Romanian Biotechnological Letters *Vol. 23, No. 2, 2018*
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ORIGINAL PAPER

Using Spatial and Seasonal Panel Model to Determine Impact of Climatic Factors on Maize Yields in Serbia

Received for publication, May, 16, 2015
Accepted, September, 12, 2017

JOVAN ZUBOVIĆ[1*], MARKO JELOČNIK[2], ALEKSANDAR ZDRAVKOVIĆ[1], JONEL SUBIĆ[2], SLAVICA RADOVANOVIĆ[3]
[1] *Institute of Economic Sciences, Zmaj Jovina Street no. 12, Belgrade, Serbia*
[2] *Institute of Agricultural Economics, Volgina Street no. 15, Belgrade, Serbia*
[3] *Republic Hydro-meteorological Service of Serbia (RHMSS), Kneza Višeslava Street no. 66, Belgrade, Serbia*
***Address for correspondence to:** jovan.zubovic@ien.bg.ac.rs*

Abstract

Maize production significantly contributes to the growth in crop production and Serbian agriculture in general. The climate in Serbia can be described as temperate continental, which favourably affects the output of crop production lines. However, temporal and spatial distribution of precipitation is uneven. According to the projections of global climate changes in the region of Southern Europe (increase in air temperatures, prolonged heat waves, decrease in precipitation and intensive droughts), crop producers could expect increased damage to their plants. The main goal of the paper is to evaluate the impact of climate factors on maize yields in Serbia, by substituting the irrigation effects with empirical longitudinal panel data on different climatic conditions (temperature, rainfall and extra-terrestrial radiation), altitudes and share of maize in the total arable land of selected municipalities. The research led us to conclusions: water shortage is statistically significant in the second phenophase; irrigation of arable land at altitudes above 200 m does not result in growth of average maize yield; the growth of temperature by 1° C above 30° C during the vegetative period results in decrease of maize yields; 1 mm increase in water deficit in phenophase 2 leads to reduction in maize yields; increase in planted acreage by one percentage point results in reduction in maize yield per hectare.

Keywords: maize, Serbia, climate factors, yields, longitudinal data model.

1. Introduction

Maize is a highly ranked cereal plant (beside wheat and rice) worldwide, given the sown areas, produced quantities and achieved yield per unit of the production area. Besides being consumed by humans and used for animal feed, technological development introduced it as an irreplaceable raw material in the production of over 1,500 different products. Reaching high and stable yields is not feasible in the conditions of water deficit in the soil. Therefore, fresh, chemically and bacteriologically clean water can be indicated as the inevitable factor for primary agriculture, since it is an essential element of growth and development process of all plants.

A study by WMO (ALCAMO & al., [1]) indicates that in the region of Southern Europe, in addition to the increase of air temperature, reduced water resource availability may be expected in the future. The impact of climatic changes on the reduced crop yields has been confirmed by several studies (GIANNAKOPOULOS & al., [10]; MORIONDO & al., [22]; KREIENKAMP & al., [19]).

The aim of this paper is to examine the impact of evapotranspiration levels on a maize yield in different phenophases. To some extent, spatial effects have been researched by STEVANOVIĆ & al., [34], who differentiates three clusters with 3 subclasses of spatial effects in Serbia, with respect to climate impact on maize production. CAI & al., [4] conducted a similar research on the impact of spatial variations. According to their research, the variation is very large when determining the relationship between the weather and maize yields. However, in this paper we apply a rather different approach, using panel data on crop yields, precipitation and share of maize in the total arable land across municipalities, grouped with respect to altitude. This paper is structured into five sections. After the introductory remarks, the second part deals with theoretical background on maize production and the impact of rainfall. The third part gives a detailed explanation of the applied econometric model, while the fourth one presents the obtained results and discussion. Conclusions and recommendations are summarized at the end of the paper.

