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The Shadow Values of Soil Hydrological Properties in the Production Potential of Climatic Regionalization of the Czech Republic

Josef Slaboch *, Lukáš Čechura, Michal Malý and Jiří Mach

Department of Economics, Faculty of Economics and Management, Czech University of Life Sciences Prague, 16500 Prague, Czech Republic
* Correspondence: jslaboch@pef.czu.cz; Tel.: +420-224382401

Abstract: The Czech Republic uses a dual system of agricultural land prices, namely the formal/official price—for tax purposes—and the market price in the case of a standard sale or purchase of farmland. This paper focuses on the construction of an econometric model to quantify the influence of soil hydrological characteristics on the production potential in a given climatic region. It also focuses on the use of this model for the determination of the official price of agricultural land, which is expressed on the basis of the code of the evaluated soil-ecological unit (ESEU) and based on defined soil characteristics. The pricing itself is based on the production potential of the land, which in practice is very important for spatial planning, as it determines the classes of agricultural land protection with regard to the possibility of setting aside agricultural land for non-productive purposes or for drawing subsidies for less favourable areas. In this context, the non-productive functions of agricultural land are also frequently discussed, especially its retention, which plays a very important role in the currently changing climatic conditions. There are a number of studies on soil retention, and numerous approaches to measuring it, but none of them address its impact on production potential and thus on the price of land. For this reason, this paper focuses on defining the influence of the retention of the main soil units (defined for the conditions of the Czech Republic) on production potential. For this definition, SUR models are used, where the endogenous variable is expressed as production potential and the exogenous variables include the basic soil characteristics such as grain size, porosity, hydrological component of the soil, and retention. The obtained outputs show both the high explanatory power of the model and the adequate parametric significance of most variables, which provides sufficient support for the use of the results in practice. In addition, the estimated models across all climatic regions are consistent with substantively logical assumptions about the link between production potential and soil hydrological properties, which secondarily demonstrates their applicability in practice, especially for state administration, but also for local government in the sense of municipalities, cities, and other organizational units.

Keywords: soil; soil hydrological characteristics; production potential; climatic regions; econometric modelling; SUR models

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1. Introduction

The production of food for nutritional security is a fundamental task of agricultural production. One factor that makes this activity important is the growing population [1]. Due to climate change caused by global warming, it will be increasingly difficult to perform this basic task in the coming years as it is a highly dependent and climate sensitive activity. Therefore, it is necessary to understand the interactions between climate and agricultural production, especially due to the higher probability of dry periods, rainfall fluctuations or increased average temperature [2,3]. The actual effects of climate change on food production have been addressed in a number of studies, which generally vary in their focus on specific crop species [4–7].

In addition to climate change, crop yield (and consequently food production) is also influenced by soil physical and chemical properties, especially hydrological properties. In the conditions of the Czech Republic, the indicator of production potential is used, which is influenced by type of the main soil unit, climatic region, exposure of a plot, its slope, etc. It is evident that this issue must be perceived comprehensively. For this reason, the introductory chapter will focus on the following areas: methods for measuring the hydrological properties of soils themselves, agronomic interventions affecting the hydrological properties of soils and options for improving the hydrological properties of soils.

Measurements of hydrological properties can be made directly or indirectly. In the case of the direct method, measuring hydrological data is very difficult in terms of capacity—the direct method may include, for example, the soil water retention curve (SWRC) [8,9]. For this reason, indirect estimation of hydrological data through pedotransfer functions (PTFs) is used instead. In this case, the basic dataset includes information on soil particle size, bulk density and organic carbon as well as information on environmental morphometric parameters (relief slope, exposure, etc.) [10–13].

Another often discussed factor is that soil degradation occurs primarily in large soil blocks, which could pose a serious threat to future food security [14,15]. The main reasons for this include increased concentration, intensification and specialization of crop and livestock production without sufficient consideration of natural, site-specific soil and climatic conditions [16–19]. In terms of new methods for measuring soil degradation, monitoring of earthworms may also be of interest, where a correlation has been shown specifically between the number of earthworms and the degree of soil degradation [20].

Land management itself should be aimed at improving or maintaining the soil in a productive state. Several indicators can be used to assess changes in the soil caused by different management practices (or different agronomic interventions). The most common indicator is the bulk density. Bulk density provides an overview of the soil environment that influences plant growth. For example, the least limiting water range (LLWR) method can be used to determine those soil properties that imply physical improvement or degradation of the soil [21]. The soil surface affects the interaction between water and soil. Based on one study [22], it can be concluded that there is a difference in soil compaction for different tillage techniques, which can affect the interaction between soil and water. This is supported by other studies that report, for example, that rotary tillage can lead to lower soil degradation and higher soil water use efficiency with relatively low mechanical costs [23,24]. Another possible technique for mitigating soil degradation is long-term sub-soiling tillage. The results show increased porosity, which positively creates a water regime in the soil [25].

When deeper tillage is used, there is higher evaporation of surface water, leading to poorer soil water distribution [26].

However, another study states that rotary tillage is suitable in cooler and wetter areas and conventional tillage is more suitable in warmer and drier areas [27].

Another problem of intensive farming is the decline of organic matter in agricultural soils. This decline reduces soil fertility, which directly impairs crop production and affects a number of other soil properties such as water holding capacity, soil mechanical strength, and soil compaction. The lack of water available for plants poses a risk to agriculture, especially in drought-prone areas. The main finding in this study is that the water available for plants increases after the addition of organic waste [28]. A similar result is also reported by a study [29] which found that the effect of intensive agriculture leads to a decrease in soil potassium, and points to suboptimal nutrient management in the study area. At the same time, soil retention capacity is also one of the key factors for the management of phosphorus, an important fertilizer for agricultural production [30]. From the above, it is appropriate to use variables such as "pH", "organic matter", and "available phosphorus, potassium and nitrogen" to assess the possible future change in soil fertility under sustainable development [31].

Other ways to reduce the impact of climate change on agricultural production may include changes in crop rotation practices or the cultivation of crops that are not entirely traditional to the location. This possibility is highlighted, for example, by a study [32] which foresees an expansion of protein crop production in south-eastern Austria, with its Central European continental climate. However, the amount of protein crops is limited by the agronomically suitable agricultural land. In some cases, the cultivation of selected crops could be shifted to higher altitudes [33].

