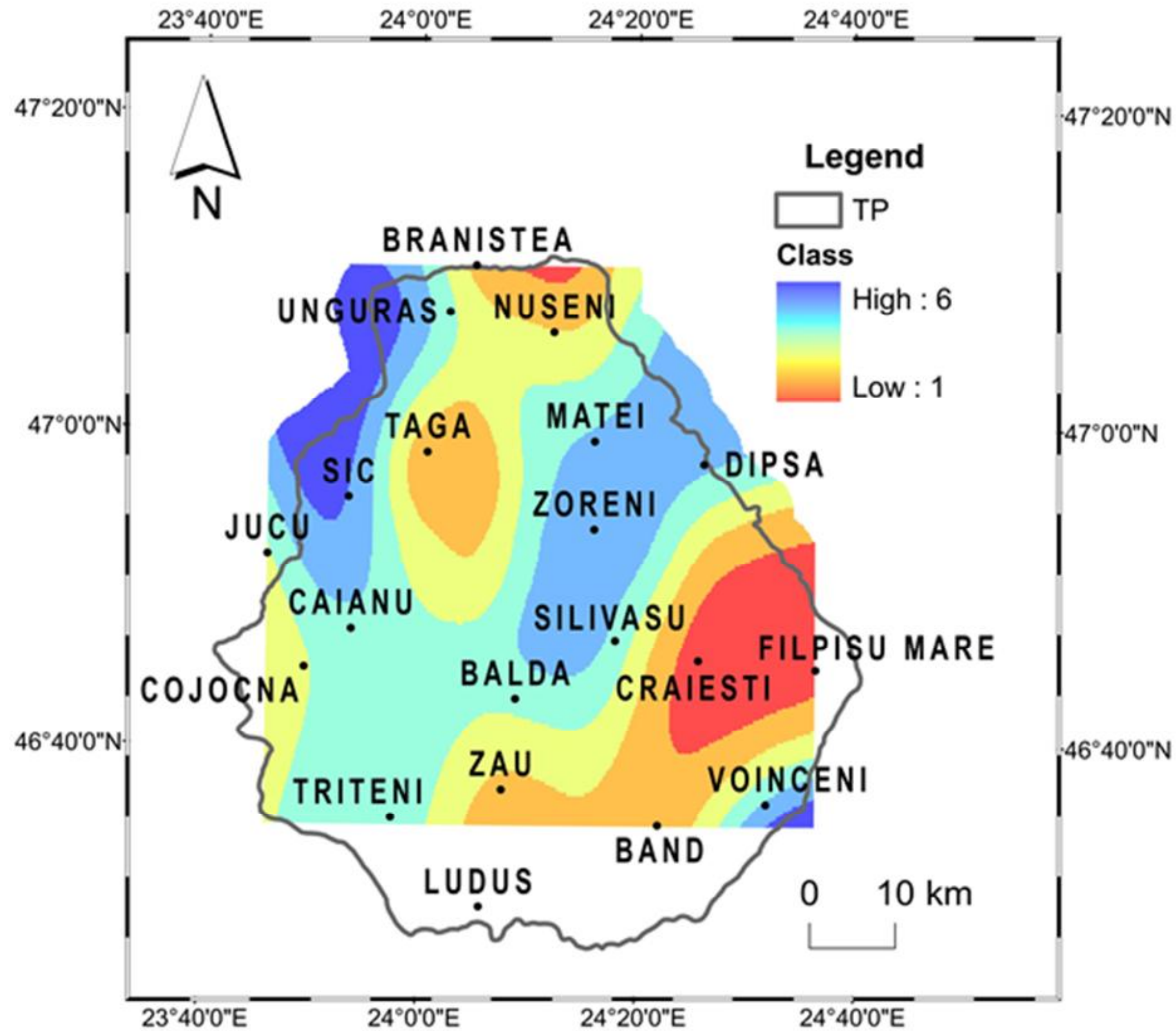

Figure 3.1. Sliced spline interpolation of AGDDs using 6 equal interval class breaks, Transylvanian Plain, Romania.

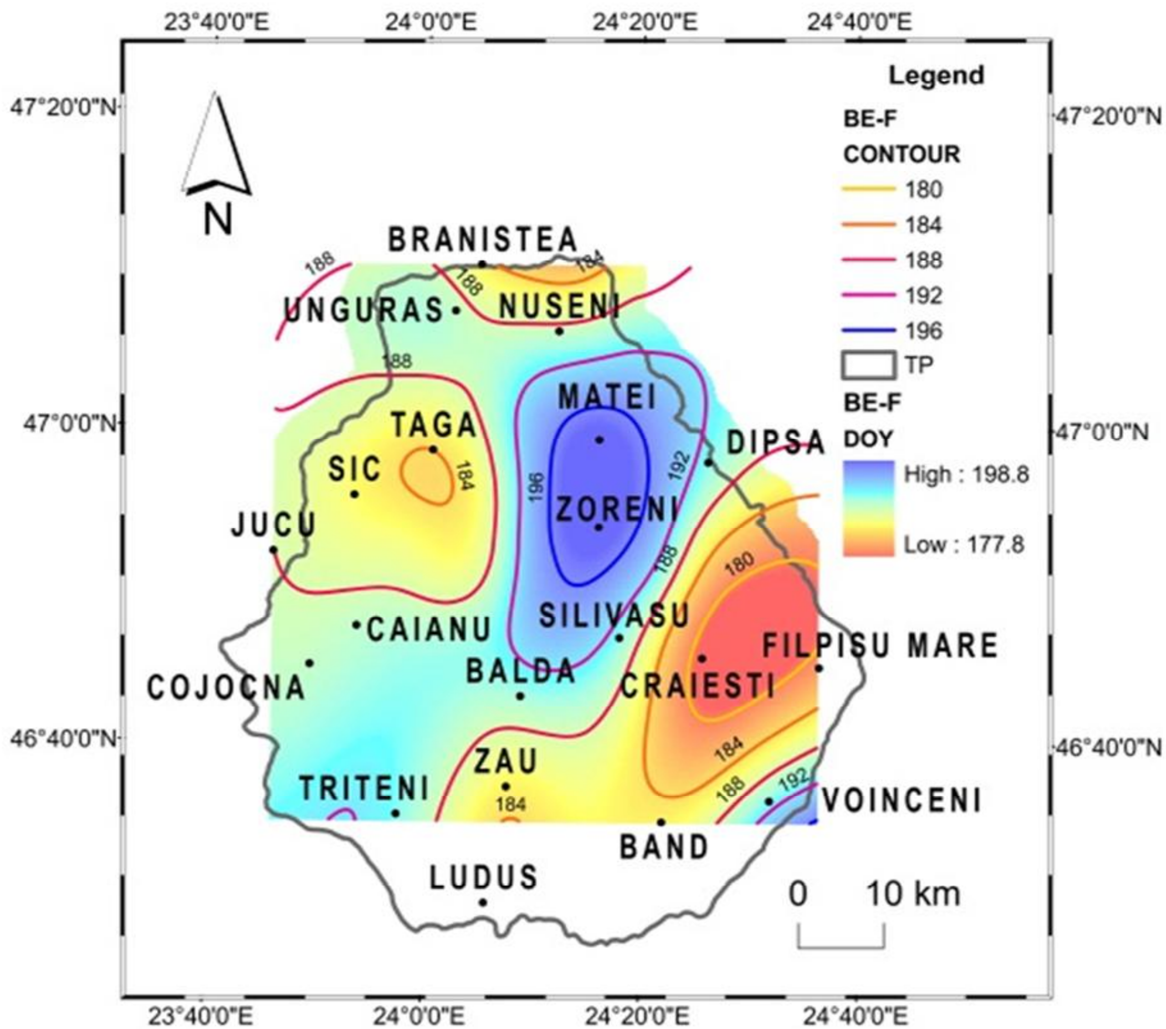

Figure 3.2. Spline interpolation of DOY that 694 AGDDs were reached using the BE-Full method, in the Transylvanian Plain, Romania.

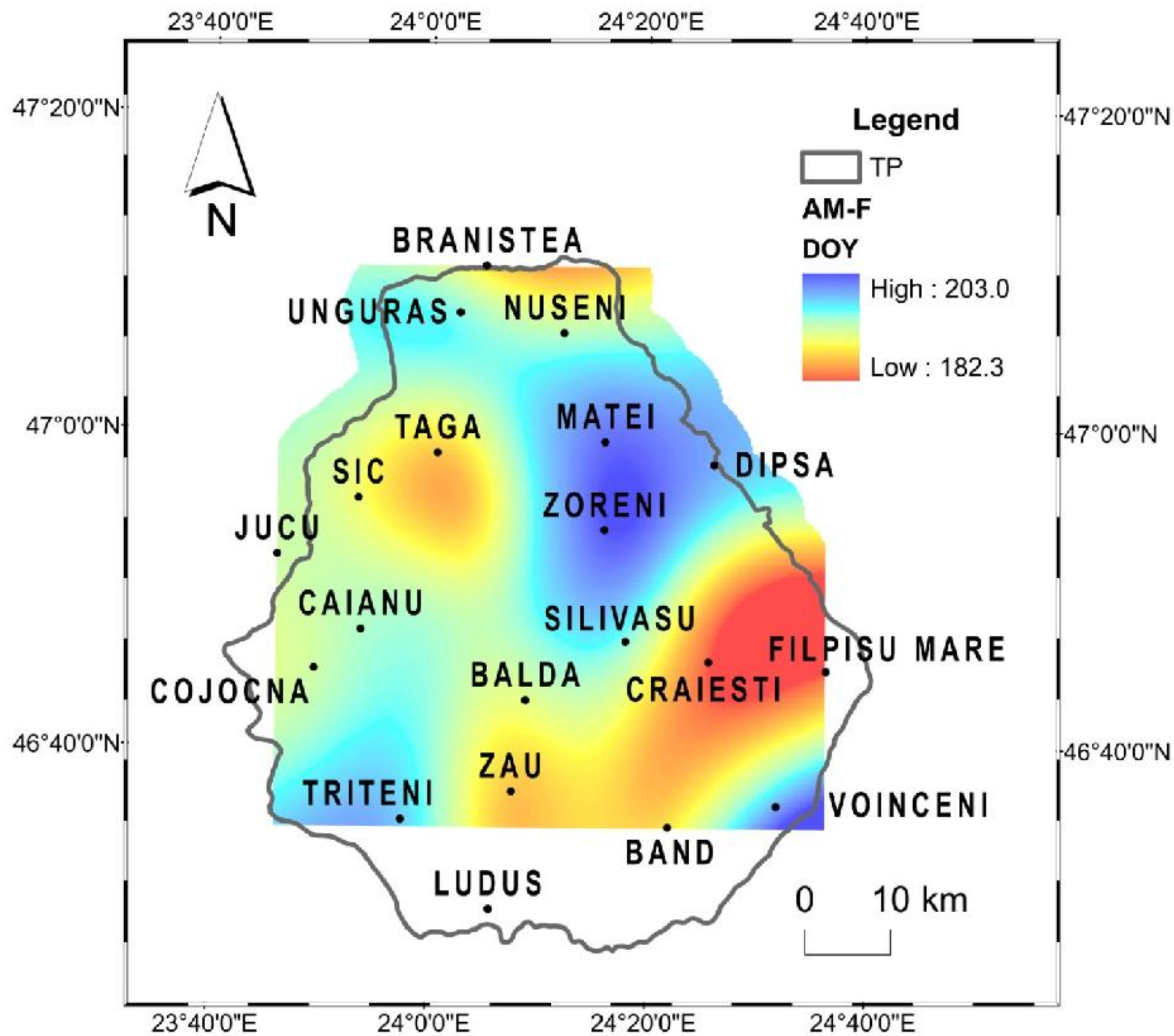

Figure 3.3. Spline interpolation of DOY that 694 AGDDs were reached using the AM-Full method, in the Transylvanian Plain, Romania.

Table 3.3 shows some of the hybrids available from DeKalb® that would be suitable for the TP. The sites that accumulate GDDs faster were placed with hybrids that require more AGDDs to tassel.

Table 3.3. Corn hybrid selection for sites based on drydown and drought tolerance.

DeKalb® Hybrid Brand	Site	Drydown†‡	AGDDs till Tasseling‡	Relative Maturity‡	Drought Tolerance†‡
DKC52-45	6, 20, 4, 9, 13, 15	1	713	102	3
DKC52-59		1	711	102	2
DKC48-37	1, 2, 5, 7, 10, 11, 12, 17	2	679	98	3
DKC42-72	8, 14, 16, 18, 19	2	672	92	2

† Scale: 1-2 = Excellent, 3-4 = Very Good, 5-6 = Good, 7-8 = Fair, 9 = Poor
‡Obtained from 2010 Seed Resource Guide (Monsanto Co., 2009).

3.4 DISCUSSION

Growing degree days could be a very useful resource for farmers in the TP. This study was not intended to definitively determine the AGDDs within the plain, but to serve as a guideline for further research. The BE-Full and AM-Full are assumed to be more accurate, since their average is making use of the full dataset of temperature. However, it is more common to see GDDs that have been calculated using minimum and maximum temperatures, due to the availability of data (Arnold, 1960; Cox, 2006). The LSD test confirmed what the interpolated maps show, Craiesti and Filpisu Mare are the warmest areas based on 2009 summer data, allowing for an earlier planting date and harvest prior to the first killing frost. The ability to increase productivity throughout the plain, would not only be beneficial for the farmers, but also for Romania. By choosing the best hybrid for a certain area, yields could be increased by 620 to 3100 kg ha^{-1} (Roth, 1992). The corn hybrids that were selected (Table 3) were based on GDDs,

drydown, drought tolerance, and insect resistance. Irrigation is practically nonexistent in the TP, making drought tolerance a key characteristic. Drydown is an important factor when evaluating corn hybrids in Romania because it becomes too expensive to use drying systems (Purcell, 2005). Roth (1992) suggested using a 10-day range in the relative maturity when comparing hybrids to account for any stress caused by weather events. Such stressful weather events are possible since August has a tendency to be very dry in Romania, limiting summer crop development before the harvest (Roth, 1992). In 2010, field truthing will be conducted in the TP to ascertain the most accurate method of calculating GDDs for the TP. Corn will be monitored at chosen stations to determine the most accurate GDD calculation based on tasseling and maturity. The fall temperatures will be used to determine the first killing frost across the TP.

3.5 CONCLUSIONS

Growing degree days are a valuable resource in Romania with the ability to increase crop productivity. Significant differences in air temperatures exist across the TP. These differences need to be acknowledged when choosing the planting date to utilize the full growing season. DeKalb® hybrids were selected using the maturity rating compared to when the individual stations accumulated 694 GDDs. Differences in air temperature across the TP are clearly evident in interpolation maps produced in ArcGIS 9.2 for 2009 data. Corn grown in the TP can be more productive with an increased knowledge of GDDs. Romania is known for many traditions, including the practice of farming the same way for generations. However, adoption of contemporary hybrids and agronomic practices holds the potential for increasing productivity on the TP.

3.6 REFERENCES

Ash, G.H.B., D.A. Blatta, B. Davies, B.A. Mitchell, R.L. Raddatz, C.F. Shaykewich, and J.L. Wilson. 1999. Agricultural climate of Manitoba [Online]. Available at http://www.gov.mb.ca/agriculture/climate/waa50s00.html (verified 25 Sept. 2009). Manitoba Agriculture-Food and Rural Initiatives, MB, Canada.

Arnold, C.Y. 1960. Maximum-minimum temperatures as a basis for computing heat units. Am. Soc. Hort. Sci. 76:682-692.

Baskerville, G.L., and P. Emin. 1969. Rapid estimation of heat accumulation from maximum and minimum temperatures. Ecology. 50:514-517.

Cox, W.J. 2006. Using the number of growing degree days from the tassel/silking date to predict corn silage harvest date. What's Cropping Up? [Online]. Available at www.css.cornell.edu/extension/WCU/Vol16No42006July-August.pdf (verified 2 Sept. 2009). Cornell University Cooperative Extension, Ithaca, NY.

ESRI. 2006. ArcGIS Desktop. Release 9.2. ESRI, Redlands, CA.