Theoretical background

Maize is of great importance for Serbia in providing national food security. Moreover, it has a high impact on foreign trade of agricultural and food products, as well as on development of certain economic sectors. Throughout the modern history, along with changes in the economy, maize significantly affected the changes of the structure of sown areas in Serbia. The increase of production and achieved yields per ha have transferred maize from the group of deficient to the group of traditionally sufficient products (STEVANOVIĆ, [33]). In the recent years, the areas sown by maize have stabilized to around 1.2 million ha (GRS, [12]), representing over 35% of total arable land. According to FAO (FAOSTAT, [9]), in the previous five-year period, production and average yields were significantly varying, primarily due to weather conditions (drought). Average yields ranged from 2.8 to 5.9 t/ha, while the total production ranged from 3.5 to 7.2 million tons. Although maize production in Serbia in 2013 represented only around 0.6% of total world production, the fact that Serbia is a regional leader in the maize production should not be overlooked.

Maize can be rightfully considered as an export trump card of Serbian agriculture, with a high share in GDP, and significant share in foreign trade. According to the Statistical office of Republic of Serbia (SORS, [30]) data, the value (quantity) of Serbian maize export dropped in 2013 to 211 mil USD (0.8 mil tons), relative to export value (quantity) of 568 mil USD (0.8 mil. tons) in 2012. Consequently, the share of maize export in total value of Serbian agricultural export dropped from 22% in 2012 to only 8% in 2013. The export contraction of exported maize quantity in 2013 was directly caused by drought, and the presence of significantly higher level of aflatoxins than allowed.

The climate in Serbia is temperate continental, with some local variations in mountain areas with continental climate. Temporal and spatial distribution of precipitation is uneven. Annual average is 673 mm, with spatial distribution ranging from 535-1,000 mm (IAE, [14]). Larger part of Serbia has a continental precipitation regime, with a higher volume of rainfalls in the warmer half of the year (the rainiest is June). About 120-150 days register precipitation over 0.1 mm. Normalized deviations of annual and especially summer quantities of precipitation indicate frequent rainfall deficits of growing intensity during the last decade. More often, the presence of heat waves with increased length initiates more frequent droughts with more expressed intensity. Projections of climate changes indicate a further increase in air temperatures and decrease in precipitation in the region of Southern Europe (IPCC, [15]), which will initiate a general decrease in yields in Serbia by up to 27% (RHMSS, [26]).

Plants' needs for water are determined by the quantity of water required to satisfy the loss of water through evapotranspiration of a healthy plant grown under the environmental conditions, not limited by soil conditions, presence of water and nutrients (PRSKALO, [24]). Therefore, the water loss during the process of evapotranspiration can be compensated by precipitation, irrigation or water reserves within the land complex. For the Serbian climate, water requirements in maize production in average are: in April, 50 mm, May, 75 mm, June, 90 mm, July, 100 mm, August, 95 mm, September, 80 mm, or for complete vegetation period, 490 mm (GLAMOČLIJA, [11]). From the aspect of water demand, critical phases in the maze development were identified as: stem elongation, tasselling, silking, flowering and grains filling.

Reduced rainfall and prolonged heat periods in recent decades continuously tend to decrease maize yields at the same time. The main cause of drought in this region is an unfavourable distribution of rainfall during the growing season. The total amount of rainfall has fallen below 300 mm (DRAGOVIĆ, [7]), which is not sufficient to maintain optimum production. According to Kresović and associates, Serbia is facing a rigid change in climate with increasing drought and therefore it is necessary to evaluate the agronomic impacts of changes in rainfall (KRESOVIĆ & al., [20]). Dragović shows in his study that average water requirement for maize is approximately 500 mm and that irrigated maize produced larger yields by 40% on average (DRAGOVIĆ, [8]).