Climate change is also displacing grapevine cultivation from the south to the north, from Southern Europe to the north, that is, from arid zones to more temperate zones [34–36]. At the same time, the cultivated crops may experience a shortening of the growing season, a change in sowing time, etc. [37,38].

Climate change itself does not have to be about crop production. This fact is highlighted, for example, by a study [39] that used Australia as an example for animal production. In most locations, climate change will lead to a prolongation of the dry summer season, which will translate into a higher risk of erosion. At the same time, there will be lower forage production. This could have a very negative impact on the economic performance of livestock farms, with the study estimating a 27% drop in operating profits already in 2030.

The required increase in agricultural production to meet future food demand will further increase pressure on soil resources [40]. Therefore, in light of climate change, soil water retention will also need to be addressed. There are a number of studies looking at the potential for increasing soil retention. One example is the application of hydrogel to the top of the soil profile, where the available water content for plants is increased [41]. Another option may be the use of biochar. The results showed that biochar reduced the bulk density of the soil and increased the water holding capacity of the soil (mainly due to its porosity) [42]. In Japan, the test results showed that soils mixed with 30% humus had the greatest potential to affect initial and final infiltration capacity, and at the same time these soils had the highest final infiltration with the lowest multiplicative leakage [43].

From the above overview, it can be seen that there are a number of studies dealing with various relationships between soil properties, but there is no study that directly addresses the effect of soil hydrological properties or individual soil quality parameters (grain size, porosity, etc.) on the magnitude or change in the production potential of agricultural soils. For this reason, the article is focused precisely on this area, since in the conditions of the Czech Republic, the production potential is the fundamental basis for determining the official price of land (determined on the basis of individual ESEU), which is then used in practice for tax or subsidy purposes and also for determining the classes of agricultural land protection, which are of great importance in the areas of landscape planning and urban and municipal development. Considering the current procedures aimed at the revaluation of the soil fund of the Czech Republic, the adjustment of the methodology of calculation of official prices or the possibility of an exact estimation of the non-productive function of soil is a very important tool for the above purposes and is therefore highly topical research that is of importance for practical use in the legislation of the Czech Republic. The aim of the presented article is to determine the influence of individual hydrological properties of soil on the production potential in the conditions of the Czech Republic, especially due to climate change. The definition of climatic regions in the Czech Republic was made in the 1970s and currently the individual parameters do not correspond to the actual conditions. The paper is structured as follows: The next section introduces materials and methods. Section 3 presents our results and Section 4 provides conclusions.

2. Materials and Methods

To address paper's objective, we used data from the Research Institute for Soil and Water Conservation (RISWC), specifically, the physical characteristics of the main soil units (MSU) within the ESEU classification (Evaluated Soil-Ecological Unit). For the purposes of the state administration in terms of tax and certain subsidies payments, Annex 4 of Decree 441/2013 Coll. Applies as the default tool. The currently valid version of Decree from the year 2013 contains 2172 ESEU codes as the basic mapping and valuation unit. At a more detailed level, the ESEU code is expressed as a five-digit number (e.g., 120345). The first digit in the code indicates the affiliation with a given climatic region (numerical expression 0–9). A climatic region (CR) comprises an area with similar climatic conditions for plant growth (average annual temperature, sum of temperatures, average rainfall, probability of dry growing seasons and guaranteed moisture in the growing season, detailed in text below). The second and third digits classifies the unit according to the main soil unit (MSU) classification system. The main soil unit is a synthetic agronomic unit characterised by a meaningful grouping of genetic soil types, subtypes, degree of hydromorphism and local relief (numerical expression 01–78). The fourth digit indicates the combination of slope and exposure (numerical expression 0–9) and the fifth digit represents the combination of soil profile depth and skeletonisation (volumetric content of gravel and stone in soil; numerical expression 0–9). The physical properties of each of the main soil units that have a link to, or influence on, the water retention capacity of soils—78 MSUs in the Czech Republic—are used as reference data to fulfil the aim of the paper. Soil water content is a crucial parameter influencing plant growth. Soil water content generally depends mainly on precipitation and groundwater level. However, the water retention capacity of the soil is very important and is determined mainly by its texture and structure. Specifically, the following properties of the main soil units were selected: grain size, porosity, hydrological soil group, and retention. Tables 1–4 below provide an overview of the key soil properties used for the econometric modelling.

Table 1. The grain size and porosity for individual MSUs.

Grain size indicates the size and relative abundance of the individual soil fractions. The grain size contributes significantly to the pedogenetic processes as well as to the agronomic and ecological characteristics of the soil. For the purpose of the articles, the grain size of MSU was divided as follows:		Porosity is defined as the volume of all the spaces between the soil solids. It is expressed as a percentage and its value in soils ranges on average from 40–60%. For the purpose of calculation, the values according to the RISWC classification were used. In terms of porosity, soils can be subdivided into the following types:	
Light	1	Light soil	35–45
Lighter	2	Medium soil	45–55
Medium	3	Heavy soil	50–70
Medium heavy	4		
Heavy	5		
Very heavy	6		

Source: Own elaboration according to the current RISWC methodology.

The different climatic regions have an influence on the different production potential. The following Table 4 defines the basic characteristics in the conditions of the Czech Republic.

Table 2. Definition of hydrological soil groups for individual MSUs.

Soils are classified into 4 groups according to their hydrological properties: A, B, Cor D based on the minimum rate of water infiltration into the soil. The infiltration capacity of soils is the ability of the soil surface to absorb water. In general, soil infiltration capacity should be medium to high to minimize surface runoff and water erosion. For the purposes of this paper, the different hydrological soil groups are defined as follows:	Group A: Soils with high infiltration rates (>0.20 mm/min) even at full saturation, comprising mostly deep and well-drained, to excessively well-drained sands and gravels.
	Group B: Soils with medium infiltration rate (0.10–0.20 mm/min) even at full saturation, comprising mainly medium deep to deep, moderately to well-drained, loamy-sand soils to clay-loam soils.
	Group C: Soils with low infiltration rates (0.05–0.10 mm/min) even at full saturation, comprising mainly soils with low permeable layer in the soil profile and clay-loam to clay soils.
	Group D: Soils with a very low infiltration rate (<0.05 mm/min) even at full saturation, comprising mainly clays with high swelling, soils with a permanently high groundwater table, soils with a clay layer at or just below the surface, and shallow soils over nearly impermeable bedrock.