Monsanto Co. 2009. 2010 Seed resource guide [Online]. Available at http://www.asgrowanddekalb.com/web/pdf/products/2010_seed_resource_guide_north.pdf (verified 25 Sept. 2009). Monsanto Company, St. Louis, MO.

Purcell, B. 2005. Romania and Bulgaria: Crop travel confirms bumper winter and spring crops [Online]. Available at http://www.fas.usda.gov/pecad/highlights/2004/11/eu_travel_pt2/index.htm (verified 15 Sept. 2009). USDA-FAS-PECAD, Washington DC.

Roth, G.W. 1992. Considerations for selecting corn hybrids in Pennsylvania [Online]. Available at http://cropsoil.psu.edu/extension/facts/agfact34.pdf (verified 24 Sept. 2009). Agronomy Facts 34, Penn State Cooperative Extension, Pennsylvania State University, University Park, PA.

Roltsch, W.J., F.G. Zalom, A.J. Strawn, J.F. Strand, and M.J. Pitcairn. 1999. Evaluation of several degree-day estimation methods in California climates. Int. J. Biometeorol. 42:169-176.

SAS Institute. 2008. The SAS system for Windows. Release 9.2. SAS Inst. Inc., Cary, NC.

Wilson. 1999. Agricultural climate of Manitoba [Online]. Available at http://www.gov.mb.ca/agriculture/climate/waa50s00.html (verified 25 Sept. 2009). Manitoba Agriculture-Food and Rural Initiatives, MB, Canada.

CHAPTER 4. ESTIMATION OF MEAN ANNUAL SOIL TEMPERATURE USING LANDSAT 7 ETM+[1]

4.1 INTRODUCTION

Soil temperature regimes are an important part of soil classification according to *U.S. Soil Taxonomy* (*USST*) (Soil Survey Staff, 1999). Soil temperature affects vegetative and soil pedogenic processes. This concept was confirmed by Jenny (1994) when establishing the five factors of soil formation. Several key pedogenic processes are affected by soil temperature: (1) Soil Depth: warmer regions typically facilitate increased weathering, in part from higher soil temperature, and soils are typically deeper; (2) Soil Color: historical soil names in the United States were often reflective of soil colors (Soil Survey Staff, 1938) with soil climate and parent material strongly influencing such colors (e.g. temperate regions frequently have darker soil colors caused by soil organic matter (SOM) accumulation with climates supporting SOM preservation, whereas tropical regions are characterized by yellow to red colors caused by strong leaching conditions under climates which favor SOM decomposition); (3) Nitrogen: Malhi *et al.* (1990) determined that a negative correlation exists between N and increasing soil temperatures; (4) Organic carbon: decreased levels of organic carbon are associated with increased soil temperatures in temperate regions (Buol *et al.*, 2003; McDaniel and Munn, 1985); (5) Clays: in soils of similar parent material, increasing soil temperatures have an exponential effect on increases in clay percentage (Jenny, 1994). Chemical reactions in the soil greatly affect not only nutrient availability but also the secondary minerals which are present. Van't Hoff (1884) showed that temperature had a consistent driving rate when evaluating chemical reactions; with every 10 °C rise in temperature, reaction rate accelerated two to threefold.

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Furthermore, optimum temperature ranges exist for all plants; temperatures exceeding this range in either the minimum or maximum direction are detrimental to the reproductive cycle of plants. Soil temperatures in the root zone of temperate plants <5 °C constitute biologic zero, the point at which vegetative cycles cease (Soil Survey Staff, 1999). A thorough understanding of temporal shifts in soil temperature is important for many agronomic practices including fertilization and pesticide application, planting dates, and harvest.

Contrary to its name, the Transylvanian Plain (TP) is a hilly region in north central Romania with elevations ranging from 200-600 m. The stratigraphy of the TP consists of Neogene sediments which were dissected by river systems in the Quaternary to form the extant hilly terrain (Ichim and Sandulescu, 1997; Sanders *et al.*, 2002). The TP is located within three districts in Romania: Cluj, Bistrita Nassaud, and Mureş. The Someş and Mureş River watersheds, which dissect the TP, bound the northern and southern most portion of the plain, respectively. It is noteworthy that the TP is considered one territorial unit in Romania, yet substantial differences occur between its northern and southern extents. The TP's mono-territorial status is inherited from its bounding rivers, which provide for its natural division from adjacent lands. However, Contiu (2005) argued that the TP should not be considered as a single geographic unit. Forested areas throughout the TP are found as isolated thickets at the tops of hills. It is believed that many of these are relic features of larger forests that extended beyond the summit and shoulder (Baciu *et al.*, 2010).

The TP is an area of agronomic importance for Romania with the main cultivated crops being corn (*Zea mays*), wheat (*Triticum aestivum*), barley (*Hordeum vulgare*), and sunflower (*Helianthus annuus*). Subsistence farming either within the town of residence or on land parcels near the towns is commonplace (Drager and Jaksch, 2001). Across all of Romania, of 3 931 350 farms recorded in 2007, 3,064,700 were subsistence farms (Martins and Spendlingwimmer,

2009), with 86% producing crops for personal consumption. Within the TP in 2002, Mureş, Bistrita Nassaud, and Cluj had 36.5, 15.6, and 26.8 % of their populations involved in agriculture, respectively (European Commission, 2002). After state farms were dissolved, land was fragmented during privatization in 1991, resulting in average land parcels of 2 ha (Drager and Jaksch, 2001). This small farm size has made technological integration difficult, with production quantity often lagging behind more advanced European countries. Based on Coordination of Information on the Environment (CORINE) land cover, land allocation has resulted in agricultural production occurring within urban areas as well as traditional agricultural areas (European Environmental Agency, 2007). Increased efficiency and productivity is necessary for Romania to compete effectively in European agricultural commodity markets. As one means of bolstering agronomic productivity, a requisite understanding of how soil temperatures impact agronomic production in Romania is required.

Mean annual soil temperature is a measure of the thermal regime of the soil. Mean annual soil temperature in the United States has been found to decrease 1-1.5 °C for every 300 m of increased elevation (Carter and Ciolkosz, 1980; Smith *et al.*, 1964). This change in soil temperature due to elevation can have implications for agriculture in a hilly region such as the Transylvanian Plain. The Soil Survey Staff (1999) recognize five main soil temperature regimes in *USST*: Cryic: <8 °C, Frigid: 0-8 °C, Mesic: 8-15 °C, Thermic: 15-22 °C, and Hyperthermic: >22 °C. Soil temperature regimes are based on mean annual soil temperature (MAST) at 50 cm (Soil Survey Staff, 1999). Taxonomically, MAST is identified at the family level as a subgroup modifier in *USST*. Furthermore, biologic minimums in MAST exist for most crops. For example, corn (*Zea mays*), the most abundant row crop in the TP, requires MAST to be >8 °C for a complete life cycle (Buol *et al.*, 2003). The time and effort involved in measuring soil temperature *in situ* over large areas is cumbersome. This has led to the common practice of

adding 1 °C to the mean annual air temperature for estimation of 50 cm MAST (Soil Survey Staff, 1999), in the TP mean annual air temperature ranges from 7-9 °C (Schreiber *et al.*, 2003). However, vegetative differences, slope aspect, slope inclination, and local management practices can influence soil temperature on a local scale, causing departures from the aforementioned estimation technique. Assuming similar slope inclinations, Shulgin (1978) found that incident solar radiation causes maximum soil temperatures on southern slopes followed by eastern, western, and northern slopes in the northern hemisphere. Shulgin's findings have important implications concerning the influence of aspect on spatial and temporal variability of soil temperature in the TP because of its highly dissected, hilly extent. Martinez *et al.* (2007) elucidated the difficulties of *in situ* soil temperature evaluation across hill slopes in dissected terrain noting the complicating factors of aspect, slope, and elevation.

Circumvention of the difficulties inherent with *in situ* soil temperature measurement is possible from a remotely sensed, satellite platform. Four Landsat 7 ETM+ images from 2002 and 2003 were analyzed to evaluate the predictive capability of MAST which was measured at 50 cm in 2009-2010. Per *USST*, long term MAST should be similar from year to year, such that an accurate comparison between different years is plausible (Soil Survey Staff, 1999). Also, since MAST is typically constant throughout the soil profile, the soil temperatures could potentially be used in heat flow models. Of the many satellite platforms available, Landsat 7 ETM+ data is optimal because it is collected every 16 days; however it is not processed if cloud cover exceeds 40% (USGS, 2011). Furthermore, in regions located between two mountain ranges (such as the TP) it is difficult in winter months to obtain Landsat images with <40% cloud cover to process. This causes difficulty in finding images for consecutive months in the winter season. Landsat 7 ETM+ band-6 measures the thermal infrared band (10.4-12.5 μm) associated with long wave radiation (3-50 μm) emitted from the earth's surface (USGS, 2011; Jenson, 2007). Other

satellites integrating thermal infrared bands for surface temperature analysis include the Moderate Resolution Imaging Spectroradiometer (MODIS) bands 31 and 32 (10.780-11.280, 11.770-12.270 μm) with a 1000 m spatial resolution, Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) bands 10-14 (8.125-8.475, 8.475-8.825, 8.925-9.275, 10.25-10.95, and 10.95-11.65 μm) with a 90 m spatial resolution, China-Brazil Earth Resources Satellite (CBERS-2) band-4 (10.40-12.50 μm) with a 160 m spatial resolution, and Advanced Very High Resolution Radiometer (AVHRR) bands 4 and 5 (10.33-11.3, 11.5-12.5 μm) with a spatial resolution of 1100 m (Jenson, 2007). Previous studies using Landsat 7 ETM+ band-6 have successfully determined water temperature, land surface temperature, and evaluated urban heat island development (Jiang and Tian, 2010; Li *et al.*, 2004; Schott *et al.*, 2001; Thomas *et al.*, 2002; Wloczyk *et al.*, 2006). However, little research has been completed comparing Landsat 7 ETM+ band-6 to MAST; a void which this research seeks to fill.

This study compares the applicability of both Landsat 7 ETM+ band-6 as well as multiple regression with variable inputs to quantify MAST in the TP. The objectives of this study were to: 1) determine the predictive capability of MAST by means of Landsat 7 ETM+ band-6, and 2) evaluate MAST dependence on land cover across the TP. We hypothesize that Landsat should be able to effectively predict MAST, even across divergent vegetation types and site conditions.

4.2 MATERIALS AND METHODS

4.2.1 Study Area

The TP consists of 395,461 ha located in north-central Romania and is highly dissected due to the alluvial systems present (Figure 4.1). Twenty data logging stations across the TP were installed to evaluate soil temperatures *in situ* in March 2009. Hobo Micro Stations (H21-002) were connected to HOBO Smart Temp (S-TMB-M002) temperature sensors located at a depth of

50 cm (On-set Computer Corp., Bourne, MA, USA). The sensors were set to record temperature measurements every 10 minutes. Data was periodically downloaded into a laptop computer and data was averaged in Microsoft® Access 2007 database to obtain monthly averages.

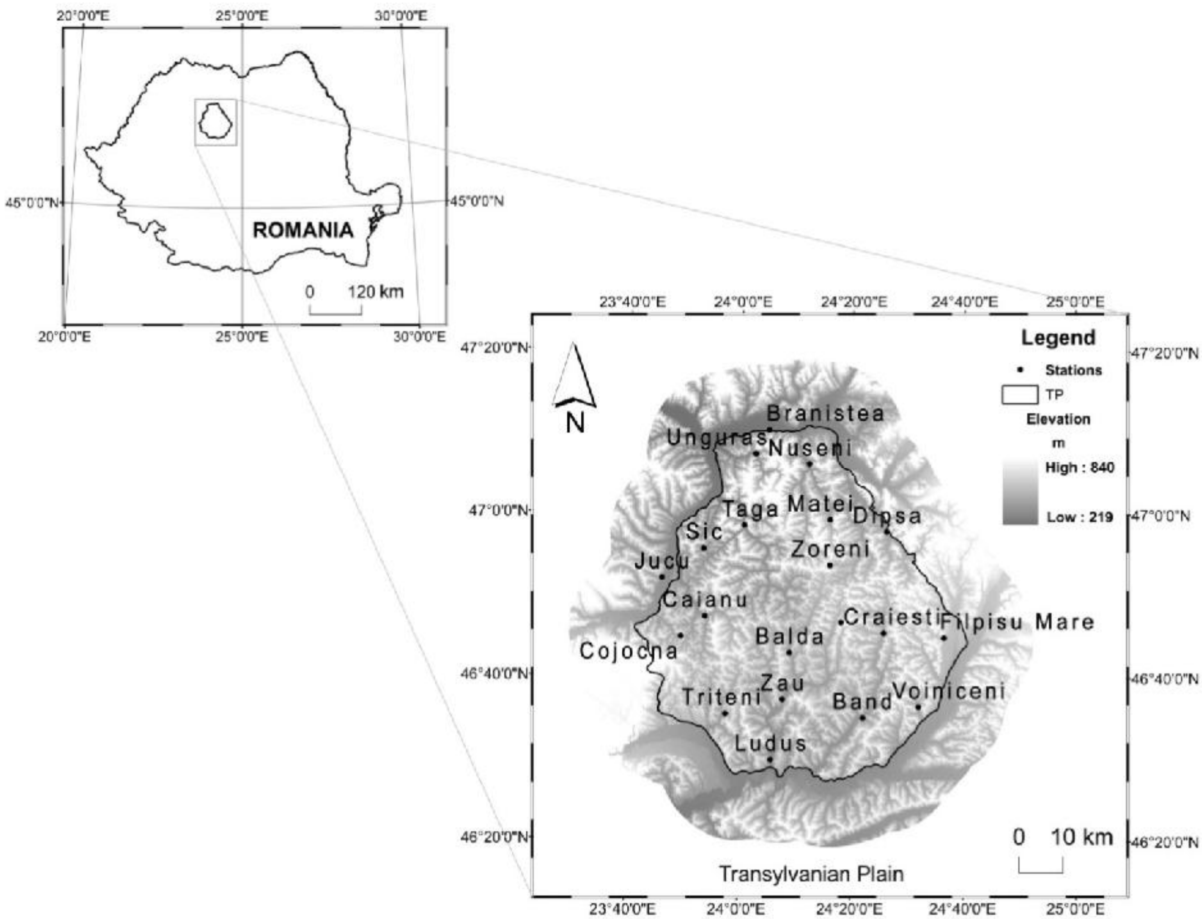

Figure 4.1. Study site, Transylvanian Plain, Romania.

At each of the 20 stations, landscape and soils were evaluated per methods set forth by Schoeneberger *et al.* (2002) (Table 4.1). Level 1 CORINE land cover data was examined to determine the cover types at the 20 stations across the TP; 10 stations were positioned in agricultural areas, and 10 in artificial areas (urban) (European Environmental Agency, 2007). Georeferencing of each site and elevation were recorded using a Garmin eTrex Vista (Olathe, KS, USA) global positioning system receiver. The georeferenced points were loaded into ArcGIS 9.3 (ESRI, The Redlands, CA, 2009a) to be used in further analyses. Organic carbon

percentages used in multiple regression analysis were obtained from the 1 km European dataset developed by Jones *et al.* (2005).

4.2.2 Statistical Analysis

Statistical analysis software (SAS) 9.2 was utilized to perform all analysis (SAS Institute, 2008). Simple linear and multiple regressions were performed using a regression procedure (Proc Reg). Simple linear regressions were evaluated to determine the relationship between all Landsat 7 ETM+ combinations (JADF, JD, JF, AD, and AF) and MAST. Where MAST values were the independent variables and Landsat 7 ETM+ values were the dependent variables (equation 4.1).

$$\text{MAST} = (\text{Landsat 7 ETM+})*(\beta_1) + \beta_0 + \varepsilon \quad (4.1)$$

Multiple regression utilized Mureş River (Mureş), elevation, and organic carbon percentage (OC%) as parameters to predict MAST (equation 4.2).

$$\text{MAST} = \text{Mureş}(\beta_1) + \text{Elevation}(\beta_2) + \text{OC\%}(\beta_3) + \beta_0 + \varepsilon \quad (4.2)$$

For the purpose of this paper parameter estimates are denoted by the β's, i.e. the slopes and intercept. Analysis of variance was utilized to determine differences between land cover and aspect using Proc Mixed. The differences between CORINE land cover classes were also analyzed via analysis of variance. Proc Mixed is an analysis of variance technique that allows for fitting mixed linear models, this pertains to aspect since it can be grouped into four cardinal directions (SAS Institute, 2009).