Several studies have been conducted on a national and regional level (SMIATEK & al., [29]; VIDAL & WADE [35]; KOSTOPOULOU & al., [18]; RAJOVIĆ, [25]; KING & al., [16]). It has been confirmed in all of these studies that climatic changes and reduced rainfalls significantly reduce maize yields. However, the largest yield reductions are expected in the area of Southern Europe in spring-sown crops: maize, sunflower and soybean (GIANNAKOPOULOS & al., [10]). This region will suffer from increased incidents of heat waves and droughts without possibilities for effectively shifting crop cultivation to other parts of the year (OLESEN & al., [23]). Cai and associates use an econometric model to determine the impact of precipitation and irrigated ratio on crop yield (CAI, & al., [3]). Econometric models were used to measure the significance of the impact of irrigation on the yield in work by Klocke and associates (KLOCKE & al., [17]). In this study they modified the methodology of Cai and associates (CAI & al., [3]) to analyse the impact of weather conditions and irrigation on crop yields.

In Serbia, a comprehensive comparative analysis of long-term spatial and seasonal impact of changed climatic factors on maize yields has not been carried out. Most of the research has focused on irrigation effects which are variable. The greatest impact of irrigation is in extremely dry years. According to Dragović, yields in irrigated fields have grown 2-3 times as much, as compared to naturally grown crops (DRAGOVIĆ, [6]). However, in years with favourable rainfalls the effects of irrigation are reduced (MAKSIMOVIĆ & al., [21]). In this paper, we try to evaluate the impact of climate factors on maize yields by substituting the irrigation effects with empirical longitudinal panel data on different climatic conditions (temperature, rainfall and extra-terrestrial radiation), altitudes and share of fields under maize in total arable land of selected municipalities.

2. Materials and Methods

In this paper, we use panel data that covers 14 Serbian municipalities over the 15-year period (1997-2011). We use stratified random sample of municipalities with respect to climate conditions, altitude and territorial dispersion, to ensure its representativeness. The annual data on crops yields and share of maize plants in arable lands are obtained from the Statistical Office of the Republic of Serbia (SORS, [31]) database. Republic Hydro-meteorological Service of Serbia (RHMSS) supported our research and provided the daily data on maximal and minimal temperature, precipitation, extra-terrestrial radiation, evapotranspiration (ETo), including corrective coefficient for maize (RHMSS, [28]). The list of municipalities with selected indicators is presented in Table no. 1.

Table 1. Selected municipalities and indicators (2011)

Group	Municipality	Representative altitude (in m)	Share of maize (in %)	Average yield (in kg)
up to 100 m	Negotin	42	9.6	3,935
	Zrenjanin	80	36.7	5,649
	Kikinda	81	45.0	6,890
	Sremska Mitrovica	81	52.9	5,133
	Alibunar (Banatski Karlovac)	89	23.8	3,285
100-200 m	Subotica (Palić)	102	50.1	5,989
	Loznica	121	35.2	3,681
	Ćuprija	123	26.7	4,549
	Zajecar	144	13.9	3,128
	Kragujevac	197	15.9	3,584
200-300 m	Kraljevo	215	12.1	4,637
	Leskovac	230	21.8	3,034
over 300 m	Požega	310	12.0	3,357
	Vranje	432	7.2	2,856

Source: According to received data (SORS, [31] and RHMSS, [28]).

We analysed the impact of temperature and the presence of water, which are main determinants of evapotranspiration, in the soil on the maize yield, using the fixed-effects regression model (subscript *i* refers to municipality, and *t* refers to year)

$$Y_{i,t} = \alpha + X_{i,t}\beta + Z_{i,t}\gamma + W_{i,t}\delta + \eta_i + \varepsilon_{i,t} \tag{1}$$

With the following notation of variables: $Y_{i,t}$ – average maize yield in kilos per hectare[1]; $X_{i,t}$ – measures of excess temperature; $Z_{i,t}$ – measures of soil water deficit per phenophases; $W_{i,t}$ – control variables; η_i – fixed effect of municipality *i*; $\varepsilon_{i,t}$ – random error, $\varepsilon_{i,t} \sim N(0, Df^2)$.