Source: Own elaboration according to the current RISWC methodology.

Table 3. Defining retention for individual MSUs.

The water retention capacity can be characterised as the amount of water that the soil is able to hold in the capillary pore system and gradually release to plants. The resulting values of water holding capacity take into account the average depth of the profile and the water content, thus characterising the actual amount of water that the soil is able to hold during rainfall.	<100 (L m^{-2})	Low
	100–160 (L m^{-2})	Lower medium
	160–220 (L m^{-2})	Medium
	220–320 (L m^{-2})	Higher medium
	>320 (L m^{-2})	High

Source: Own elaboration according to the current RISWC methodology.

Table 4. Definition of climatic regions in the Czech Republic.

Climatic Region	Sum of Temperature Above 10 °C (°C)	Average Temperature (°C)	Average Rainfall (mm)	Probability of Dry Growing Seasons (%)	Moisture Security
CR0	2800–3100	9–10	500–600	30–50	0–3
CR1	2600–2800	8–9	pod 500	40–60	0–2
CR2	2600–2800	8–9	500–600	20–30	2–4
CR3	2500–2800	7–9	550–650	10–20	4–7
CR4	2400–2600	7–8.5	450–550	30–40	0–4
CR5	2200–2500	7–8	550–650	15–30	4–10
CR6	2500–2700	7.5–8.5	700–900	0–10	over 10
CR7	2200–2400	6–7	650–750	5–15	over 10
CR8	2000–2200	5–6	700–800	0–15	over 10
CR9	under 2000	under 5	over 800	0	over 10

Source: Own elaboration according to the current RISWC methodology.

The bonitization of the agricultural land fund was carried out on the basis of Government Resolution No. 101 from 1971, when the goal was to assess and evaluate the absolute and relative production capabilities of agricultural land and the conditions for their most effective use. The bonitization results are regularly updated and supplemented/adjusted. The production potential system of ESEU is based on the calculation of the production and energy capacity of the soil and habitat. According to the legislation and calculation methodology, the production potential can be a maximum of 100 points. The properties of the main soil unit can make up (depending on the parameters) up to 75% of the maximum point value. The resulting production potential values are important for the distribution of soils within the quality range, from highly productive soils with stabilized yields to non-productive soils. With respect to this distribution, protection classes are established in order to limit the use of highly productive lands for purposes other than food production.

Specifically, the production potential of a particular main soil was originally determined by field experiments in different climatic regions. These experiments produced the normative standards of the production potential of main soils in a particular climatic region, which serve for the calculation of official soil prices. These normative standards were supplemented by different soil characteristics (see Tables 1–4). Our model specification directly links the soil characteristics with the production potential and thus provides the shadow values of each soil characteristic in a particular climatic region. That is, we explain the production potential (prod_pot) using granularity ("granularity"), porosity ("porosity"), hydrological component of soil ("HSC_A/B/C") and retention capacity ("retention"):

$$\text{yi = f (granularityi, porosityi, HSC\_A/B/Ci, retentioni)} \quad (1)$$

where y_i stands for the production potential of a particular main soil unit and i indicates climatic region, i = 1, . . . , I.

The estimation procedure is based on the Seemingly Unrelated Regression (SUR) approach. That is, each equation explaining the yield potential of a given main soil unit (MSU) in a single climatic region is, by itself, a classical regression [44]. Formally, we can write the SUR model:

$$\begin{pmatrix} y_1 \\ y_2 \\ y_3 \\ \vdots \\ y_I \end{pmatrix} = \begin{pmatrix} X_1 & 0 & 0 & \cdots & 0 \\ 0 & X_2 & 0 & \cdots & 0 \\ 0 & 0 & X_3 & \cdots & 0 \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & 0 & \cdots & X_I \end{pmatrix} \begin{pmatrix} \beta_1 \\ \beta_2 \\ \beta_3 \\ \vdots \\ \beta_I \end{pmatrix} + \begin{pmatrix} \varepsilon_1 \\ \varepsilon_2 \\ \varepsilon_3 \\ \vdots \\ \varepsilon_I \end{pmatrix} = X\beta + \varepsilon \quad (2)$$

where $\boldsymbol{X_i}$ is a matrix of covariates (namely: granularity ("granularity"), porosity ("porosity"), hydrological component of soil ("HSC_A/B/C") and retention capacity ("retention")). $\boldsymbol{\beta_i}$ is a vector of parameters to be estimated and ε_i is a vector of residuals, which is supposed to be $\varepsilon_i \sim n.i.d\left(0, \sigma_\varepsilon^2\right)$.

Having the covariance matrix:

$$S = \begin{vmatrix} s_{11} & \cdots & s_{1I} \\ \cdots & \cdots & \cdots \\ s_{I1} & \cdots & s_{II} \end{vmatrix} \quad (3)$$

and defining:

$$\Omega = S \otimes I \quad (4)$$

then the GLS estimator of the model parameters (2) is (4,5):

$$\hat{\beta} = \left[X^T \Omega^{-1} X\right]^{-1} X^T \Omega^{-1} y = \left[X^T\left(S^{-1} \otimes I\right)X\right]^{-1} X^T\left(S^{-1} \otimes I\right)y \quad (5)$$

and expanding the Kronecker products we can write:

$$\hat{\beta} = \begin{bmatrix} \sigma^{11} X_1^T X_1 & \sigma^{12} X_1^T X_2 & \cdots & \sigma^{1I} X_1^T X_I \\ \sigma^{21} X_2^T X_1 & \sigma^{22} X_2^T X_2 & \cdots & \sigma^{2I} X_2^T X_I \\ \cdots & \cdots & \cdots & \cdots \\ \sigma^{I1} X_I^T X_1 & \sigma^{I2} X_I^T X_2 & \cdots & \sigma^{II} X_I^T X_I \end{bmatrix}^{-1} \begin{bmatrix} \sum_{i=1}^{I} \sigma^{1i} X_1^T y_i \\ \sum_{i=1}^{I} \sigma^{2i} X_2^T y_i \\ \cdots \\ \sum_{i=1}^{I} \sigma^{Ii} X_I^T y_i \end{bmatrix} \quad (6)$$

where σ^{ij} stands for the *ij-th* element of $\boldsymbol{S}^{-1}$. (6) implies that this estimator is different from ordinary least squares (OLS). In particular, it is evident that the equations are linked by their disturbances. In other words, the SUR estimator is equivalent to the OLS estimator if the error terms are not correlated across equations. If the opposite is true, the SUR estimator is more efficient. Since we may assume that the production potential of a particular soil unit may be spatially correlated across the climatic regions, which implies the mutual correlation of the error terms, we apply the SUR approach to model (2) as a more efficient estimator.