Table 4.1. Site information for 20 soil temperature data logging stations in the Transylvanian Plain, Romania.

Site	Elevation /m	Slope /%	Organic carbon – Jones[a] /%	Soil order – *USST*	Soil group – FAO
Balda	361	12	4.92	Mollisol	Phaeozem
Triteni	342	12	4.92	Mollisol	Phaeozem
Ludus	293	3	4.75	Mollisol	Phaeozem
Band	319	1	4.92	Mollisol	Phaeozem
Jucu	326	17	3.91	Mollisol	Phaeozem
Craiesti	375	1	5.08	Mollisol	Phaeozem
Silivasu	463	7	5.24	Inceptisol	Cambisol
Dipsa	356	7	2.17	Mollisol	Phaeozem
Taga	469	17	2.10	Alfisol	Luvisol
Caianu[b]	469	17	5.08	Mollisol	Chernozem
Cojocna	579	12	5.24	Mollisol	Phaeozem
Unguras	291	12	1.16	Alfisol	Luvisol
Branistea	266	1	1.12	Alfisol	Luvisol
Voinceni	345	0.5	2.10	Mollisol	Cambisol
Zau de Campie	320	12	4.92	Alfisol	Luvisol
Sic	363	25	4.92	Alfisol	Luvisol
Nuseni	296	30	2.17	Vertisol	Vertisol
Matei	322	0	2.24	Inceptisol	Cambisol
Zoreni	445	17	3.85	Alfisol	Luvisol
Filpisu Mare	375	19	1.19	Alfisol	Luvisol

[a]Data was obtained from 1 km raster data (Jones *et al.*, 2005).
[b]Data was excluded from analysis due to sensor failure in the winter of 2009.

Aspect was defined as north, south, east, or west and was used in the class statement. The TP was divided into nine sections (further explained in the CORINE land cover section below) which were also used in the class statement and were denoted as random.

4.2.3 Satellite Data

Landsat 7 ETM+ band-6 data was analyzed to evaluate land surface temperature (LST) of the TP. Landsat 7 ETM+ images were obtained for 04 July, 21 Aug., and 11 Dec. 2002; and 13 Feb. 2003. Landsat 7 ETM+ band-6 scans a wavelength range of 10.40 – 12.50 µm under high and low gain conditions, but the former was utilized as it provides higher sensitivity (USGS, 2010). Resolution of the imagery was 60 m. For complete coverage of the TP, two adjacent images were joined as a mosaic using an automatic most nadir seamline method in ERDAS Imagine11 (ERDAS, Norcross, GA, USA, 2011). This method allowed for seamless image combination without feathering or smoothing which could impair thermal data. Landsat 7 ETM+ digital numbers (DN) were converted to spectral radiance and then to Kelvin to obtain LST values. Spectral radiance or electromagnetic radiation is identified in both Eq.1 and 2 as L_λ. Image conversion from DN to spectral radiance was obtained per equation 4.3:

$$L_\lambda = ((LMAX_\lambda - LMIN_\lambda)/(QCMAX - QCMIN)) * (DN-QCMIN) + LMIN_\lambda \quad (4.3)$$

where, DN is the calibrated pixel value in the Landsat image; $LMAX_\lambda$ is the high value of spectral radiance; $LMIN_\lambda$ is the low value of spectral radiance; QCMAX is the maximum value for the DN; and QCMIN is the minimum value for the DN. From equation 4.3, spectral radiance (L_λ) was used to calculate LST in Kelvin per equation 4.4:

$$T = ((K2)/\ln((K1/L_\lambda)+ 1) \quad (4.4)$$

where, K1 and K2 are 666.09 $W/m^2 \cdot sr \cdot \mu m$ and 1282.71 K, respectively (USGS 2011).

Equation 4.4 is an estimate of the Planck curve converting radiance to temperature, provided by USGS (2011). Both equations 4.3 and 4.4 were calculated in ERDAS Imagine11 for all seamed images. Once temperatures are established as Kelvin, values can be transformed into either degrees Celsius or Fahrenheit. Landsat 7 ETM+ images were not corrected for atmospheric conditions. All of the images were selected due to low amounts of cloud cover. It has been shown that with clear skies atmospheric correction does not significantly change the pixel values for thermal bands (Bartolucci *et al.*, 1988; Sugita and Brutsaert, 1993; D.H. Braud – Coastal Studies Institute, Louisiana State University, personal communication, 2011). Mean annual soil temperature was derived from the simple linear regressions performed in SAS 9.2 using Proc Reg.

4.2.4 MAST Calculation

Mean annual soil temperature was calculated from a winter (December, January, February) and summer (June, July, August) mean at a soil depth of 50 cm from Mar. 2009 – Feb. 2010 (Table 4.2). The two aforementioned means are then averaged to produce MAST for the 20 sites (equation 4.5).

$$\text{MAST} = ((\text{Dec.} + \text{Jan.} + \text{Feb.})/3 + (\text{June} + \text{Jul.} + \text{Aug.})/3)/2 \qquad (4.5)$$

For 2009 data, June, July, August, and December were evaluated, whilst January and February were from 2010 data. The station at Caianu was omitted from analysis due to sensor failure in the winter of 2009.

4.2.5 MAST prediction using Multiple Regression

The classic model of elevation and latitude is inaccurate in the TP because of the lack of latitudinal differences (Carter and Ciolkosz, 1980).

Table 4.2. Field measured mean annual soil temperatures from 20 data logging stations across the Transylvanian Plain, Romania from March 2009 to February 2010.

Site	$MAST_{in\ situ}$ / °C
Balda	11.7
Triteni	11.6
Ludus	12.0
Band	11.7
Jucu	11.8
Craiesti	11.5
Silivasu	10.9
Dipsa	12.1
Taga	11.5
Caianu[a]	10.7
Cojocna	11.0
Unguras	11.5
Branistea	11.4
Voinceni	12.1
Zau de Campie	13.0
Sic	10.9
Nuseni	10.8
Matei	10.8
Zoreni	10.9
Filpisu Mare	12.9

[a]Site not included in analysis, due to sensor failure.

Since latitude did not significantly influence the multiple regression, distance to Mureş was used to represent the influence of sun angle on soil temperatures. The TP has a small range of latitude, by using distance to Mureş (m) more differences are accounted for stretching from the southernmost portion of the TP which is demarcated by the Mureş River to the northernmost denoted by the Someş River. Distance to Mureş was created in ArcGIS 9.3 using the Euclidean Distance Function. This was achieved by converting the river polyline into a raster, and each cell which surrounded the river is given a true Euclidean distance (m) (ESRI, 2009b). A multiple regression composed of elevation and distance to Mureş resulted in a low coefficient of determination, and led to the need for an improved model to more accurately establish soil

temperatures in this region. As such, multiple regression analysis was based on the previous model of elevation and latitude, but with one new additional parameter: organic carbon percentage (Carter and Ciolkosz, 1980). Organic carbon is known to have an influence on soil temperature due to albedo effects from soil color (Smith *et al.*, 1964; Franzmeier *et al.*, 1969). The Jones *et al.* (2005) dataset provided complete coverage of organic carbon percentage (0-30 cm) across the TP with more detail than an interpolation of the lab data from the 19 stations (Figure 4.2). To evaluate Jenny's (1994) statement regarding soil temperature effects on organic carbon a grid system was used. Six of nine grids used to evaluate land cover temperature differences contained the *in situ* stations. The mean of each grids organic carbon percentage was compared to $MAST_{Landsat}$. This is important for regions similar to the TP where soils are dominantly dark colored mollisols. Elevated levels of organic carbon darken the color and can cause soils to warm more quickly than soils with lower organic matter. As such, soils tilled and left fallow over the winter expose darker soil to solar radiation, warming the soil and potentially allowing for seed germination at an earlier date. Conversely, if soils are left uncovered later in the growing season, soil moisture will be lost at a greater rate due to the increase in soil temperature. The multiple regression parameter estimates obtained from SAS 9.2 were analyzed in ArcGIS 9.3 using ModelBuilder to produce a map showing the mean annual soil temperature across the TP (equation 4.6).

$$MAST = 0.00003564(\text{Elevation}) - 0.00001656(\text{Mureş}) - 0.515(\text{OC\%}) + 13.400 \quad (4.6)$$

4.2.6 Satellite Combinations

Due to cloud cover in winter months, the first year which had consecutive winter and summer images available was 2002-2003. The images representative of summer were July and August, while December and February images represented winter.

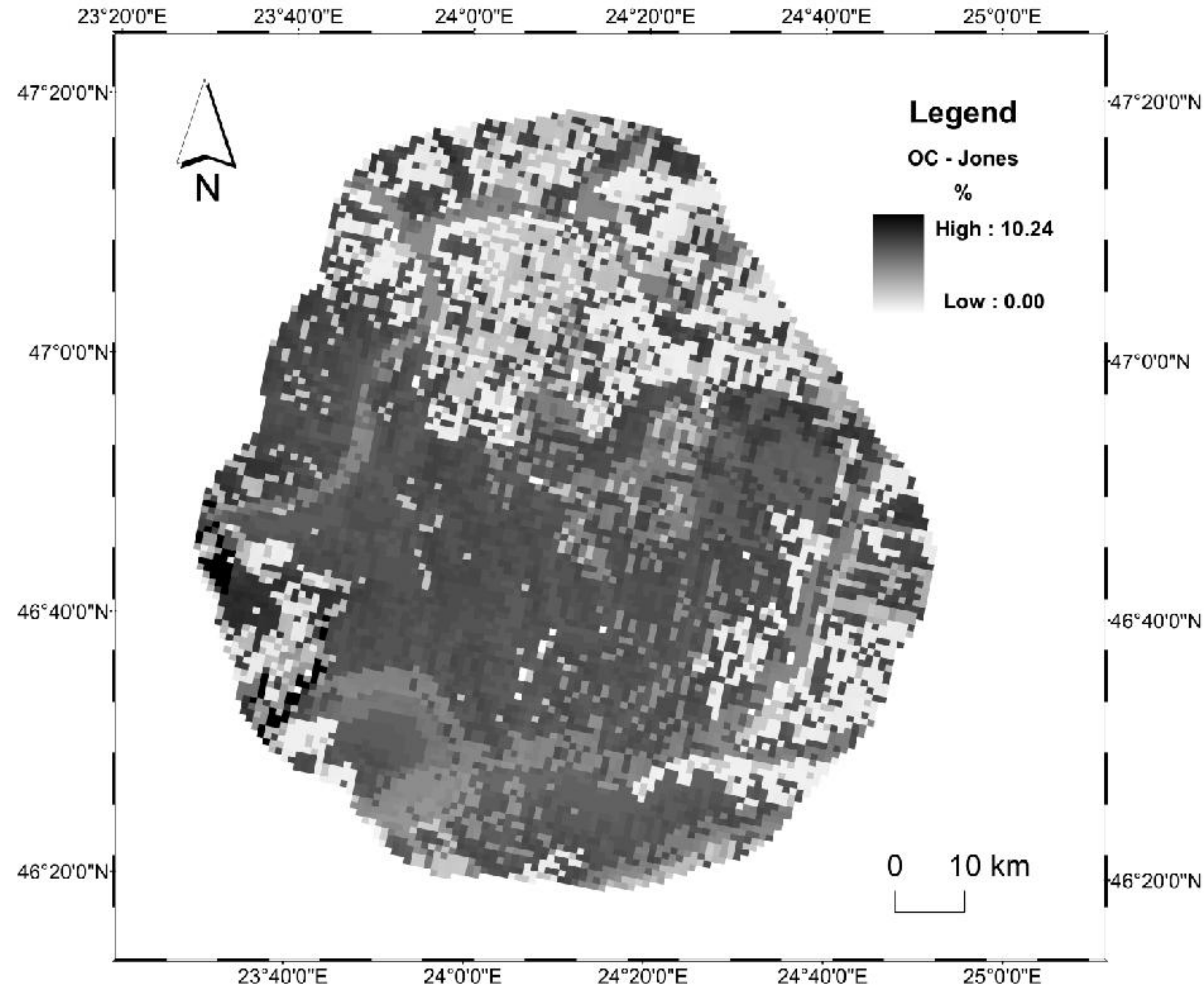

Figure 4.2. Coverage of organic carbon percentage (0-30 cm) across the Transylvanian Plain, Romania (Jones *et al.*, 2005).

The following combinations were evaluated: July, August, December, and February (JADF), July and February (JF), August and December (AD), July and December (JD), and August and February (AF). The aforementioned combinations were chosen to account for the winter and summer extremes experienced by a temperate region located in the northern hemisphere. The parameter estimates for JADF are found in Table 4.3 were obtained from simple linear

regressions analyzed in SAS 9.2, which were used to build a model in ArcGIS 9.3 to produce a map of MAST across the TP.

Table 4.3. Simple linear regression parameter estimates and coefficients of determination for relationships between mean annual soil temperature and Landsat 7 ETM+ combinations in the Transylvanian Plain, Romania.

Variable	Intercept	Slope	R^2
JADF[a]	6.32	0.67	0.63
JD[b]	6.85	0.46	0.55
JF[c]	8.65	0.37	0.28
AD[d]	7.41	0.54	0.59
AF[e]	9.57	0.38	0.24

[a] July, August, December, and February
[b] July and December
[c] July and February
[d] August and December
[e] August and February

4.2.7 CORINE land cover

For the evaluation of land cover differences, the TP was partitioned into nine sections via a fishnet procedure in ArcGIS 9.3 (Figure 4.3). Three land cover types were considered in the TP based upon level 1 classification: forest, artificial, and agriculture. The size of a full square within the fishnet was 40 x 40 km. In each of the nine sections, random points were placed within each of the land cover types. The random points were then averaged to obtain a soil temperature value for agriculture, forest, and artificial land in each section. The averages were evaluated in SAS 9.2 using a Proc Mixed analysis to determine differences between the three land cover types.

4.2.8 Aspect

Random points were generated to evaluate aspect variation across the TP. The same nine sections which evaluated land cover were used. Aspect was divided into four equal sections signifying north, south, east, and west: 315.00- 45, 45.00-135, 135.00-225, and 225.00-315˚, respectively.