We consider two variables as the measures of excess temperature in the vegetation period (VP), (from 20/04 till 30/09): *Over30* and *HW*. Variable $\mathrm{Over30}_{i,t}$ measures aggregately, for the whole period of vegetation, at which amount maximal daily temperatures $\mathrm{maxdt}_{i,t;j}$ were exceeding 30 degrees of Celsius. It is computed according to the formula:

$$Over30_{i,t} = \sum_j I_{i,t;j}(maxdt_{i,t;j} - 30), \begin{Bmatrix} I_{i,t;j} = 1, maxdt_{i,t;j} > 30 \\ I_{i,t;j} = 0, maxdt_{i,t;j} \leq 30 \end{Bmatrix}; \; j \in VP \tag{2}$$

Hot wave (HW) - *k*, of length (in days) $l_{i,t;k}, l_{i,t;k} \geq 5$ is defined as a period in which, for at least 5 consecutive days maximal daily temperatures were exceeding 30 degrees, $maxdt_{i,t;j} > 30$ Variable $\mathrm{HW}_{i,t}$ counts the number of non-overlapping hot waves within the vegetation period, weighted by their lengths according to the following weighting scheme:

$$HW_{i,t} = \sum_k q_{i,t;k}, \qquad q_{i,t;k} = \begin{Bmatrix} 1, l_{i,t;k} = 5 \\ 1 * (l_{i,t;k} - 5), l_{i,t;k} > 5 \end{Bmatrix}; \; l_{i,t;k} = 5,6, \ldots; k = 1,2, \ldots \tag{3}$$

With these two measures we strived to encompass the overall impact of extremely high temperatures (variable *Over30*), but also the length of the period in which the recorded temperatures were extremely high (variable *HW*). By doing that, we take into account the possibility that maize yield may be differently affected if extremely high temperatures are

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[1] Elimination of impact of higher yields achieved on farms with an implemented irrigation system in maize production on average yields recorded by SORS is based on the fact that irrigated surfaces under maize in Serbia are on the level of statistical error. In other words, according to the Chamber of Commerce and Industry of Serbia (CCIS, [5]) and the Statistical Office of the Republic of Serbia (SORS, [32]), irrigation systems in function cover slightly more than 1% of available agricultural surfaces. Within the structure of irrigated surfaces, more than 36% of them are under cereals and silage maize.

moderately diversified over the whole period or concentrated in a couple of hot waves. Measures of the water deficit are defined for each phenophase *m*, *m*=1,…,4. The total water deficit $ff^m_{i,t;j}$ in m^{th} phenophase is computed as a sum of differences between daily potential evapotranspiration $et^{m,r}_{i,t}$ and daily real evapotranspiration $et^{m,r}_{i,t}$, $\Delta et^m_{i,t} = et^{m,p}_{i,t} - et^{m,r}_{i,t}$, with respect to the length of given phenophase l^m, according to the equation:

$$ff^m_{i,t;j} = \sum_j^{l^m} \Delta et^m_{i,t;j} \tag{4}$$

Potential and real evapotranspiration are calculated according to Hargreaves' formula[2]. As the water deficit for given phenophase is an aggregate measure, and the lengths of phenophases are different, we averaged all $ff^m_{i,t}$ with respect to the length of phenophase:

$$\overline{ff^m_{i,t}} = ff^m_{i,t}/l^m \tag{5}$$

Among possible control variables we chose the soil moisture saturation on the sowing day (20/04) -$ff^0_{i,t}$, the share of maize planted acreage in total arable land $P_{i,t}$, as well as the change of maize planted acreage $\Delta P_{i,t}$. The soil moisture saturation $ff^0_{i,t}$ is computed as the ratio of a soil water content on the sowing day $\omega^0_{i,t}$ and the field water capacity $\omega^*_{i,t}$.

$$ff^0_{i,t} = {\omega^0_{i,t}}/{\omega^*_{i,t}} \tag{6}$$

The rationale of applying this variable lays in an expectation that higher water content on the sowing day (if not excessive) can boost the growth of maize. The relationship between the maize yield and the share of maize planted acreage $P_{i,t}$ can be argued to be positive (both share of maize plants and the average maize yield should be higher if the land is suitable for maize planting), but also negative (planting at the margins of arable land can lower the average yield).