Finally, we assume the strict exogeneity of $\boldsymbol{X_i}$. To avoid potential heteroscedasticity problems related to the biased estimate of the covariance matrix, standard errors of the parameter using bootstrapping is calculated.

3. Results and Discussion

Table 5 provides the SUR models estimates for each climatic region (partial results for single climatic region, including descriptive model statistics, are presented in Tables A1–A10). The models reflect the effect of soil hydrological properties on the production potential in a given climatic region and are defined as comparable in order to obtain the production potential of a respective region. In terms of the variable specification, the endogenous variable is the production potential (Prod_pot), which implies the ability to achieve quality production under certain soil-climatic conditions, and its value allows to quantify the economic effect of land use. In particular, the results show the relationship between production potential and soil-hydrological aspects of a given climatic region.

In the overall assessment of the estimated models, there are outcomes that share common features. The climatic regions that are characterised by worse conditions, i.e., in the rating scale, specifically mainly the extreme climatic regions (for example CR0 or CR1), have very limited possibilities to improve their production potential due to water retention properties. This is assumed to be very likely due to the presence of unsuitable soil types and other soil composition. The only way to improve production potential in these regions is to increase the hydrological component of the soil in order to increase infiltration capacity. The situation is changing from the extreme climatic regions towards the typically favourable soil-climatic conditions. In addition to the variable of the hydrological composition of the soil, porosity and retention are also important determinants of production potential, and in climatic regions 3 and 5 even soil granularity is an important determinant, with the intensity of the effect also tending to increase from the extreme (i.e., climatically unsuitable regions) to the middle regions (i.e., regions with suitable climatic characteristics).

Comparison of the unit effect of the covariates can lead to conclusion that the strongest changes in production potential in all models are determined by soil hydrology, which (if significant) brings a multiple positive increase in production potential in all models. Further, granularity is the next over-proportionally influential factor, but it is only present in two climatic regions, CR3 and CR5. Next, another significant variable in the unit effect comparison is soil porosity, which sub-proportionally influences production potential in most climatic regions. Retention, which yields a negligible increase in production potential, has the smallest unit effect in the estimated models.

Table 5. SUR model, CR 0-9, reg Prod_pot(bootstrap), *source: own estimate*.

SUR	CR0	CR1	CR2	CR3	CR4	CR5	CR6	CR7	CR8	CR9
Granularity	1.257106	0.436529	9.556196	2.340792 **	1.867402 *	2.764695 **	1.815334	2.241771 *	1.373544	0.341074
Porosity	0.6782325 ***	0.5865935 ***	0.1203967	0.6188024 ***	0.5492881 ***	0.5134200 ***	0.5642998 ***	0.4651339 ***	0.0391655 ***	0.2757740 ***
HSC_A	18.94964 *	18.44326 **	40.85582 **	27.75406 ***	22.46120 ***	28.68111 ***	25.31264 ***	29.24092 ***	25.90095 ***	29.39995 ***
HSC_B	13.08379 **	12.79214 ***	20.68173 ***	18.63752***	12.09717 ***	17.09947 ***	15.07666 ***	18.54992 ***	18.80815 ***	20.69848 ***
HSC_C	6.883012	8.276861 *	14.52052	14.34763 ***	10.31714 ***	12.25322 ***	10.63730 **	12.43798 **	11.17213 *	11.10779 **
Retention	0.0940297 ***	0.0886133 ***	0.0460241	0.0812278 ***	0.0807939 ***	0.0777999 ***	0.0740525 ***	0.0627546 ***	0.0574769 ***	0.0555235 *
_cons	12.93851	14.16770 **	7.914516	9.830487 *	9.596183 *	5.231818	10.26998	6.295129	8.322698	10.27807
Wald chi2	281.30	311.64	94.24	555.20	384.41	675.81	574.84	505.90	386.51	268.35
R-squared	0.8865	0.8646	0.2350	0.8684	0.8577	0.8661	0.8800	0.8647	0.8399	0.8671

Note: significance of parameter estimation—* $\alpha = 0.1$, ** $\alpha = 0.05$, *** $\alpha = 0.01$.

As far as the water retention is concerned, we can observe that the value of the parameter decreases from CR0 to CR9 (the exception is CR2, which is specific in terms of results). This result corresponds to the distribution of climatic regions, with CR0 being the warmest and driest, while CR9 has the lowest average temperatures and is very humid. Thus, in general, it can be concluded that with higher humidity and higher average precipitation, the magnitude and influence of the soil water retention parameter will decrease, which is the inference that is consistent within the model, and it means that in climatic regions that are rich in precipitation and have enough moisture, the soil is already sufficiently saturated, and, therefore, an increase in, for example, the total amount of precipitation does not bring such an effect on the production potential as in regions poor in moisture. Therefore, in regions with sufficient moisture, water retention has a lower intensity of influence, i.e., a lower parameter. Another important confirmed assumption is the significant influence of hydrological soil groups on production potential. For each climatic region there is a clear decreasing magnitude of the parameters from HSC_A to HSC_C. These results suggest that, with lower water infiltration into the soil, the production potential decreases. This phenomenon can furthermore have a negative effect in the form of higher water erosion, where the topsoil is washed away.

Detailed insight into the estimation results for each climatic region, we can say that the model for climatic region 0 (see Appendix A for details) has a very high goodness of fit (R-squared = 88.65%) and, without taking into account the statistical significance, the estimated parameters address a logical link to the production potential. The estimated parameters of the variables representing porosity, average water infiltration capacity and retention are statistically significant at the significance level 5%/α = 0.05/, with high infiltration capacity being on the borderline of a statistically significant variable. All the above-mentioned variables display a positive effect on production potential, i.e., an increase in both porosity and retention leads to an increase in production potential. This result is, also, supported by the hydrological component of the soil, which, in addition to the values of the estimated parameters, confirms the assumption that it is a very strong factor (a unit increase causes a multiple increase in potential). In particular, the higher the water infiltration capacity, the higher the production potential.