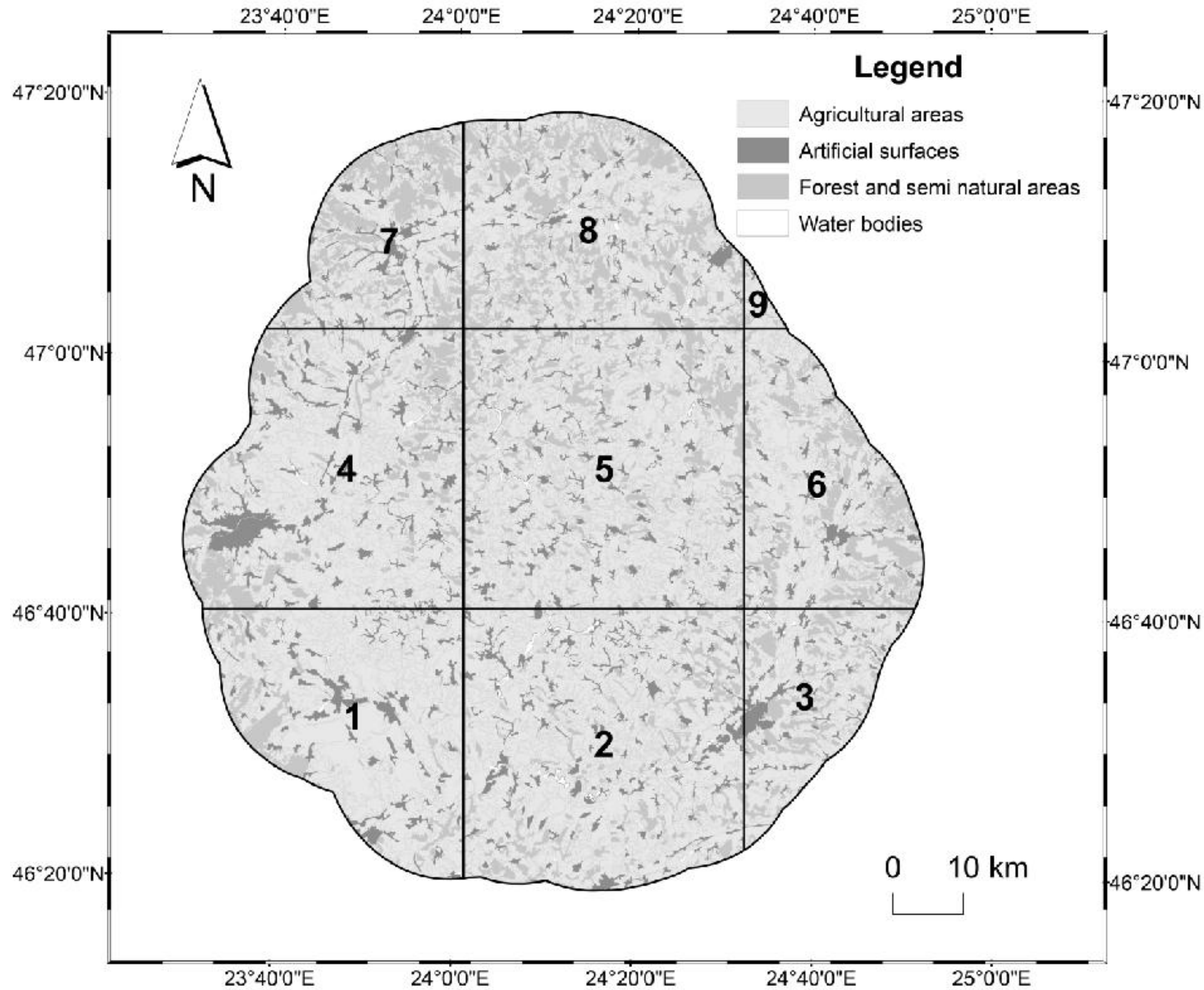

Figure 4.3. Land cover across the Transylvanian Plain, Romania divided by a 40 x 40 km fishnet.

The north, south, east, and west averages were analyzed for differences using SAS 9.2 and a Proc Mixed analysis.

4.3 RESULTS AND DISCUSSION

Winter and spring pose unique challenges for finding Landsat images with low enough cloud cover to analyze. Landsat scenes from 2002 to 2010 for December, January, and February were surveyed to determine scenes available and scenes with >40% cloud cover. Over the evaluated time lapse, 27 scenes were available for the TP region; coverage provided by path 184,

rows 27 and 28. In path 184 row 27 and 28, 55% and 41% of the scenes had cloud cover >40%, respectively.

The multiple regression to predict $MAST_{Regression}$ using distance to Mureş and elevation as variables, was not successful in the TP (R^2=0.14). The addition of organic carbon percentage into the soil temperature model increased the percentage of correctly classified temperatures by 28% (R^2=0.42). In sections of the TP where higher MASTs occur organic carbon percentages are lower (R^2=0.53) (Jenny, 1994; McDaniel and Munn, 1985) (Figure 4.4).

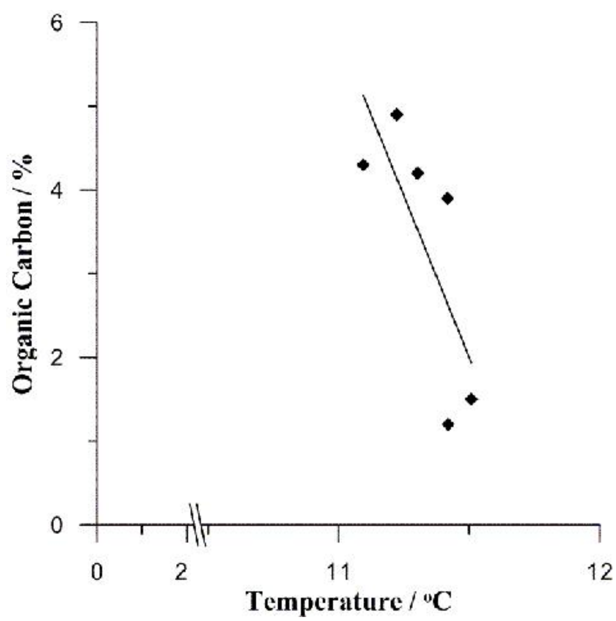

Figure 4.4. Negative relationship between organic carbon percentage and $MAST_{Landsat}$ (OC = -7.7($MAST_{Landsat}$) + 90.7) in the Transylvanian Plain, Romania.

This is particularly important in regions with soil temperature regimes cooler than thermic, where organic carbon percentage is higher (Table 4.4); conditions which perfectly describe the TP. Distance to Mureş had an influence on the multiple regression due to the TP's extent across two watersheds; while correspondingly accounting for latitudinal trends (Figure 4.5).

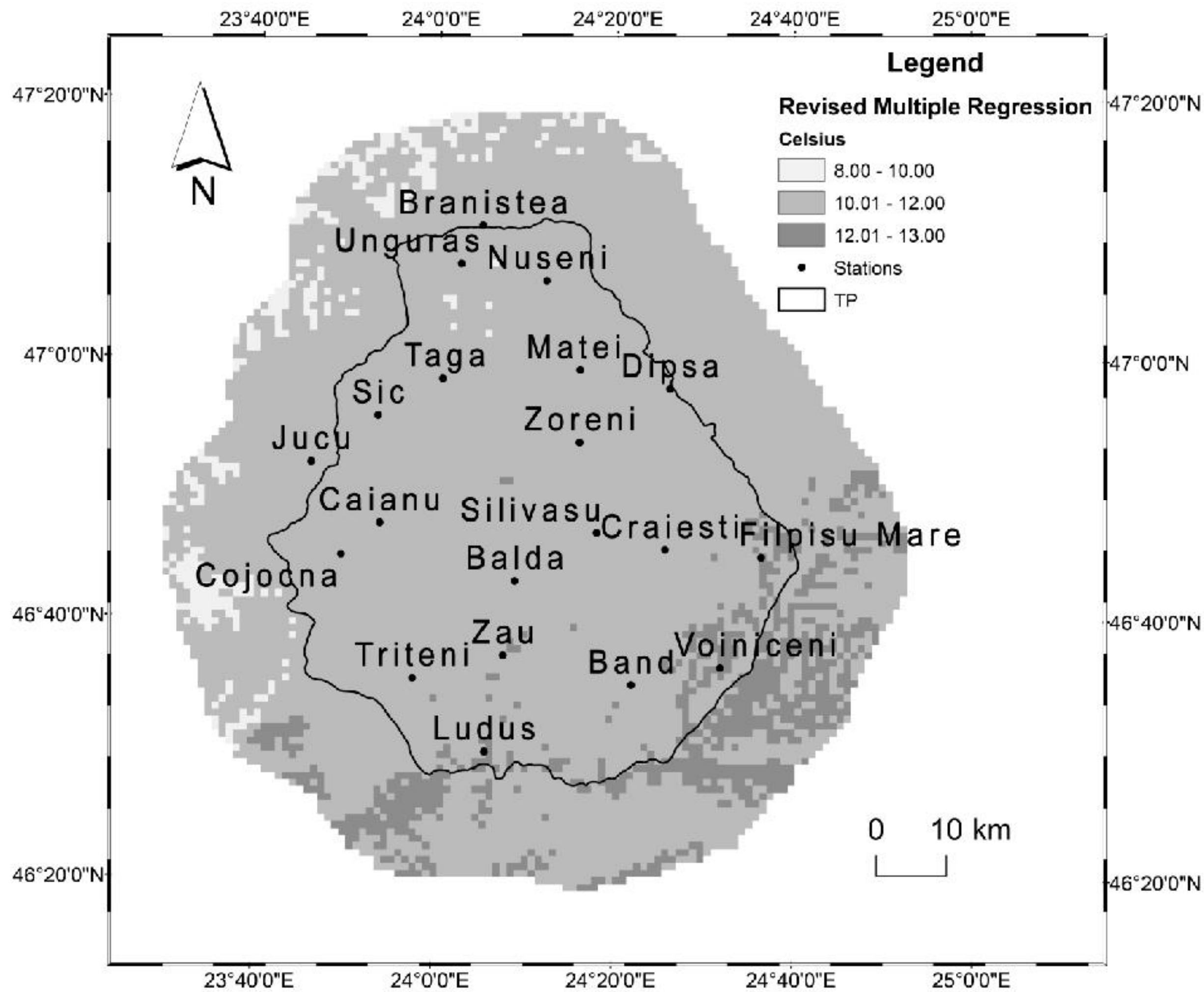

Figure 4.5. Estimated 50 cm mean annual soil temperature based on revised multiple regression, Transylvanian Plain, Romania.

Table 4.4. ANOVA results of the revised multiple regression with soil organic carbon included for mean annual soil temperature evaluation in the Transylvanian Plain, Romania.

Source	df	Sum of Squares	Mean Square Error	F-value	P-value
Model	3	3.43	1.14	3.63	0.037
Error	15	4.72	0.31		
Corrected Total	18	8.14			
R^2	0.42				
Adjusted R^2	0.30				

The analysis of variance results from Landsat 7 ETM+ combinations illustrate that JADF provided the highest relationship to MAST in the TP (R^2=0.63) compared to the revised multiple regression (R^2=0.42). (Figure 4.6 (a), Tables 4.3, 4.5). July and February data had a much weaker relationship to MAST (R^2=0.28) (Figure 4.6 (b), Tables 4.3, 4.5).

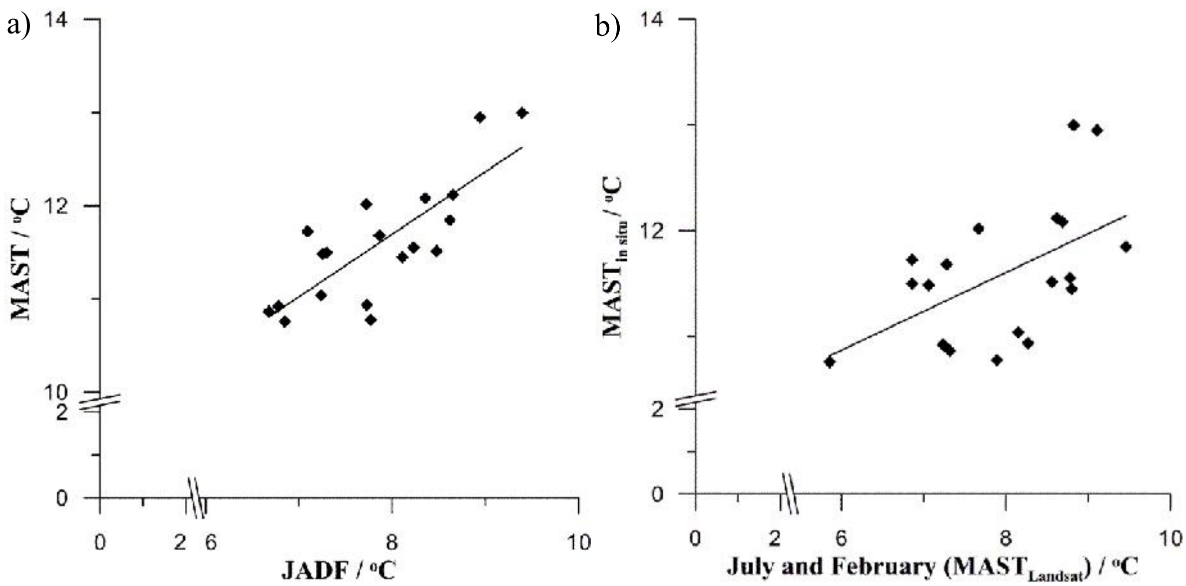

Figure 4.6. a) Relationship between July, August, December, and February Landsat 7 ETM+ and $MAST_{\textit{in situ}}$ ($MAST_{Landsat}$ = 0.67($MAST_{\textit{in-situ}}$) + 6.32) in the Transylvanian Plain, Romania.
b) Relationship between July and February Landsat 7 ETM+ and $MAST_{\textit{in situ}}$ ($MAST_{Landsat}$ = 0.37($MAST_{\textit{in-situ}}$) + 8.65) in the Transylvanian Plain, Romania.

August and December were very close (R^2=0.59) to predicting the same relationship to MAST as JADF (Figure 4.7, Tables 4.3, 4.5). Thus, JADF showed the strongest relationship to MAST (Tables 4.3, 4.5). The four months used are the same as recommended by Soil Survey Staff (1999) for *in situ* measurement, *sans* June and January. This combination of JADF produced temperatures which ranged from 8-16 °C, which 10-12 °C provided the largest extent at 219 151 ha. Combinations which included February and solely one other month resulted in weak relationships to MAST (Table 4.3).

Table 4.5. Analysis of variance evaluating Landsat 7 ETM+ month combinations with *in situ* soil temperature at 50 cm in the Transylvanian Plain, Romania.

Variable	Variation source	df	Sum of squares	Mean square	F	Sig.
JADF[a]	Between groups	1	4.7	4.7	28.19	0.0001
	Within groups	17	2.8	0.2		
	Total	18	7.5			
JD[b]	Between groups	1	4.4	4.4	23.38	0.0002
	Within groups	17	3.2	0.2		
	Total	18	7.5			
JF[c]	Between groups	1	1.9	1.9	6.08	0.0246
	Within groups	17	5.6	0.3		
	Total	18	7.5			
AD[d]	Between groups	1	4.6	4.6	27.13	0.0001
	Within groups	17	2.9	0.2		
	Total	18	7.5			
AF[e]	Between groups	1	1.7	1.7	4.8	0.0428
	Within groups	17	5.9	0.3		
	Total	18	7.5			

[a] July, August, December, and February
[b] July and December
[c] July and February
[d] August and December
[e] August and February

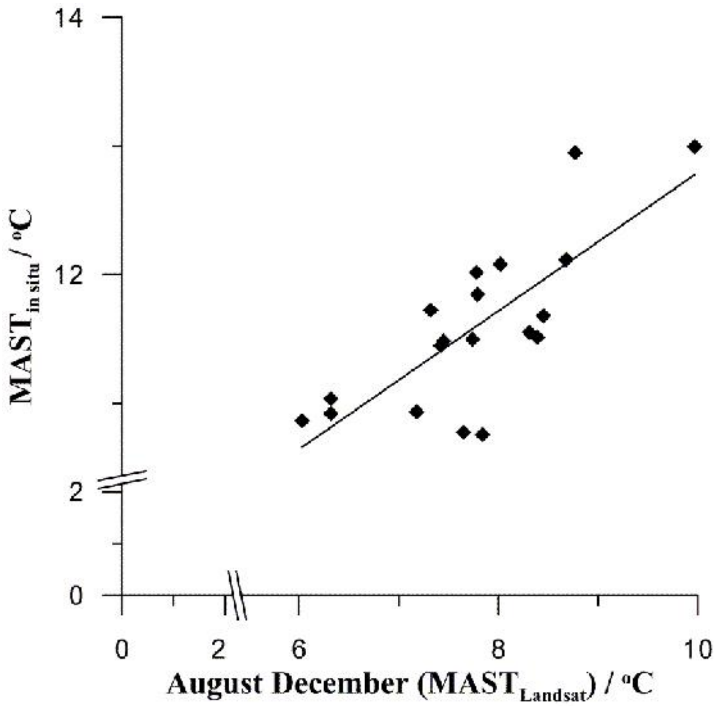

Figure 4.7. Relationship between August and December Landsat 7 ETM+ and $MAST_{in\ situ}$ ($MAST_{Landsat} = 0.54(MAST_{in\text{-}situ}) + 7.41$) in the Transylvanian Plain, Romania.

Snow covering the TP in February 2003 likely interfered with soil temperature due to albedo and insulation effects. Kohn and Royer (2010) found that lower frequency microwaves (<18.7 GHz) were better able to analyze soil temperature below snow cover compared to band-6, which provides a "skin" measurement. Therefore, snow cover must be considered when choosing Landsat images for soil temperature evaluation.

Landsat 7 ETM+ had a stronger relationship with MAST than the revised multiple regression with coefficients of determination of 0.63 and 0.42, respectively. Also, if the accepted method of adding 1 °C to the mean annual air temperature was utilized the MAST's would

theoretically range from 8-10 °C (Soil Survey Staff, 1999). While, *in situ* 50 cm soil temperatures were found to be 10.76-13.00℃. Furthermore, Landsat 7 ETM+ accounted for aspect differences better than multiple regression (Figures 4.4 & 4.8). Since aspect is on a polar scale, it is cumbersome to evaluate statistically without transformation (Mardia, 1975). Across the TP, temperatures were found to range from 8-16 °C, and were divided into four classes to measure spatial coverage (Table 4.6).

Table 4.6. Sum of temperatures from Landsat 7 ETM+ in four classes in the Transylvanian Plain,Romania.

Temperature Range / °C	Area /ha
8-10	14 276
10-12	219 151
12-14	156 029
14-16	6 006

Landsat evaluation of MAST is a better alternative in hilly terrain to the more traditional multiple regression technique which cannot easily account for slope and aspect differences. In a hilly region, it can be difficult to obtain a reliable distribution of stations accurately reflecting all slopes and aspects. As such, using Landsat in combination with a few well-spaced sensors for ground truthing can provide reliable MAST data.

Differences between land cover types were present and dramatically impacted soil temperature analysis. Artificial land was found to be significantly warmer with an overall average of 11.84 °C than both forest and agricultural lands (Table 4.7). No significant difference existed between forest and agriculture with averages of 11.30 and 11.37 °C, respectively. This supports the findings of Jiang and Tian (2010) who found that the temperatures of artificial regions exceeded agricultural and forested lands. Such temperature increases in artificial areas

are linked to impervious surfaces found in urban areas which retain heat for longer durations; a phenomenon commonly referred to as urban heat islands. Finally, the MAST's, obtained from Landsat 7 ETM+, were found to rank from east, being the warmest, to west, south, and north (11.41, 11.40, 11.32, and 11.15 °C), respectively.

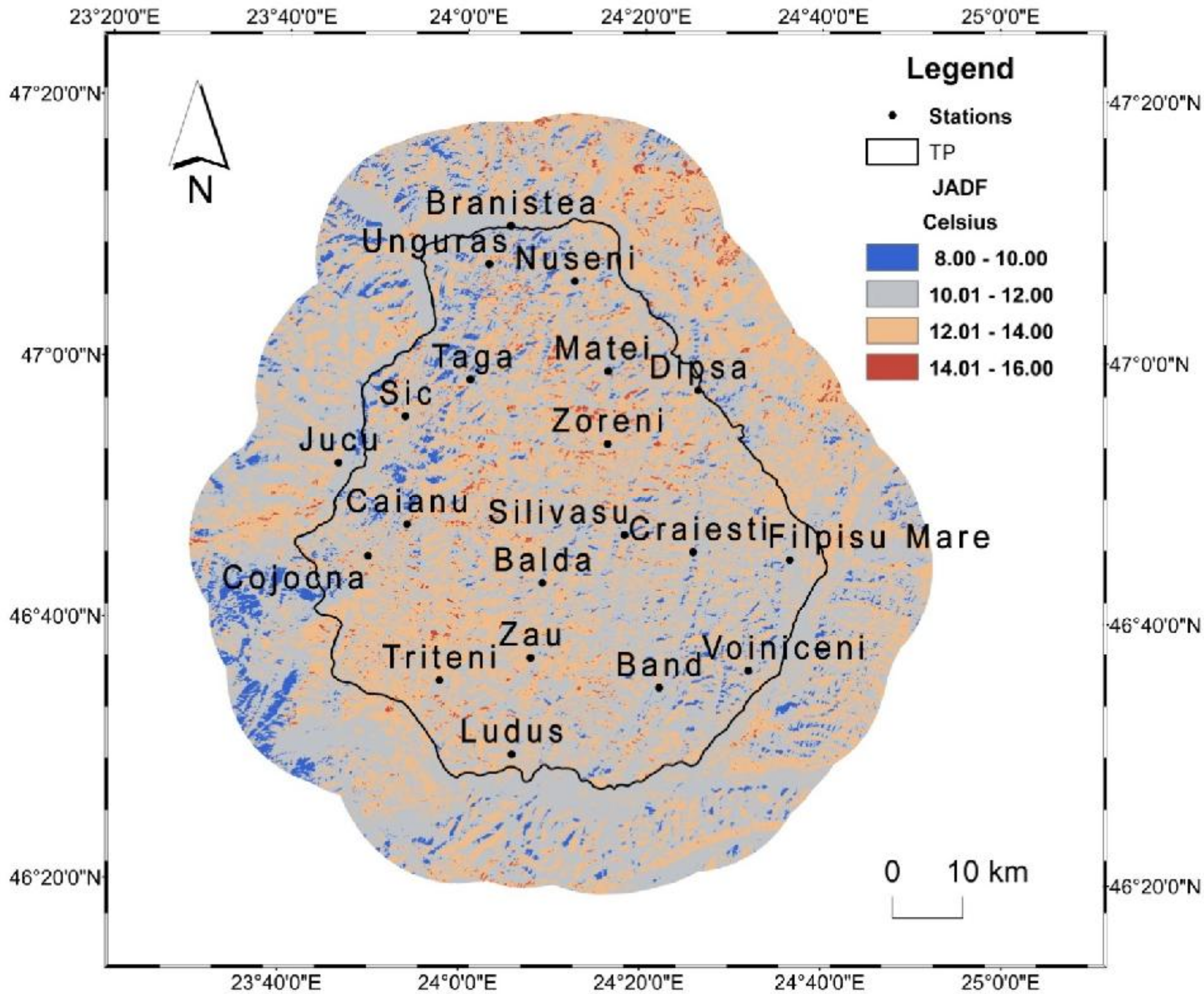

Figure 4.8. Mean annual soil temperature predicted from Landsat 7 ETM+ based on data from July, August, December, and January, Transylvanian Plain, Romania.

Table 4.7. Least squares means differences of agriculture, forest, and artificial land cover with a Tukey-Kramer adjustment in the Transylvanian Plain, Romania.

Land cover 1	Land cover 2	Estimate	Standard error	df	t-value	P-value
Agriculture	Artificial	-0.478	0.083	16	-5.78	0.0001
Agriculture	Forest	0.067	0.083	16	0.81	0.7048
Artificial	Forest	0.544	0.083	16	6.58	0.0001

Since Landsat 7 ETM+ is sensing at approximately 9:00 am it is likely a result of east facing slopes receiving the largest amount of radiation at this time period (Lambert and Roberts, 1976). However; east, west, and south aspects were not significantly different from one another which could produce results similar to Shulgin's (1978) findings (Table 4.8). North was significantly different from east, west, and south as would be expected in hilly terrain (Smith *et al.*, 1964). Even though the means are in a different order than normally observed, these means were for aspects across the entire 395, 000 ha of the TP, not a singular hill.

Table 4.8. Least squares means differences of north, south, east, and west slope aspects with a Tukey-Kramer adjustment in the Transylvanian Plain, Romania.

Slope aspect 1	Slope aspect 2	Estimate	Standard error	df	t-value	P-value
North	South	-0.173	0.043	24	-4.02	0.003
East	South	0.096	0.043	24	2.21	0.148
East	West	0.544	0.043	24	0.26	0.994
East	North	0.269	0.043	24	6.23	<0.001
North	West	-0.258	0.043	24	-5.97	<0.001
South	West	-0.084	0.043	24	-1.96	0.232

4.4 CONCLUSIONS

Landsat 7 ETM+ provided a relationship with field measured mean annual soil temperature in the TP. This method is applicable in regions which do not receive substantial cloud cover which hinders Landsat image acquisition. Multiple regression using distance to Mureş and elevation had a weak relation to MAST but was improved with the addition of organic carbon percentage. By using a simple most nadir seaming method to join Landsat images

together, data feathering was averted which would have reduced the reliability of the land surface temperature values obtained. It would require more stations collecting temperature data across the TP to show temperature differences based on aspect however, Landsat 7 ETM+ data successfully estimated soil temperatures accounting for aspect and land cover (Tables 4.7 and 4.8). Impervious surfaces, associated with 'artificial' or urban areas had increased MAST compared to other land use types. This could potentially allow for earlier planting dates in peri-urban agricultural areas of the TP. Northern and southern slopes were significantly different across the TP.

Even though the TP is considered by many to be a single geomorphic unit, analysis from this study has shown the MAST of the TP to be highly diverse in response to hill inclination and aspect. In such an area of temperature heterogeneity, there is a need for a method to accurately identify which areas have higher MAST so that appropriate planting and land management techniques can capture the maximum growing period for enhanced agronomic production. However, other regions need evaluation to determine the summer and winter months having the best predictive relationships; they may differ from those of the TP. As such, Landsat 7 ETM+ needs to be evaluated in other regions with known MAST values (supported by field collected soil temperature data) to validate its use for determining soil temperatures across large regions. Future work will evaluate MAST values in a sinusoidal temperature model to allow for prediction of mean monthly soil temperature.

4.5 REFERENCES

Baciu, N., C. Stanescu, O.L. Muntean, R. Mihaiescu, and T. Mihaiescu. 2010. Geo-systems and types of geo-facets in the Transylvanian plain – Tools for defining cultural landscapes. Present Environment , and Sustainable Development, 4, 255-262.

Bartolucci, L.A., M. Chang, P.E. Anuta, and M.R. Graves. 1988. Atmospheric effects of Landsat TM thermal IR data. IEEE Transactions on Geosciences and Remote Sensing, 26, 171-176.

Buol, S.W., R.J. Southard, R.C. Graham, and P.A. McDaniel. 2003. Soil Genesis and Classification, 5th edition. Blackwell Publishing, Ames, IA, USA.

Carter, B.J. and E.J. Ciolkosz. 1980. Soil temperature regimes of the central Appalachians. Soil Sci. Soc. Am. J., 44: 1052-1058.

Contiu, H.V. 2005. Territorial unity elements of the Mureş passage between Reghin and the confluence with Aries. Scientific Bulletin of the "Petru Maior" University of Targu Mureş, 1, 219-224.

Drager, D. and Jaksch, T. 2001. Romania. In; Agricultural Transformation and Land Use in Central and Eastern Europe. (eds S.J. Goetz, T. Jaksch, and R. Siebert). Ashgate, Aldershot, UK.

European Commission. 2002. Volume 11: Portrait of the Regions – Romania. Office for Official Publications of the European Communities, Luxembourg.

European Environment Agency. 2007. Corine land cover 2000 – 100 m. (At http://www.eea.europa.eu/data-and-maps/data/corine-land-cover-2000-clc2000-100-m-version-9-2007. Accessed: 05/05/2011).

ERDAS. 2011. ERDAS IMAGINE 11.Version 11.0.2.Norcross, GA, USA.

ESRI. 2009a. ArcGIS Desktop. Release 9.3. ESRI, The Redlands, CA, USA.

ESRI. 2009b. ArcGIS Desktop Help. Release 9.3. ESRI, The Redlands, CA, USA.

Franzmeier, D.P., Pedersen, E.J., Longwell, T.J., Byrne, J.G., and Losche, C.K. 1969. Properties of some soils in the Cumberland Plateau as related to slope aspect and position. Soil Science Society of America Journal, 33, 755-761.

Ichim, I. and Sandulescu, M. 1997. Romania. In; Encyclopedia of European and Asian regional geology. (eds E.M. Moores , and R.W. Fairbridge), p. 624-630. Chapman and Hall, London.

Jenny, H. 1994. Factors of Soil Formation: A System of Quantitative Pedology. Dover Publications, Inc. New York.

Jenson, J.R. 2007. Remote Sensing of the Environment: an Earth Resource perspective. 2nd edition. Pearson Education Inc., New Jersey.

Jiang, J. and Tian, G. 2010. Analysis of the impact of land use/land cover change on land surface temperature with remote sensing. Procedia Environmental Sciences, 2, 571-575.

Jones, R.J.A., Heiderer, R., Rusco, E., Loveland, P.J., and Montanarella, L. 2005. Estimating organic carbon in the soils of Europe for policy support. European Journal of Soil Science, 56, 655-671.

Kohn, J. and Royer, A. 2010. AMSR-E data inversion for soil temperature estimation under snow cover. Remote Sensing of Environment, 114, 2951-2961.

Lambert, M.G. and Roberts, E. 1976. Aspect differences in an unimproved hill country pasture. New Zealand Journal of Agricultural Research, 19, 459-467.

Li, F., T.J. Jackson, W.P. Kustas, T.J. Schmugge, A.N. French, M.H. Cosh, and R. Bindlish. 2004. Deriving land surface temperature from Landsat 5 and 7 during SMEX02/SMACEX. Remote Sensing of Environment 92:521-534.

Malhi, S.S., McGill, W.B., and Nyborg, M. 1990. Nitrate losses in soils: Effect of temperature, moisture, and substrate concentration. Soil Biology, and Biochemistry, 22, 733-737.

Mardia, K.V. 1975. Statistics of directional data. Journal of the Royal Statistical Society, 37, 349-393.

Martinez, C., Hancock, G.R., Wells, T., and Kalma, J.D. 2007. An assessment of the variability of soil temperature at the catchment scale. In; MODSIM 2007 International Congress on Modeling and Simulation. (eds L. Oxley and D. Kulasiri), p. 2319-2325. Modeling , and Simulation Society of Australia and New Zealand, December 2007. (At: http://www.mssanz.org.au/MODSIM07/papers/43_s47/AnAssessmentofs47_Martnez_.pdf. Accessed: 30/05/2011).

Martins, C. and F. Spendlingwimmer. 2009. Farm Structure Survey in Romania – 2007. European Commission - Eurostat. (At: http://epp.eurostat.ec.europa.eu/cache/ITY_OFFPUB/KS-SF-09-080/EN/KS-SF-09-080-EN.PDF. Accessed: 30/05/2011).

McDaniel, P.A., and L.C. Munn. 1985. Effect of organic carbon-texture relationships in Mollisols and Aridisols. Soil Science Society of America 49:1486-1489.

Sanders C., R. Huismans, J.D. van Wees, and P. Andriessen. 2002. The Neogene history of the Transylvanian basin in relation to its surrounding mountains. EGU Stephan Mueller Special Publication Series 3:121-133.

SAS Institute. 2008. The SAS system for Windows. Release 9.2. SAS Institute Inc., Cary, NC, USA.

SAS Institute. 2009. Help and Documentation. Release 9.2. SAS Institute Inc., Cary, NC, USA.

Schoeneberger, P.J., D.A. Wysocki, E.C. Benham, and W.D. Broderson. (Eds). 2002. Field Book for Describing and Sampling Soils, Version 2.0.Natural Resources Conservation Service, National Soil Survey Center, Lincoln, NE, USA.

Schott, J.R., J.A. Barsi, B.L. Nordgren, N.G. Raqueno, and D. de Alwis. 2001. Calibration of Landsat thermal data and application to water resource studies. Remote Sensing of the Environment 78:108-117.

Schreiber, W.E., L. Dragut, and T.C. Man. 2003. Landscapes in the Western Part of the Transylvanian Plain. Presa Universitara Clujeana, Cluj-Napoca, Romania.

Shulgin, A.M. 1978. Soil Climate and its Control (Translated from Russian). Indian National Scientific Documentation Centre, New Delhi.

Smith, G.D., F. Newhall, L.H. Robinson, and D. Swanson. 1964. Soil Temperature Regimes- their Characteristics and Predictability, USDA, SCS TP-144.

Soil Survey Staff. 1938. Soils and Men: The 1938 Yearbook in Agriculture. USDA, Washington D.C. USA.

Soil Survey Staff. 1999. Soil Taxonomy: A Basic System of Soil Classification for Making and Interpreting Soil Surveys. 2nd edition. Agricultural Handbook 436, NRCS-USDA, Washington D.C. USA.