In climatic region 1 (see Table A2 for details), a goodness of fit is again high (R-squared = 86.46%) and the statistical significance of the individual parameters has improved. With the exception of granularity and low infiltration capacity, all parameters are significant at the 5% significance level/α = 0.05/. Furthermore, all significant parameters have a positive effect on production potential. In particular, a unit increase in porosity increases the potential by about 0.6 units, a unit increase in retention increases the potential by about 0.09 units, and the hydrological components of the soil increase the potential by about 18 units for high infiltration capacity and by about 13 units for medium infiltration capacity (all ceteris paribus (c.p.)).

Climatic region 2 (see Table A3 for details) is an outlier in terms of model goodness of fit and, at the same time, a significant outlier in the group of regions. This can possibly be explained by the highly specific composition of the soils in this region as well as by the relatively different climatic conditions, which, in combination with the different soil structure, causes non-standard behaviour of the specified variables. This conclusion is supported in particular by the outputs of the statistical verification of the model, where the variation of dependent variable is explained only from 23.5 % by the variations of independent variables and only two estimated parameters are significant, exclusively in the form of high- or medium-level soil hydrological components. Another peculiarity is the intensity of the significant variables, which is at a much higher level. In this model, a unit increase in infiltration capacity is accompanied by an increase in production potential of about 21 units (for medium capacity) and about 41 units for high capacity, c.p.

In contrast, the model for climatic region 3 (see Table A4 for details) provides an estimate that is very reliable in terms of statistical verification compared to CR2. The model shows a high R-squared (86.84 %), and all parameters are statistically significant except for the constant/α = 0.05/. All estimated variables have a positive effect on the production potential, i.e., their increase will lead to an increase in the production potential. At the same time, climatic region 3 represents the region where the soil grain factor is statistically significant. Specifically, a unit increase in grain size would increase the potential by 2.34 units, c.p. A unit increase in porosity would increase the potential by 0.6 units, and a unit increase in retention would increase the potential by 0.08 units, all c.p. Like in previous cases, the highest unit increase is caused by the hydrological component of the soil, where, however, compared to the previous climatic regions, soils with low infiltration capacity are also significant. In terms of intensity, the effect on the production potential is proportional to the infiltration capacity, i.e., the higher the capacity the more intensively it can increase the assessed potential.

The model estimation for climatic region 4 (see Table A5 for details) achieves very similar results. The overall goodness of fit is high (R-squared = 85.77%) and there are a high number of statistically significant parameters. The grain size has dropped out, which is a slight difference from CR3. The direction of forcing and the strength of influence of the explanatory variables are again very similar to climatic region 3, and therefore it can only be generally summarised that all the explanatory variables have a positive effect on the production, and the highest unit effect is on soil hydrology at all infiltration levels.

The model for climatic region 5 (see Table A6 for details) provides very similar outputs, with the results being very similar to both CR3 and CR4 in terms of statistical and substantive logic. R-squared is 86.61%, and all covariates (including grain size) are shown to be highly statistically significant. At the same time, we can conclude that the effects of the included variables are again in line with the assessment of CR3 and CR4. Even the model for climatic region 6 (detailed in Table A7) builds on previous outputs with consistent results. The model shows high goodness of fit with R-squared equal to 88%. In terms of parameter significance, all covariates except for granularity explains production potential. The structure of the influence of the significant variables, i.e., their direction and intensity, is, as expected, broadly consistent with the results obtained for CR3, CR4 and CR5.

The model for climatic region 7 (see Table A8 for details) also continues to follow a very similar pattern of the previous models. The R-squared value is 86.47%, and the significant variables are porosity, all levels of soil hydrology, and retention. The effect on the explained variable is again very similar in principle (with slightly different intensities in all regions surveyed).

The model outputs for climatic region 8 (see Table A9 for details) start to deteriorate slightly compared to the other regions, but the consistency of the estimated models is still statistically quite evident. In particular, there is a slight decrease in the tightness of dependency in the model to 83.99%, and only the porosity, retention and soil hydrological parameters at high and medium infiltration levels are statistically significant. When assessing a unit effect of the significant variables, the general scope is maintained, but there is a proportional decrease in the intensity of the positive effects on production potential.

The model for the last climatic region 9 (see Table A10 for details) confirms the low expectations on the estimate results. Due to the lower number of observations, the representation of specific soils and different climatic factors, the achieved outputs are already slightly different compared to other regions. The goodness of fit remains high (R-squared = 86.71%) and only the porosity and water infiltration capacity parameters are statistically significant at 5% significance level. The variables have again positive effect on the production potential; however, the intensity of the effect is lower as compared to other CRs.

Several partial conclusions can be drawn from the analysis. Primarily, it is evident that the proposed models provide very consistent outputs estimates, suggesting that they are correctly specified. Moreover, the estimated models across all climatic regions are consistent with substantively logical assumptions about the link between production potential and soil hydrological properties, which again confirms the relevance of the model approach. At this point, it is very difficult to discuss the achieved results with the outputs of the current literature. The analyzed land valuation system is relatively rare for a small group of European countries, and specifically in the conditions of the Czech Republic, it is made up of a decades-old structure of indicators. The basic purpose of the results is to point out the need to change the indicators used to value land, especially in relation to the ongoing climate changes. Unfortunately, there is no adequately relevant research available in this field of contemporary science, with which it would be possible to compare the achieved results in a discussion. In this regard, the paper explicitly responds to the requirements of the state administration towards the necessary modernization and offers outputs that have not been published by anyone else in the given area. In the literature review, a system for valuing land was characterized based on a set of rated units, which, however, currently do not sufficiently reflect changes in the climate and the corresponding necessary changes in land management. The subject of the research was the production potential in relation to soil retention, which although only represents a selected soil characteristic, has an explicit impact on the quality of the soil and the production potential derived from it. The latter is then a basic factor for the ability and quality of crop cultivation, which directly affects both the price of land as a production factor and the price of agricultural products in terms of the achieved output. In respect with these methodological and theoretical findings, it can also be concluded that soil hydrological parameters have a real influence on production potential, and it is therefore more than desirable to require in practice the compliance with the principles of good hydrological protection and soil care, as this statistically significantly increases soil potential and thus the economic effect from productive use. Moreover, the results suggest that hydrological care and soil protection have the greatest importance in the climatic regions which are classified as the most important production areas of the Czech Republic. Last but not least, another usable output of the achieved results is also the modification of the map of climatic regions (see Figure A1). However, the presented map has its origins in state administration institutions dating from around 1970. This is also why there was a clear demand for the modification of the documents for the definition of climatic regions, and thus for changes in the map. The basic indicator that should accurately document the mentioned changes is the production potential, which was the main subject of the estimated models, while the outputs demonstrate the suitability of conceptual changes in its use. Based on that, the necessity of a new definition of climatic regions and thus the restructuring of the original map base is evident.