Sugita, M. and W. Brutsaert. 1993. Comparison of land surface temperature derived from satellite observations with ground truth during FIFE. International Journal of Remote Sensing 14:1659-1676.

Thomas, A., D. Byrne, and R. Weatherbee. 2002. Coastal sea surface temperature variability from Landsat infrared data. Remote Sensing of the Environment 81:262-272.

United States Geological Survey. 2010. FAQs [Online]. (At: http://landsat.usgs.gov/thermal_band_on_Landsat_7.php. Accessed: 03/05/2011).

United States Geological Survey. 2011. Landsat 7 Science Data Users Handbook [Online]. (At: http://landsathandbook.gsfc.nasa.gov/. Accessed: 06/05/2011).

Van't Hoff, J.H. 1884. Etudes de Dynamique Chimique. Muller, Amsterdam.

Wloczyk, C., R. Richter, E. Borg, and W. Neubert. 2006. Sea and lake surface temperature retrieval from Landsat thermal data in Northern Germany. International J. of Remote Sensing 27:2489-2502.

CHAPTER 5. CONCLUSIONS

Twenty locations in the Transylvanian Plain, Romania were selected for a soil temperature and pedology study. Albeit that the Transylvanian Plain (TP) is considered a singular geographic unit, significant spatial variability was observed across the TP. Part of the difference concerns the TP being drained by two different watersheds. Furthermore, anthropogenic influence and land use management have resulted in soil temperature and soil classification differences.

The two watersheds which drain the TP have formed a highly dissected region located between the Apuseni Mountains to the west and the Carpathian Mountains to the east. The surrounding mountain ranges result in warm, dry winds known as Foehn, which produce a drier southern portion of the TP. This dry air can be detrimental to crop production. Along with dry Foehn winds from the Southern Carpathians, the TP receives its highest precipitation during the summer months which can result in landslides. The landslides can lead to loss of life, property, and environmental resources. These landslides are the result of a layer of marl sediment which can cause overlying sediments to fail after intense summer rainfall.

Soil classification systems worldwide are different due to different ways in which the data is used. The final product created by means of a soil classification system needs to be known so that important properties can be chosen. The *Romanian System of Soil Taxonomy* (*RSST*) is intended as a national system and not to be extrapolated to other continents. Conversely, *United States Soil Taxonomy* (*USST*) was developed with the goal of providing an international system which could be used on any continent. At the locations studied, there were 10 Mollisols, 4 Alfisols, and 6 Inceptisols. The majority of the Mollisols were found in the southern portion of the plain, which is predominately grassland. After evaluating the first

objective of this project, the majority of differences between *USST* and *RSST* stemmed from the domestic development and application of *RSST,* which was never intended to be an international system. Also, ideological differences concerning the movement of calcium carbonate through the soil were identified. The *RSST* denotes that calcium carbonate only moves upward in the profile in response to evapotranspiration. Conversely, *USST* recognizes that carbonates can move both upward and downward in the profile; the latter being the result of eolian carbonate deposition with subsequent dissolution and reprecipitation in the subsoil. In *USST,* soil temperature has been used for classification since the 1960s. Soil temperature is an important property of the soil, with implications concerning soil development, biota, nutrient availability, and atmospheric conditions. G.D. Smith promoted the use of soil temperature regimes in *USST* to provide a sense of the soil climate when considering soil classification. It is a variable property which can lead to difficulties in the measurement, but is valuable because of its effect on other soil properties. Because plants have biologic zeros, or the temperature at which growth ceases, soil temperature is also important for agriculture in the TP.

The TP is an important agricultural center in Romania. Approximately 23 percent of the arable land in the TP supports corn (*Zea mays* L.) production. This agricultural commodity is an important food source, feed for stock, and fuel for the residents of the TP. With improved farming techniques subsistence farmers could increase their productivity, whether by tilling across the slope to reduce further erosion, or planting earlier if the season is warm enough. One method which was used to determine the feasibility of earlier planting was growing degree days (GDD). Growing degree days were used to evaluate the second objective for this study. Significant differences were found in the AGDD among the 20 stations across the TP. Craiesti and Filpisu Mare were the two warmest stations (2009) in the TP which would allow for longer

growing seasons compared to the other stations. Based on planting on 20 April 2009, Craiesti and Filpisu Mare would have tasseled 21 days sooner than Matei or Zoreni. The possibility of prolonging the growing season is also dependent on soil moisture. Also, due to the dated method of drying systems in Romania timely drydown is important before early fall rains begin. Any change in agronomic practices can be daunting for farmers when their livelihood is jeopardized. By incorporating newer practices under the guidance of agronomic researchers, subsistence farming could increase productivity.

The final objective of predicting soil temperature was assessed by using Landsat 7 ETM+ data. Mean annual soil temperature (MAST) is an important classification parameter from *USST* because it provides information concerning the overall climate of a pedon. The measurement of MAST is important for the agronomic use of soils as well as taxonomic classification. Soil temperature estimated using Landsat 7 ETM+ provided a strong relationship with *in situ* MAST in the TP. The use of Landsat 7 provided a better relationship than using the more common multiple regression method. Landsat was capable of accounting for aspect differences which were lost when the data was modeled by means of the multiple regression technique. Furthermore, significant differences were found in soil temperatures depending on the land use. Urban areas were warmer than both forested and agricultural lands in the TP. This is not only important for studies concerning urban heat islands, but provides warmer soil temperatures for subsistence farmers located within urban areas.

Overall, the TP is a diverse system due to the geomorphological characteristics of the region and cultural management practices applied to agronomic production. The geologic processes which have shape the hills and valleys of the TP have also provided farmers with

unique soil and climatic properties. Because the study focused on agricultural lands, future work is needed to assess soil temperatures found on summits and forested areas of the TP.

APPENDIX A. SOIL TEMPERATURE DATA

A.1 Monthly Mean Temperature (°C) at 20 stations in the Transylvanian Plain, RO.

Site	ID	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec	MAST
		-------2010-----		--				-2009-		--				
Balda	1	3.31	1.77	4.17	11.24	15.33	17.54	21.05	21.07	18.97	13.66	9.25	5.35	11.68
Triteni	2	3.35	2.73	3.69	10.97	15.95	17.61	20.19	20.36	17.36	12.20	8.73	5.07	11.55
Ludus	3	3.55	2.85	4.41	11.89	16.56	18.59	21.19	20.63	18.29	13.78	9.38	5.28	12.02
Band	4	3.49	2.47	4.54	12.04	16.91	19.00	20.15	19.98	17.73	13.15	9.17	5.25	11.72
Jucu	5	4.03	2.81	4.53	11.32	15.85	17.95	20.07	19.93	18.22	13.73	9.82	6.29	11.85
Craiesti	6	2.82	1.88	4.12	12.37	17.23	19.14	20.80	19.73	17.45	12.83	8.81	4.54	11.48
Silivasu	7	3.81	2.73	3.93	9.56	13.30	15.77	18.34	19.14	17.10	13.03	9.19	5.73	10.92
Dipsa	8	4.47	2.98	4.10	10.69	14.82	17.37	20.78	20.66	18.44	13.75	9.80	6.45	12.12
Taga	9	3.89	2.54	3.41	8.80	12.82	16.78	20.08	19.97	17.21	12.70	9.19	5.73	11.50
Caianu	10	2.92	1.78	3.38	9.75	14.30	16.99	19.46	19.13	17.07	11.69†	7.29†	4.00†	10.71
Cojocna	11	3.85	2.74	3.51	9.13	13.22	16.05	18.78	18.97	16.90	12.98	9.18	5.83	11.04
Unguras	12	3.09	2.49	5.21	12.72	15.77	17.56	20.88	20.07	17.08	12.81	9.32	4.98	11.51
Branistea	13	2.82	1.80	3.67	10.61	14.82	17.76	20.94	20.59	17.71	12.59	8.62	4.77	11.45
Voinceni	14	3.13	1.50	4.26	10.90	15.55	18.73	21.73	21.79	18.88	13.88	9.63	5.62	12.08
Zau de Campie	15	4.00	3.01	5.82	11.84	16.32	19.15	22.28	23.38	21.60	16.03	10.73	6.16	13.00
Sic	16	3.45	2.22	3.48	9.31	13.01	16.22	18.86	18.68	16.69	12.77	9.29	5.75	10.86
Nuseni	17	3.35	2.18	4.14	10.08	13.30	15.87	19.12	18.62	16.22	12.59	8.98	5.51	10.77
Matei	18	3.78	2.39	3.79	9.81	13.84	16.22	18.15	18.34	17.14	12.85	9.23	5.66	10.76
Zoreni	19	3.25	1.77	3.36	9.61	13.63	16.54	19.04	19.51	17.17	12.94	9.11	5.51	10.94
Filipisu Mare	20	3.74	2.82	5.14	12.58	16.97	19.09	22.62	23.43	21.14	15.33	10.10	6.00	12.95

†Data is from 2008- Caianu was not used in the final models because of this missing data from 2009.

A.2 Monthly soil temperature (°C) at Balda in the Transylvanian Plain, Romania.

Balda			
Months	10 cm	50 cm	Moisture cm^3/cm^3
	---------------------2008-------------------		
April	12.786	11.119	0.283
May	17.26	14.848	0.241
June	20.287	18.044	0.238
July	21.381	19.823	0.259
August	21.369	20.273	0.174
September	16.067	17.290	0.188
October	10.709	12.592	0.250
November	4.914	8.121	0.150
December	1.901	4.318	0.404
	--------------------2009-------------------		
January	-1.478	0.943	0.128
February	1.533	2.776	0.027
March	4.233	4.174	0.094
April	13.901	11.241	0.199
May	17.812	15.333	0.473
June	19.792	17.540	0.331
July	22.479	21.050	0.332
August	21.986	21.071	0.161
September	18.616	18.965	0.035
October	11.521	13.656	NA
November	7.256	9.248	0.168
December	2.558	5.348	0.324
	---------------------2010--------------------		
January	1.241	3.306	0.303
February	-0.345	1.770	0.449

A.3 Monthly soil temperature (°C) at Band in the Transylvanian Plain, Romania.

Band			
Months	10 cm	50 cm	Moisture cm^3/cm^3
	---------------------2008---------------------		
April	13.788	12.102	0.245
May	19.035	16.416	0.238
June	21.797	19.782	0.229
July	21.885	20.262	0.199
August	23.122	21.424	0.153
September	16.948	17.831	0.155
October	11.498	12.824	0.189
November	5.449	8.280	0.177
December	2.303	4.549	0.187
	----------------------2009-------------------		
January	-1.015	0.909	0.127
February	1.797	2.943	0.263
March	4.753	4.542	0.267
April	14.249	12.036	0.221
May	19.067	16.910	0.183
June	21.116	19.002	0.224
July	21.412	20.153	0.216
August	20.814	19.981	0.162
September	17.146	17.732	0.177
October	11.519	13.155	0.208
November	7.578	9.175	0.255
December	2.812	5.251	0.250
	----------------------2010--------------------		
January	1.609	3.489	0.232
February	1.773	2.470	0.216
March	5.588	5.604	0.253
April	11.665	10.654	0.251
May	16.763	15.073	0.219
June	19.386	17.819	0.251
July	23.639	21.381	0.253
August	21.926	21.146	0.216
September	15.886	16.655	0.232
October	9.732	12.371	0.203

A.4 Monthly soil temperature (°C) at Branistea in the Transylvanian Plain, Romania.

Branistea			
Months	10 cm	50 cm	Moisture cm^3/cm^3
	--------------------------2009--------------------		
March	4.019	3.667	0.285
April	12.757	10.609	0.275
May	16.661	14.819	0.268
June	19.986	17.761	0.279
July	23.260	20.945	0.257
August	21.921	20.592	0.252
September	17.634	17.709	0.211
October	10.977	12.589	0.239
November	7.166	8.617	0.273
December	2.541	4.772	0.265
	--------------------------2010---------------------		
January	1.227	2.817	0.247
February	1.087	1.801	0.218
March	4.869	4.587	0.258
April	10.778	9.528	0.265
May	16.346	14.355	0.278
June	19.285	17.461	0.252
July	20.441	18.981	0.260
August	22.288	20.097	0.267

A.5 Monthly soil temperature (°C) at Caianu in the Transylvanian Plain, Romania.

	Caianu		
Months	10 cm	50 cm	Moisture cm^3/cm^3
	---------------------2008---------------------		
April	10.685	9.830	0.290
May	15.588	13.579	0.243
June	19.522	17.702	0.262
July	19.536	19.018	0.245
August	19.419	19.155	0.221
September	14.101	15.638	0.239
October	10.055	11.692	0.299
November	4.243	7.287	0.299
December	1.564	3.997	0.291
	---------------------2009-------------------		
January	-1.772	0.782	0.208
February	0.950	2.389	0.257
March	3.103	3.381	0.270
April	11.060	9.753	0.180
May	15.801	14.304	0.153
June	18.295	16.987	0.229
July	NA	19.459	0.213
August	NA	19.130	0.165
September	NA	17.067	0.129
October	NA	NA	0.045
November	NA	NA	NA
December	NA	NA	NA
	--------------------2010------------------		
January	NA	2.915	NA
February	NA	1.777	NA
March	NA	4.172	NA
April	13.517	9.110	NA
May	16.744	14.102	NA
June	23.696	17.817	0.365
July	28.039	20.217	0.349
August	29.937	20.401	0.322
September	25.109	16.398	0.260
October	21.326	11.979	0.246

A.6 Monthly soil temperature (°C) at Cojocna in the Transylvanian Plain, Romania.

Cojocna			
Months	10 cm	50 cm	Moisture cm^3/cm^3
	-------------------------2009----------------------		
March	3.307	3.508	0.325
April	11.345	9.130	0.271
May	15.466	13.222	0.183
June	18.455	16.045	0.235
July	20.954	18.780	0.288
August	20.244	18.973	0.287
September	16.352	16.898	0.214
October	10.668	12.983	0.248
November	6.590	9.181	0.307
December	2.497	5.832	0.305
	------------------------2010-----------------------		
January	1.351	3.851	0.310
February	1.118	2.744	0.298
March	3.753	3.987	0.324
April	10.839	8.950	0.296
May	15.489	13.213	0.248
June	19.189	16.551	0.286
July	20.948	18.773	0.292
August	20.893	19.404	0.276
September	16.130	16.658	0.247
October	10.334	12.829	0.258
November	6.590	9.181	0.307
December	2.497	5.832	0.305

A.7 Monthly soil temperature (°C) at Craiesti in the Transylvanian Plain, Romania.

Craiesti			
Months	10 cm	50 cm	Moisture cm^3/cm^3
	---------------------2008---------------------		
April	11.522	9.920	0.272
May	17.283	15.169	0.274
June	21.327	19.495	0.288
July	20.649	19.930	0.276
August	20.506	19.832	0.282
September	15.180	16.045	0.268
October	11.443	12.307	0.279
November	5.734	7.755	0.267
December	2.423	4.028	0.269
	---------------------2009-------------------		
January	-1.169	0.426	0.175
February	1.627	2.278	0.271
March	4.362	4.115	0.279
April	14.434	12.372	0.253
May	18.981	17.227	0.223
June	20.692	19.142	0.263
July	21.516	20.799	0.246
August	20.333	19.732	0.216
September	17.413	17.452	0.189
October	11.528	12.835	0.223
November	7.432	8.813	0.266
December	2.430	4.540	0.240
	---------------------2010-------------------		
January	1.330	2.816	NA
February	1.165	1.876	NA
March	4.814	4.842	NA
April	10.836	9.860	NA
May	17.128	15.564	0.065
June	20.969	19.642	0.275
July	20.810	19.864	0.233
August	22.475	21.477	0.214
September	16.745	17.216	0.205
October	11.422	12.900	0.208

A.8 Monthly soil temperature (°C) at Dipsa in the Transylvanian Plain, Romania.