The issues raised in this article are addressed by a number of authors, but from a slightly different perspective. These are mainly studies that examines the relationship between the irrigation and agricultural production, or the relationship between the declining water supply and increasing water demand, or focuses on shadow pricing of water in given regions [45–50].

In general, it is noticeable that some areas of the world experience periods of severe drought that have a negative impact on agricultural production. In the most affected areas, the possible introduction of water retention systems is an option to reduce water stress during drought periods while reducing flood potential during certain parts of the year [51]. However, it must be stressed that in some countries, there is an economically inefficient use of water resources that reduces groundwater supplies [47]. In the context of the complex water management, it is also necessary to distinguish between inflow and conveyed water [50]. The price of water plays a major role in improving of water allocation and also has an incentive effect to protect the scarce water resources or for higher productivity [52]. Research on water price is important to effectively address the water resource crisis, with agriculture having the greatest potential for water savings [53].

Several studies have shown the impact of climate change on conditions in Europe. The results show that significant changes in European summers have already occurred and are expected to intensify in the future, leading to widespread dry conditions that are more extreme in the south. If only the effect of precipitation is taken into account, the contrast between the wetter conditions in the north and the drier conditions in southern Europe is apparent [54–57].

4. Conclusions

One of the objectives of the paper was to verify the links between soil hydrological properties (especially retention) and the production potential of the main soil units in individual climatic regions of the Czech Republic using an econometric approach. At the same time, the task was to specify a theoretical model that could quantify this link in an exact way, so that the production potential could be quantified with respect to the soil retention capacity, which is the basis for determining the official price of land. Quantifying the impact of retention and other soil determinants on production potential has a number of desirable practical implications. Changes in average temperatures and precipitation are evident throughout Europe. Climate change is having a major impact on the distribution of climatic areas on the Czech Republic territory and on potential production of agriculture sector. The Czech Republic is currently in the process of adjusting its climate regions, as their original classification does not correspond to the actual values (especially temperature and precipitation, see Table 4). This makes it necessary to adjust the production potential of the individual ESEU codes to take into account the new climatic regionalisation. The policy implications can be summarised as follows: the property tax liability for agricultural operators may change, which also has an impact on public finances; at the same time, it may affect the allocation of subsidies, especially for areas with natural constraints (ANC).

In the current legislation, protection classes are set for individual soil blocks, precisely with regard to the level of production potential. These protection classes have a significant impact on spatial planning within municipal and urban areas, while soils with a high production potential can hardly be used for non-agricultural purposes, typically in the context of conversion to building land, etc. There are 5 classes of protection for agricultural land:

I. Class: the most valuable soils in individual climatic regions, mainly in flat or only slightly sloping areas, which can be withdrawn from the agricultural land fund only exceptionally, mainly for projects related to restoring the ecological stability of the landscape or for linear constructions of fundamental importance.
II. Class: agricultural soils which have above-average production capacity within individual climatic regions. In relation to the protection of agricultural land, these are highly protected soils, only conditionally withdrawable and, with regard to landscape planning, only conditionally developable.
III. Class: soils with average productive capacity and a medium degree of protection, which can be used for development in landscape planning.
IV. Class: soils with predominantly below-average productive capacity within the relevant climatic regions with only limited protection, usable for development.
V. Class: soils with very low productive capacity, including shallow, very sloping, hydromorphic, gravelly to stony soils and soils most vulnerable to erosion. These are mostly agricultural soils that are dispensable for agricultural purposes. More efficient non-agricultural use can be expected for these soils.

It is therefore clear that the determination of production potential and the resulting protection class plays a crucial role in landscape planning and regional development. Current practice has so far been to adopt enumeratively determined values of production potential; however, these are already highly outdated (often more than 20 years old) and do not correspond to changes in the landscape and geoclimatic development. Another relatively common problem is the lack of production potential values for newly created soil blocks or revaluated soil units. In both cases, this distorts or even halts the process of land development, but it is a necessary part of the changes taking place in the national economy. For similar purposes, the presented outputs can therefore be used with a high degree of success, providing a methodological apparatus for the exact quantification of production potential based on current (or preferred) soil properties or, in the latter case, allowing the estimation of the theoretical value of production potential for newly defined soil blocks.

It is also appropriate to draw attention to situations where soils may have low production potential, but at the same time are very valuable for a given location in terms of non-production potential (typically desirable flood water retention, etc.). For these purposes, further research can focus on shadow pricing in terms of retention, and thus also express the very important non-productive function of soils in the light of ongoing climate change.

This output can be a basic stepping stone for further adjustments or modifications of the model, taking into account other physical soil properties affecting production potential. It is also the basis for valuing soil retention using a shadow price approach.

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Appendix A

Table A1. SUR CR = 0, reg Prod_pot(bootstrap), source: own estimate.

Linear regression						
Number of obs. = 41						
Replications = 50						
Wald chi2 (6) = 281.30						
Prob > chi2 = 20.0000						
R-squared = v0.8865						
Adj R-squared = 0.8664						
Root MSE = 7.8294						
	Observed	Bootstrap		Normal-based		
Prod_Pot_	Coef.	Std. Err.	z	P > |z|	[95% Conf. Interval]	
Granularity	1.257106	1.910761	0.660	0.511	−2.487916	5.002129
Porosity	0.6782325	0.1116133	6.080	0.000	0.4594744	0.8969906
HSC_A	18.94964	9.837508	1.930	0.054	−0.3315221	38.2308
HSC_B	13.08379	5.40563	2.420	0.016	2.488955	23.67863
HSC_C	6.883012	5.656087	1.220	0.224	−4.202715	17.96874
Retention	0.0940297	0.0152583	6.160	0.000	0.064124	0.1239354
_cons	12.93851	10.02195	1.290	0.197	−6.704162	32.58118

Table A2. SUR CR=1, reg Prod_pot(bootstrap), source: own estimate.

Linear regression						
Number of obs. = 53						
Replications = 50						
Wald chi2 (6) = 311.64						
Prob > chi2 = 0.0000						
R-squared = 0.8646						
Adj R-squared = 0.8469						
Root MSE = 8.1559						
	Observed	Bootstrap		Normal-based		
Prod_Pot_	Coef.	Std. Err.	z	P > |z|	[95% Conf.	Interval]
Granularity	0.436529	1.355715	0.320	0.747	−2.220623	3.093681
Porosity	0.5865935	0.1219016	4.810	0.000	0.3476707	0.8255163
HSC_A	18.44326	7.520886	2.450	0.014	3.702598	33.18393
HSC_B	12.79214	4.30768	2.970	0.003	4.349246	21.23504
HSC_C	8.276861	4.591135	1.800	0.071	−0.7215978	17.27532
Retention	0.0886133	0.016802	5.270	0.000	0.055682	0.1215446
_cons	14.1677	6.951538	2.040	0.042	0.5429328	27.79246

Table A3. SUR CR=2, reg Prod_pot(bootstrap), source: own estimate.

Linear regression						
Number of obs. = 64						
Replications = 49						
Wald chi2 (6) = 94.24						
Prob > chi2 = 0.0000						
R-squared = 0.2350						
Adj R-squared = 0.1544						
Root MSE = 26.0131						
	Observed	Bootstrap		Normal-based		
Prod_Pot_	Coef.	Std. Err.	z	P > |z|	[95% Conf.	Interval]
Granularity	9.556196	6.915536	1.380	0.167	−3.998006	23.1104
Porosity	0.1203967	0.4935385	0.240	0.807	−0.846921	1.087714
HSC_A	40.85582	17.84527	2.290	0.022	5.879732	75.8319
HSC_B	20.68173	7.153777	2.890	0.004	6.660581	34.70287
HSC_C	14.52052	9.308718	1.560	0.119	−3.724237	32.76527
Retention	0.0460241	0.0395272	1.160	0.244	−0.0314477	0.123496
_cons	7.914516	17.2866	0.460	0.647	−25.96659	41.79562

Table A4. SUR CR = 3, reg Prod_pot(bootstrap), source: own estimate.

Linear regression						
Number of obs. = 74						
Replications = 50						
Wald chi2 (6) = 555.20						
Prob > chi2 = 0.0000						
R-squared = 0.8684						
Adj R-squared = 0.8566						
Root MSE = 7.9989						
	Observed	Bootstrap		Normal-based		
Prod_Pot_	Coef.	Std. Err.	z	P > |z|	[95% Conf. Interval]	
Granularity	2.340792	1.187777	1.970	0.049	0.0127913	4.668793
Porosity	0.6188024	0.1010675	6.120	0.000	0.4207139	0.816891
HSC_A	27.75406	6.716169	4.130	0.000	14.59061	40.91751
HSC_B	18.63752	3.984225	4.680	0.000	10.82859	26.44646
HSC_C	14.34763	4.158505	3.450	0.001	6.197108	22.49815
Retention	0.0812278	0.0130261	6.240	0.000	0.0556971	0.1067585
_cons	9.830487	5.843231	1.680	0.092	−1.622035	21.28301

Table A5. SUR CR=4, reg Prod_pot(bootstrap), source: own estimate.

Linear regression						
Number of obs. = 65						
Replications = 50						
Wald chi2 (6) = 384.41						
Prob > chi2 = 0.0000						
R-squared = 0.8577						
Adj R-squared = 0.8430						
Root MSE = 7.4282						
	Observed	Bootstrap		Normal-based		
Prod_Pot_	Coef.	Std. Err.	z	P > |z|	[95% Conf. Interval]	
Granularity	1.867402	1.027967	1.820	0.069	−0.1473764	3.882181
Porosity	0.5492881	0.0797734	6.890	0.000	0.3929352	0.705641
HSC_A	22.4612	5.309397	4.230	0.000	12.05497	32.86743
HSC_B	12.09717	3.552524	3.410	0.001	5.13435	19.05999
HSC_C	10.31714	3.443211	3.000	0.003	3.568574	17.06571
Retention	0.0807939	0.0112907	7.160	0.000	0.0586645	0.1029233
_cons	9.596183	5.065899	1.890	0.058	−0.3327964	19.52516

Table A6. SUR CR=5, reg Prod_pot(bootstrap), source: own estimate.

Linear regression						
Number of obs. = 67						
Replications = 50						
Wald chi2 (6) = 675.81						
Prob > chi2 = 0.0000						
R-squared = 0.8661						
Adj R-squared = 0.8528						
Root MSE = 7.6480						
	Observed	Bootstrap			Normal-based	
Prod_Pot_	Coef.	Std. Err.	z	P > |z|	[95% Conf. Interval]	
Granularity	2.764695	1.09802	2.520	0.012	0.6126161	4.916774
Porosity	0.51342	0.0758189	6.770	0.000	0.3648178	0.6620222
HSC_A	28.68111	5.887361	4.870	0.000	17.1421	40.22013
HSC_B	17.09947	4.222617	4.050	0.000	8.823288	25.37564
HSC_C	12.25322	4.383512	2.800	0.005	3.66170	20.84475
Retention	0.0777999	0.0118941	6.540	0.000	0.0544878	0.1011119
_cons	5.231818	5.352544	0.980	0.328	−5.258976	15.72261

Table A7. SUR CR=6, reg Prod_pot(bootstrap), source: own estimate.

Linear regression						
Number of obs. = 55						
Replications = 50						
Wald chi2 (6) = 574.84						
Prob > chi2 = 0.0000						
R-squared = 0.8800						
Adj R-squared = 0.8650						
Root MSE = 7.4968						
	Observed	Bootstrap			Normal-based	
Prod_Pot_	Coef.	Std. Err.	z	P > |z|	[95% Conf. Interval]	
Granularity	1.815334	1.291262	1.410	0.160	−0.7154937	4.346161
Porosity	0.5642998	0.0844904	6.680	0.000	0.3987017	0.729898
HSC_A	25.31264	7.226343	3.500	0.000	11.14927	39.47601
HSC_B	15.07666	4.582874	3.290	0.001	6.094388	24.05893
HSC_C	10.63730	4.300475	2.470	0.013	2.208522	19.06608
Retention	0.0740525	0.0145355	5.090	0.000	0.0455634	0.1025415
_cons	10.26998	6.868558	1.500	0.135	−3.192151	23.7321

Table A8. CR=7, reg Prod_pot(bootstrap), source: own estimate.