	Dipsa		
Months	10 cm	50 cm	Moisture cm^3/cm^3
	--------------------2008--------------------		
April	11.789	10.607	0.331
May	17.270	14.769	0.317
June	21.361	18.909	0.315
July	20.992	19.601	0.278
August	20.038	19.396	0.252
September	15.405	16.701	0.222
October	11.508	13.052	0.267
November	6.082	9.286	0.282
December	2.757	5.493	0.289
	---------------------2009--------------------		
January	-0.856	2.091	0.127
February	1.793	3.193	0.279
March	3.946	4.101	0.332
April	13.266	10.685	0.271
May	17.519	14.818	0.248
June	20.381	17.374	0.266
July	23.730	20.781	0.245
August	22.406	20.664	0.261
September	18.146	18.439	0.193
October	11.658	13.745	0.232
November	7.616	9.797	0.280
December	3.340	6.447	0.286
	---------------------2010-------------------		
January	1.866	4.465	0.279
February	1.515	2.978	0.277
March	4.738	4.996	0.284
April	10.557	9.393	0.290
May	16.327	14.208	0.290
June	19.121	17.182	0.293
July	21.740	19.420	0.294
August	23.611	21.473	0.225
September	16.251	17.276	0.193
October	10.216	13.197	0.169

A.9 Monthly soil temperature (°C) at Filpisu Mare in the Transylvanian Plain, Romania.

Filpisu Mare			
Months	10 cm	50 cm	Moisture cm^3/cm^3
	-----------------------2009-----------------------		
March	5.182	5.136	0.292
April	15.683	12.583	0.254
May	19.726	16.970	0.200
June	21.595	19.087	0.243
July	25.559	22.622	0.216
August	25.090	23.427	0.239
September	21.815	21.144	0.213
October	13.535	15.328	0.245
November	8.340	10.096	0.272
December	3.486	5.998	0.270
	-----------------------2010-----------------------		
January	1.790	3.743	0.253
February	2.196	2.816	0.266
March	5.957	5.619	0.277
April	12.182	10.621	0.281
May	17.241	15.075	0.278
June	21.673	19.440	0.276
July	23.398	21.385	0.275
August	25.247	23.196	0.233
September	18.520	19.068	0.272
October	12.455	14.523	0.226

A.10 Monthly soil temperature (°C) at Jucu in the Transylvanian Plain, Romania.

	Jucu		
Months	10 cm	50 cm	Moisture cm^3/cm^3
	---------------------2008---------------------		
April	12.857	11.392	0.338
May	17.006	14.757	0.312
June	20.269	18.109	0.309
July	21.443	19.769	0.304
August	22.845	20.768	0.263
September	17.052	17.531	0.241
October	11.934	13.176	0.289
November	6.132	8.919	0.268
December	3.008	5.208	0.305
	----------------------2009--------------------		
January	-0.670	1.695	0.215
February	2.163	3.139	0.295
March	4.714	4.527	0.314
April	14.026	11.316	0.275
May	18.811	15.852	0.230
June	20.397	17.948	0.283
July	21.889	20.074	0.272
August	21.224	19.930	0.234
September	18.587	18.217	0.211
October	12.103	13.728	0.272
November	7.863	9.816	0.320
December	3.600	6.288	0.315
	---------------------2010-------------------		
January	1.814	4.031	0.309
February	1.590	2.806	0.296
March	5.472	5.421	0.307
April	10.836	9.851	0.303
May	15.383	13.749	0.303
June	18.493	16.832	0.328
July	20.030	18.579	0.325
August	19.888	19.040	0.292
September	14.747	15.593	0.265
October	9.631	12.207	0.261

A.11 Monthly soil temperature (°C) at Ludus in the Transylvanian Plain, Romania.

Ludus			
Months	10 cm	50 cm	Moisture cm^3/cm^3
-------------------2008--------------------			
April	13.646	11.605	0.283
May	17.525	15.051	0.270
June	20.887	18.848	0.271
July	20.629	19.356	0.207
August	20.574	19.360	0.191
September	16.068	16.625	0.192
October	11.988	12.861	0.231
November	5.937	8.343	0.214
December	2.468	4.413	0.243
---------------------2009-------------------			
January	-1.480	0.418	0.147
February	1.685	2.356	0.243
March	5.038	4.406	0.261
April	14.980	11.893	0.245
May	19.230	16.564	0.224
June	20.595	18.590	0.254
July	23.055	21.195	0.196
August	21.291	20.633	0.202
September	18.311	18.294	0.118
October	12.255	13.781	0.195
November	7.657	9.376	0.267
December	2.870	5.284	0.257
-------------------2010-----------------			
January	1.770	3.548	0.245
February	2.219	2.852	0.221
March	5.972	5.638	0.264
April	11.663	10.374	0.275
May	17.658	15.597	0.279
June	22.150	19.727	0.294
July	22.043	20.183	0.291
August	21.783	20.674	0.215
September	16.896	17.052	0.203
October	10.701	12.748	0.253

A.12 Monthly soil temperature (°C) at Matei in the Transylvanian Plain, Romania.

Matei			
Months	10 cm	50 cm	Moisture cm^3/cm^3
	------------------------2009-------------------------		
March	3.913	3.795	0.320
April	12.501	9.807	0.288
May	16.669	13.843	0.220
June	18.486	16.219	0.284
July	21.356	18.146	0.740
August	19.856	18.342	0.125
September	17.468	17.139	0.130
October	11.681	12.852	0.178
November	8.050	9.229	0.199
December	3.206	5.664	-0.060
	-------------------------2010---------------------		
January	2.803	3.781	-0.213
February	3.288	2.391	0.113
March	5.605	4.379	0.047
April	11.847	8.994	0.006
May	16.589	13.220	0.132
June	21.608	17.636	0.161
July	20.837	18.337	0.097
August	21.906	19.320	0.202
September	16.962	16.575	0.213
October	10.348	12.491	0.213

A.13 Monthly soil temperature (°C) at Nuseni in the Transylvanian Plain, Romania.

Nuseni			
Months	10 cm	50 cm	Moisture cm^3/cm^3
	-----------------------2009--------------------------		
March	4.378	4.138	0.323
April	12.295	10.083	0.287
May	15.186	13.302	0.243
June	18.079	15.870	0.281
July	21.157	19.121	0.275
August	19.833	18.618	0.240
September	15.938	16.219	0.203
October	10.962	12.591	0.260
November	7.376	8.977	0.319
December	2.987	5.510	0.320
	------------------------2010-----------------------		
January	1.443	3.352	0.303
February	1.127	2.179	0.296
March	4.614	4.474	0.322
April	10.226	9.002	0.322
May	14.632	12.834	0.311
June	17.458	15.598	0.316
July	18.798	17.135	0.324
August	19.380	18.094	0.246
September	14.598	15.050	0.232
October	8.955	11.415	0.216

A.14 Monthly soil temperature (°C) at Sic in the Transylvanian Plain, Romania.

	Sic		
Months	10 cm	50 cm	Moisture cm^3/cm^3
	2009		
March	3.721	3.481	0.296
April	11.558	9.312	0.240
May	15.242	13.009	0.190
June	18.468	16.222	0.289
July	20.539	18.859	0.298
August	19.527	18.681	0.233
September	16.411	16.686	0.163
October	11.307	12.771	0.221
November	7.680	9.294	0.282
December	3.211	5.749	0.280
	2010		
January	1.547	3.451	0.277
February	1.154	2.223	0.277
March	4.404	4.356	0.281
April	10.189	8.873	0.277
May	14.963	12.958	0.277
June	18.772	16.791	0.314
July	20.887	18.965	0.314
August	21.415	20.247	0.267
September	16.310	16.870	0.250
October	11.010	13.387	0.251

A.15 Monthly soil temperature (°C) at Silivasu in the Transylvanian Plain, Romania.

Silivasu			
Months	10 cm	50 cm	Moisture cm^3/cm^3
-------------------2008--------------------			
April	11.059	9.895	0.304
May	15.667	13.318	0.262
June	19.661	17.375	0.281
July	20.363	18.932	0.284
August	19.495	18.659	0.248
September	15.355	16.282	0.253
October	10.802	12.260	0.295
November	5.569	8.268	0.295
December	2.611	4.896	0.301
--------------------2009-------------------			
January	-0.998	1.428	0.188
February	1.795	2.955	0.288
March	3.292	3.926	0.299
April	10.779	9.560	0.239
May	15.281	13.305	0.197
June	17.461	15.771	0.241
July	NA	18.336	0.208
August	NA	19.145	0.201
September	NA	17.099	0.169
October	NA	13.025	0.230
November	NA	9.193	0.299
December	NA	5.732	0.297
-------------------2010-----------------			
January	1.818	3.810	0.303
February	1.494	2.734	0.299
March	4.216	4.605	0.305
April	9.797	8.825	0.309
May	14.465	13.011	0.292
June	17.559	16.614	0.287
July	19.305	18.575	0.253
August	19.603	19.255	0.237
September	15.515	15.911	0.272
October	11.079	12.312	0.212

A.16 Monthly soil temperature (°C) at Taga in the Transylvanian Plain, Romania.

Taga			
Months	10 cm	50 cm	Moisture cm^3/cm^3
	-------------------2008--------------------		
April	10.816	9.286	0.310
May	15.652	13.207	0.256
June	20.354	18.012	0.253
July	21.222	19.432	0.227
August	21.268	19.900	0.157
September	15.633	16.938	0.168
October	10.712	12.633	0.240
November	5.218	8.492	0.240
December	2.010	4.458	0.252
	---------------------2009-------------------		
January	-1.254	1.224	0.143
February	0.953	2.051	0.224
March	3.425	3.413	0.269
April	11.294	8.801	0.155
May	18.402	12.817	0.107
June	21.138	16.777	0.215
July	NA	20.083	0.213
August	NA	19.968	0.203
September	NA	17.207	0.138
October	NA	12.702	0.197
November	NA	9.185	0.253
December	NA	5.730	0.251
	-------------------2010-----------------		
January	-0.052	3.890	0.238
February	1.118	2.540	0.222
March	4.173	4.036	0.248
April	9.962	8.083	0.245
May	15.452	11.894	0.251
June	20.252	17.123	0.283
July	22.263	20.374	0.271
August	22.078	21.719	0.227
September	15.308	17.859	0.225
October	8.858	13.919	0.223

A.17 Monthly soil temperature (°C) at Triteni in the Transylvanian Plain, Romania.

Triteni			
Months	10 cm	50 cm	Moisture cm^3/cm^3
	---------------------2008---------------------		
April	11.669	11.030	0.316
May	16.114	14.993	0.306
June	18.873	17.812	0.297
July	19.406	18.457	0.277
August	20.275	19.419	0.267
September	14.416	15.580	0.258
October	9.803	11.350	0.296
November	4.324	7.182	0.301
December	1.321	3.874	0.289
	----------------------2009-------------------		
January	-1.767	0.736	0.183
February	0.778	2.003	0.276
March	3.527	3.694	0.298
April	13.022	10.972	0.290
May	17.984	15.951	0.244
June	19.807	17.606	0.289
July	22.206	20.188	0.255
August	21.424	20.364	0.265
September	16.982	17.363	0.187
October	10.246	12.204	0.241
November	6.768	8.726	0.303
December	2.321	5.072	0.306
	---------------------2010-------------------		
January	1.296	3.351	0.295
February	1.557	2.729	0.286
March	4.596	4.919	0.301
April	11.071	9.817	0.311
May	16.504	14.684	0.307
June	19.656	17.719	0.309
July	20.991	19.352	0.318
August	21.127	20.121	0.258
September	14.618	15.612	0.232
October	8.421	11.057	0.261

A.18 Monthly soil temperature (°C) at Unguras in the Transylvanian Plain, Romania.

Unguras			
Months	10 cm	50 cm	Moisture cm^3/cm^3
	-------------------------2009-------------------------		
March	5.233	5.209	0.324
April	14.465	12.719	0.305
May	16.920	15.767	0.251
June	18.521	17.564	0.271
July	21.920	20.876	0.266
August	20.484	20.074	0.250
September	16.808	17.076	0.206
October	14.289	12.807	0.238
November	22.091	9.319	0.368
December	17.868	4.985	0.417
	------------------------2010-------------------------		
January	12.133	3.091	0.427
February	16.128	2.492	0.400
March	19.336	5.872	0.421
April	18.965	10.735	0.431
May	27.047	14.655	0.520
June	33.311	17.191	0.615
July	23.528	19.026	0.470
August	23.300	19.478	0.377

A.19 Monthly soil temperature (°C) at Voinceni in the Transylvanian Plain, Romania.

Voinceni			
Months	10 cm	50 cm	Moisture cm^3/cm^3
	--------------------------2009-------------------------		
March	4.690	4.259	0.303
April	13.460	10.902	0.244
May	18.492	15.548	0.215
June	21.577	18.733	0.263
July	24.111	21.730	0.261
August	23.015	21.788	0.233
September	18.709	18.881	0.205
October	12.176	13.880	0.241
November	7.934	9.626	0.279
December	3.120	5.617	0.274
	------------------------2010------------------------		
January	1.681	3.127	0.271
February	1.123	1.498	0.258
March	4.792	4.213	0.276
April	10.907	9.324	0.280
May	16.232	14.228	0.270

A.20 Monthly soil temperature (°C) at Zau in the Transylvanian Plain, Romania.

	Zau		
Months	10 cm	50 cm	Moisture cm^3/cm^3
	-----------------------2009-----------------------------		
March	5.984	5.824	0.305
April	14.111	11.844	0.246
May	18.765	16.318	0.199
June	21.681	19.150	0.238
July	24.811	22.281	0.196
August	25.185	23.381	0.178
September	21.993	21.600	0.149
October	13.952	16.028	0.209
November	8.687	10.734	0.266
December	3.524	6.160	0.268
	-----------------------2010-------------------------		
January	2.110	3.997	0.263
February	2.466	3.015	0.267
March	6.568	6.222	0.267
April	12.764	11.149	0.262
May	17.980	15.865	0.261
June	21.351	19.495	0.268
July	23.558	21.481	0.262
August	24.610	22.936	0.206
September	18.526	19.129	0.193

A.21 Monthly soil temperature (°C) at Zoreni in the Transylvanian Plain, Romania.

Zoreni			
Months	10 cm	50 cm	Moisture cm^3/cm^3
	--------------------------2009------------------------		
March	3.620	3.359	NA
April	12.151	9.606	NA
May	16.451	13.628	NA
June	18.637	16.541	NA
July	21.340	19.036	NA
August	21.187	19.508	NA
September	17.284	17.167	NA
October	11.268	12.941	NA
November	7.317	9.113	0.268
December	2.938	5.514	0.270
	-------------------------2010-------------------------		
January	1.205	3.248	0.255
February	0.592	1.766	0.259
March	3.977	3.852	0.267
April	10.374	8.745	0.266
May	15.152	12.975	0.251
June	19.730	17.028	0.276
July	20.618	18.808	0.242
August	21.770	19.867	0.226
September	15.930	16.365	0.237
October	10.312	12.633	0.214

APPENDIX B. STATION DATA

B.1 Pedon data at 20 study sites in the Transylvanian Plain, Romania.

Horizon	Depth cm	Clay	Sand	Silt	Texture	Hue	Value	Chroma	Structure Grade	Structure Shape	Consistency
		----------%---------									
					-----Balda-----						
Ap	10	48	11	41	Silty Clay	10YR	3	2	Weak	Subangular Blocky	Friable
2Bw1	24	48	11	41	Silty Clay	10YR	3	2	Weak	Subangular Blocky	Firm
2Bw2	38	51	10	39	Clay	10YR	3	2	Strong	Angular Blocky	Firm
					-----Band-----						
Ap	12	30	41	28	Clay Loam	10YR	3	2	Weak	Granular	Friable
Bt1	38	31	41	28	Clay Loam	10YR	3	2	Moderate	Subangular Blocky	Firm
Bt2	45	33	41	25	Clay Loam	10YR	3	2	Moderate	Subangular Blocky	Firm
					-----Branistea-----						
Ap	12	24	42	34	Loam	2.5YR	4	1	Weak	Subangular Blocky	Firm
Bw1	26	25	48	27	Loam	2.5YR	5	3	Weak	Subangular Blocky	Firm
Bw2	40	31	15	54	Silty Clay Loam	2.5YR	5	3	----------	------------	----------
Bw3	100+	37	13	50	Silty Clay Loam	2.5YR	5	3	----------	------------	----------
					-----Caianu-----						
Ap	5	47	11	43	Silty Clay	10YR	3	2	Weak	Angular Blocky	Very Firm
Bw	18	47	15	38	Silty Clay	10YR	3	2	Strong	Angular Blocky	Very Firm
Bk1	30	44	15	41	Silty Clay	10YR	5	3	Weak	Subangular Blocky	Very Firm
Bk2	60	47	6	47	Silty Clay	10YR	6	3	Weak	Subangular Blocky	Firm
Ck	100+	49	1	50	Silty Clay	10YR	6	3	----------	--------------	----------

Appendix B.1 cont.