Linear regression						
Number of obs. = 56						
Replications = 50						
Wald chi2 (6) = 505.90						
Prob > chi2 = 0.0000						
R-squared = 0.8647						
Adj R-squared = 0.8482						
Root MSE = 7.1687						
	Observed	Bootstrap			Normal-based	
Prod_Pot_	Coef.	Std. Err.	z	P > |z|	[95% Conf. Interval]	
Granularity	2.241771	1.250111	1.790	0.073	−0.2084011	4.691944
Porosity	0.4651339	0.0868724	5.350	0.000	0.2948672	0.6354007
HSC_A	29.24092	7.27305	4.020	0.000	14.986	43.49583
HSC_B	18.54992	5.269801	3.520	0.000	8.221301	28.87854
HSC_C	12.43798	4.936449	2.520	0.012	2.762718	22.11324
Retention	0.0627546	0.0122939	5.100	0.000	0.0386589	0.0868503
_cons	6.295129	6.477444	0.970	0.331	−6.400429	18.99069

Table A9. SUR CR=8, reg Prod_pot(bootstrap), source: own estimate.

Linear regression						
Number of obs. = 36						
Replications = 49						
Wald chi2 (6) = 386.51						
Prob > chi2 = 0.0000						
R-squared = 0.8399						
Adj R-squared = 0.8068						
Root MSE = 7.6270						
	Observed	Bootstrap			Normal-based	
Prod_Pot_	Coef.	Std. Err.	z	P > |z|	[95% Conf. Interval]	
Granularity	1.373544	1.605578	0.860	0.392	−1.773332	4.520419
Porosity	0.3916553	0.0957329	4.090	0.000	0.2040223	0.5792883
HSC_A	25.90095	7.698021	3.360	0.001	10.81311	40.9888
HSC_B	18.80815	5.791104	3.250	0.001	7.457793	30.1585
HSC_C	11.17213	5.790087	1.930	0.054	−0.1762279	22.5205
Retention	0.0574769	0.016899	3.400	0.001	0.0243555	0.0905982
_cons	8.322698	7.541953	1.100	0.270	−6.459258	23.10465

Table A10. SUR CR=9, reg Prod_pot(bootstrap), source: own estimate.

Linear regression						
Number of obs. = 25						
Replications = 46						
Wald chi2 (6) = 268.35						
Prob > chi2 = 0.0000						
R-squared = 0.8671						
Adj R-squared = 0.8228						
Root MSE = 7.2739						
	Observed	Bootstrap		Normal-based		
Prod_Pot_	Coef.	Std. Err.	z	P > |z|	[95% Conf. Interval]	
Granularity	0.341074	2.575923	0.130	0.895	−4.707641	5.38979
Porosity	0.275774	0.1034242	2.670	0.008	0.0730663	0.4784816
HSC_A	29.39995	8.945681	3.290	0.001	11.86673	46.93316
HSC_B	20.69848	6.587195	3.140	0.002	7.787815	33.60915
HSC_C	11.10779	5.384854	2.060	0.039	0.5536684	21.66191
Retention	0.0555235	0.028923	1.920	0.055	−0.0011645	0.1122115
_cons	10.27807	13.41451	0.770	0.444	−16.01389	36.57002

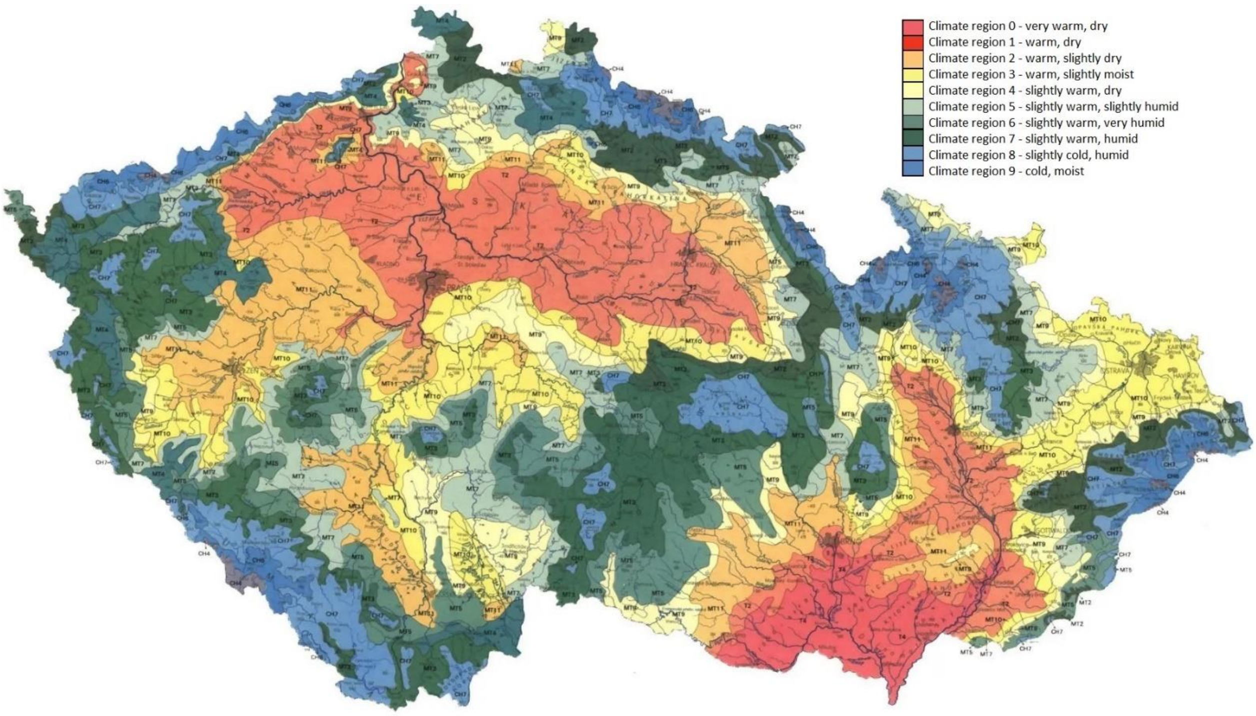

Figure A1. Maps of climatic regionalization of the Czech Republic.

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