Horizon	Depth cm	Clay	Sand	Silt	Texture	Hue	Value	Chroma	Structure Grade	Structure Shape	Consistency
		---------%---------									
--Cojocna---------------------------------------											
Ap	13	28	15	57	Silty Clay Loam	10YR	3	2	Moderate	Granular	Firm
Bt1	35	32	18	50	Silty Clay Loam	10YR	3	2	Strong	Angular Blocky	Firm
Bt2	50	40	10	50	Silty Clay Loam	10YR	3	2	Moderate	Angular Blocky	Very Firm
Bt3	100+	45	18	36	Clay	10YR	3	2	---------	------------	--------
--Craiesti---------------------------------------											
Ap	21	38	26	36	Clay Loam	10YR	3	2	Weak	Subangular Blocky	Firm
Bw	60	37	27	36	Clay Loam	10YR	3	2	Moderate	Subangular Blocky	Firm
Ck	100+	34	20	46	Clay Loam	10YR	4	2	---------	------------	--------
--Dipsa---------------------------------------											
Ap	10	37	30	33	Clay Loam	10YR	4	2	Moderate	Subangular Blocky	Firm
Bt1	31	39	28	33	Clay Loam	10YR	3	2	Moderate	Subangular Blocky	Firm
Bt2	45	33	27	40	Clay Loam	10YR	3	2	Moderate	Angular Blocky	Firm
Bt3	52+	48	14	38	Clay	10YR	3	2	Moderate	Angular Blocky	Firm
--Filpisu Mare---------------------------------------											
Ap	20	36	33	30	Clay Loam	10YR	4	3	Weak	Subangular Blocky	Firm
Bw1	21	39	31	30	Clay Loam	10YR	4	3	Moderate	Subangular Blocky	Firm
Bw2	100+	41	28	30	Clay	10YR	4	3	Moderate	Subangular Blocky	Firm
--Jucu---------------------------------------											
Ap	9	48	10	42	Silty Clay	10YR	3	2	Moderate	Subangular Blocky	Firm
Bw1	34	52	4	44	Silty Clay	10YR	3	2	Moderate	Subangular Blocky	Firm
Bw2	55	55	5	40	Silty Clay	10YR	3	2	---------	------------	--------
C	100+	36	6	59	Silty Clay Loam	10YR	4	2	---------	------------	--------

Appendix B.1 cont.

Horizon	Depth cm	Clay	Sand	Silt	Texture	Hue	Value	Chroma	Structure Grade	Structure Shape	Consistency
		---------%---------									
					---Ludus---						
Ap	10	43	9	47	Silty Clay	10YR	3	2	Moderate	Subangular Blocky	Firm
Bt	90	48	13	39	Clay	10YR	3	2	Strong	Subangular Blocky	Very Firm
C	100+	54	5	42	Silty Clay	10YR	5	3	---------	------------	--------
					---Matei---						
Ap	16	38	0	61	Silty Clay Loam	2.5Y	4	2	Weak	Subangular Blocky	Firm
Bw	50+	41	6	54	Silty Clay Loam	2.5Y	4	2	Moderate	Subangular Blocky	Firm
					---Nuseni---						
Ap	15	29	27	44	Clay Loam	2.5Y	4	2	Weak	Subangular Blocky	Firm
Bt	50+	36	34	30	Clay Loam	2.5Y	4	3	Strong	Subangular Blocky	Firm
					---Sic---						
Ap	12	40	21	39	Clay Loam	2.5Y	4	2	Weak	Subangular Blocky	Firm
Btk1	22	43	34	23	Clay	2.5Y	4	2	Moderate	Subangular Blocky	Firm
Btk2	50	40	34	26	Clay Loam	2.5Y	6	4	Moderate	Subangular Blocky	Firm
C	100+	38	28	34	Clay Loam	2.5Y	5	4	---------	------------	--------
					---Silivasu---						
Ap	19	37	20	43	Clay Loam	10YR	3	2	Moderate	Granular	Firm
Bt	34	42	16	42	Silty Clay	10YR	3	2	Moderate	Subangular Blocky	Firm
Bw	100+	48	10	42	Silty Clay	10YR	3	2	Weak	Subangular Blocky	Firm
					---Taga---						
Ap	5	34	28	38	Clay Loam	10YR	4	2	Weak	Granular	Friable
Bt1	18	36	34	30	Clay Loam	10YR	3	2	Moderate	Angular Blocky	Firm
Bt2	100+	44	36	20	Clay	10YR	4	2	Weak	Subangular Blocky	Firm

Appendix B.1 cont.

Horizon	Depth	Clay	Sand	Silt	Texture	Hue	Value	Chroma	Structure Grade	Structure Shape	Consistency
	cm	-------------%-------	------								
					Triteni						
Ap	8	32	20	48	Silty Clay Loam	10YR	3	1	Moderate	Subangular Blocky	Firm
Bt1	42	37	24	39	Clay Loam	10YR	3	2	Moderate	Subangular Blocky	Firm
Bt2	100+	38	26	36	Clay Loam	10YR	3	2	Moderate	Subangular Blocky	Firm
					Unguras						
Ap	6	32	21	47	Clay Loam	2.5Y	4	2	Weak	Subangular Blocky	Firm
Bt1	17	34	15	51	Silty Clay Loam	2.5Y	5	3	Moderate	Subangular Blocky	Firm
Bt2	55+	31	22	47	Clay Loam	2.5Y	4	3	---------	------------	--------
					Voinceni						
Ap	13	28	32	40	Clay Loam	2.5Y	3	2	Moderate	Granular	Firm
Bt1	40	28	38	34	Clay Loam	2.5Y	3	2	Strong	Angular Blocky	Firm
Bt2	100+	32	32	36	Clay Loam	2.5Y	3	2	Strong	Angular Blocky	Very Firm
					Zau						
Ap	13	32	28	40	Clay Loam	10YR	4	2	Weak	Subangular Blocky	Firm
A/B	26	34	32	34	Clay Loam	10YR	4	2	Weak	Subangular Blocky	Firm
B	50+	32	34	34	Clay Loam	2.5Y	5	3	Moderate	Subangular Blocky	Very Firm
					Zoreni						
Ap	19	27	22	51	Silt Loam	10YR	4	2	Moderate	Subangular Blocky	Firm
Bt1	40	34	32	34	Clay Loam	10YR	4	2	Moderate	Subangular Blocky	Firm
Bt2	80+	38	27	35	Clay Loam	10YR	4	2	---------	------------	--------

APPENDIX C. EXPANDED MATERIALS AND METHODS

Stations

Twenty stations were deployed in the Transylvanian Plain (TP), Romania pertaining to a soil temperature and pedology study. The first 10 stations were deployed in March of 2008, with an additional 10 stations added in March of 2009. Data logging equipment was installed at all locations with two set-ups employed: 10 stations with rain-gauges (Rain+) and 10 stations without rain-gauges (Rain-). The equipment configuration is shown in Figure C.1.

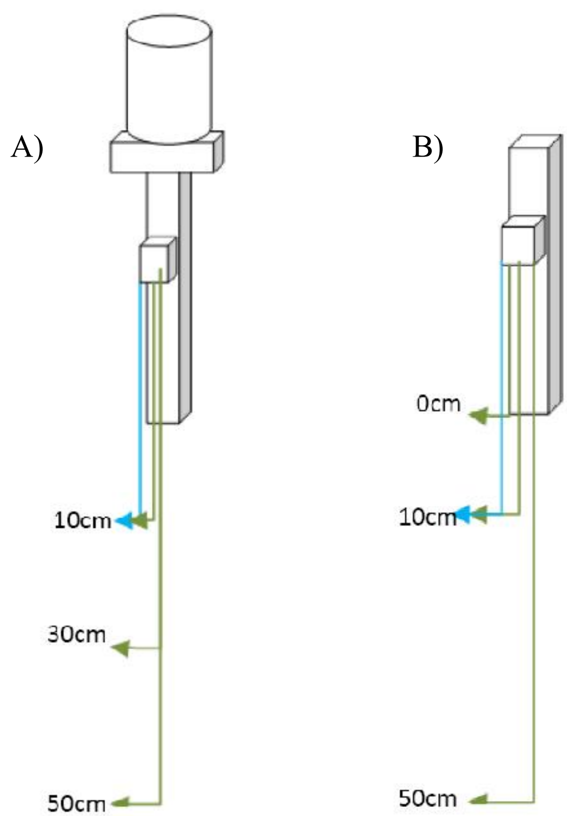

Figure C.1. Station equipment configuration: A) Rain-gauge station (Rain+) and B) Station without rain-gauge (Rain-).

Soil temperature and soil moisture were measured using HOBO Smart Temp (S-TMB-M002) temperature sensors and Decagon EC-5 (S-SMC-M005) moisture sensors. The sensors were

connected to a HOBO Micro Station (H21-002) data logger at each site (On-set Computer Corp., Bourne, MA, USA). At 10 stations, an additional tipping bucket rain gauge was installed (RG3-M) which measured rain fall as well as air temperature (On-set Computer Corp., Bourne, MA, USA) (Table C.1).

Table C.1. Twenty stations located within the Transylvanian Plain, Romania and whether a rain gauge is present.

Station number	Station name	Rain gauge
1	Balda	No
2	Triteni	No
3	Ludus	Yes
4	Band	No
5	Jucu	Yes
6	Craiesti	No
7	Silivasu	Yes
8	Dipsa	Yes
9	Taga	No
10	Caianu	Yes
11	Cojocna	Yes
12	Unguras	Yes
13	Branistea	Yes
14	Voinceni	Yes
15	Zau	Yes
16	Sic	No
17	Nuseni	No
18	Matei	No
19	Zoreni	No
20	Filpisu Mare	No

Data was collected every 10 minutes for soil temperature and soil moisture data at all 20 stations. Air temperature was recorded every 30 minutes and rain fall was recorded when a rainfall event occurred. Data was downloaded approximately every two months via a laptop computer using HOBOware Pro Software Version 2.3.0 (On-set Computer Corp., Bourne, MA, USA).

Soil Sampling and Analysis

Pedons were described at 20 locations within the Transylvanian Plain, Romania (TP). After pedons were described, samples were obtained and placed in sealed plastic bags. All samples were shipped back to Louisiana State University in Baton Rouge, LA for further laboratory evaluation. Samples were air dried, ground to pass through a 2 mm sieve, and placed in sealed plastic bags for further processing.

Particle size analysis was evaluated via a modified hydrometer method (Gee and Bauder, 1986). The samples were oven dried at 105℃ for 24 h and a 50 g sample was placed in a 500 mL wide mouth plastic bottle. To disperse the clay particles, 20 mL of Sodium Hexametaphosphate was added to the bottle and filled half way with DI water. The bottles were then placed in a reciprocal shaker for 4 hours. Samples were rinsed into 1 L graduated cylinders with DI water, and a plunger was used to mix the aqueous solution. A sand reading was obtained 40 s after the plunger had been removed using a soil hydrometer. The solution settled for 24 h to allow all sands and silts to settle out before a clay reading was measured.

Electrical conductivity (EC) and pH were measured using a saturated paste methodology (Salinity Laboratory Staff, 1954; Soil Survey Staff, 2004). Small plastic cups were filled with approximately 50 g of soil and saturated with DI water until a thick slurry was produced. Samples were allowed to sit overnight before pH and EC were measured using a Orion 2-Star pH meter (Thermo Scientific, Waltham, MA, USA) and model 4063CC digital salinity bridge (Traceable Calibration Control Company, Friendswood, TX, USA).

Organic matter was measured via loss on ignition at 400℃ in a muffle furnace (Nelson and Sommers, 1996). Three to five grams of sample was placed in ceramic crucibles. Samples were weighed after drying for 24 h at 105℃. Samples were then placed in a muffle furnace for

16 h at 400℃ to combust the organic material in the soil. Samples were placed into a desiccator until cool. Final weights were then measured.

Plant available elements were measured via Mehlich III extraction (Soil Survey Staff, 2004). Mehlich III extractants were measured via a CIROS inductively coupled plasma atomic emission spectrometer (ICP-AES) (Spectro Analytical Instruments, Marlboro, MA, USA). Previously dried and ground samples were weighed and mixed with Mehlich III solution (Mehlich, 1984). Samples were shaken 5 minutes and then centrifuged for 10 minutes. The solution was then decanted and filtered into glass test tubes for analysis via ICP-AES.

Statistical Analysis

Data was analyzed using statistical analysis software 9.0 (SAS). Statistical analyses run were Proc Reg (regression), Proc Mixed (mixed models), and Proc GLM (general linear modeling). The aforementioned procedures will be further elucidated (SAS Institute, 2009).

Multiple and simple linear regression were evaluated using the regression procedure (Proc Reg) in SAS 9.0 (SAS Institute Inc., Cary, NC). Classical assumptions for the regression procedure are: 1) All explanatory variables are included and the mean is zero, 2) Regression variables are correctly measured, 3) The value of the error is expected to be zero, 4) The variance is 1, and 5) All observations are uncorrelated (multiple regression). Additionally it is assumed that the data is normally distributed.

Analysis of variance was evaluated using Proc Mixed as well as Proc GLM. The mixed procedure in SAS 9.0 is a likelihood-based approach to analyzing general linear mixed models. Proc Mixed allows for a less restrictive model compared to GLM, by allowing both correlation and heterogeneous variances. The main assumptions for mixed models are: 1) Normal data, 2)

The means are linear with regards to the parameters, and 3) The variances and covariances exhibit a structure found in Proc Mixed. Proc Mixed allows for random effects in the model. The GLM procedure is more restrictive than Proc Mixed. The primary assumptions for Proc GLM are: 1) Normality, 2) The model represents the behavior of the data, and 3) The error terms are independent of one another. If random effects are included into the Proc GLM statement, the program will still evaluate the parameters as fixed effects. Overall, both analysis of variance procedures are similar with the exception to their ability to evaluate random and fixed effects.

References

Gee, G.W., and J.W. Bauder. 1986. Particle size analysis. *In* J.M. Bigham (ed.) Methods of soil analysis: Part 1- physical and mineralogical methods. SSSA-ASA. Madison, WI

Mehlich, A. 1984. Mehlich 3 soil test extractant: A modification of Mehlich 2 extractant. Commun. Soil Sci. Plant Anal. 15:1409-1416.

Salinity Laboratory Staff. 1954. Diagnosis and improvement of saline and alkali soils - Agriculture Handbook No 60. USDA. US Gov. Print. Off., Washington, DC.

SAS Institute. 2009. Help and Documentation. Release 9.2. SAS Institute Inc., Cary, NC, USA.

Soil Survey Staff. 2004. Soil survey laboratory methods manual, Version 4.0. USDA-NRCS. US Gov. Print. Off., Washington, DC.

APPENDIX D. PERMISSION TO REPRINT

February 1, 2012

Memorandum

To: The LSU Graduate School

From: Editorial Staff, *Studia Universitatis Babeş-Bolyai Geographia*

Re: Permission to reprint

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Your proof should now be available for correcting.

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VITA

Beatrix Haggard was born in Azle, Texas, where she also grew up. She attended Tarleton State University in Stephenville, Texas, and graduated in May 2008 with a Bachelor of Science in agronomy and range management with a minor in geology and a soil science emphasis. As an undergraduate student she had an internship with NRCS in Marfa, Texas, as well as Fairbanks, Alaska, as a soil scientist trainee. During her time at Louisiana State University she met her wonderful husband who just happened to be sitting at the desk on the opposite side of the office.