Municipality's altitude Lt_i is a time-invariant variable which has an impact on the maize yield and is also picked by an estimation of fixed-effect η_i. However, the impact of altitude is a subject of particular interest in our research, so we defined dummy variable Alt_i based on grouping municipalities with respect to altitude in four ranges:

$$Alt_i = \left\{ \begin{matrix} 1; Lt_i < 100 \\ 2; 101 \leq Lt_i < 200 \\ 3; 201 \ \leq Lt_i < 300 \\ 4, Lt_i \geq 300 \end{matrix} \right\}$$

This is in line with our sampling procedure, as we stratified the population of maize-planted municipalities, with respect to the previous classification of altitudes. Municipalities are randomly selected from stratums, proportionally to the share of each stratum in population. We use variable Alt_i to estimate the pooled panel data regression model as a benchmark to the fixed-effects model. In addition, we estimated four particular fixed-effects models for each altitude range Alt_i, to examine if the differences in the impact of explanatory variables on the maize yield exist across altitudes. It has to be mentioned that yield potential

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[2] Although FAO, as a standard for the calculation of the referent evapotranspiration (ETo), considers Penman-Monteith model (FAO56-PM), national Hydro-meteorological Service applies a somewhat simpler Hargreaves model for the operational purposes, where daily calculations are based on maximal, minimal and average daily temperatures, as well as on extra-terrestrial solar radiation and the length of daylight for the given locality. The calculated ETo, corrected by an appropriate coefficient for an observed crop, can be used for a daily assessment of the missing quantity of water in irrigation of a certain crop (RHMSS, [27]).

of certain maize hybrid, crop infectivity, land quality, applied agro-techniques, application of chemicals etc. in the established model are observed as time-invariant factors, encompassed by the estimation of fixed effects. Limitations of the research are the following:

- We didn't take into account the fact that different FAO maturity groups are seeded across municipalities in our sample. As data for this variable are not available, we use FAO group 600 as the most typical seed group in Serbia[3].
- We used the most general definition of phenophases (for FAO group 600), as a vegetative period of maize is generally divided into next 4 phenological stages (BEZDAN, [2]): 1) emergence - germination (from sowing - 20th April to 1st May); 2) vegetative up-growth (1st May – 15th July); 3) flowering and fertilization (15th July – 5th August); and 4) grain filling period and maturation (5th August – 30th September). Of course, phenophases can have different starting and ending dates, with respect to the particular climate conditions of a given year and municipality.

3. Results and discussion

By specifying a model (1) with fixed-effects, we eliminated an unobserved heterogeneity as a possible issue of panel data analysis. Yet, possible presence of endogeneity and high co-linearity in the data may influence the precision and reliability of the estimation. We tried to handle co-linearity by testing the robustness of estimates, examining the marginal changes in the values of estimated regression coefficients and R-squared instigated by adding and omitting explanatory variables. On the other hand, possible endogeneity in the model remains a limitation in our research. Table no. 2 shows correlation matrix of all regressors in the model. Coefficients of correlation, as expected, confirm the presence of high co-linearity among the regressors where the dynamic is driven by temperature, especially between the soil moisture saturation and water deficit in phenophase 1 (-0.9), as well as measures of the excess temperature HW and Over30 (0.88).

Table 2. Correlation Matrix of Regressors

	HW	**Over30**	**ff1_avg**	**ff2_avg**	**ff3_avg**	**ff4_avg**	**ff0**	**ΔP**	**P**
HW	1								
Over30	0.8823	1							
ff1_avg	0.4507	0.5537	1						
ff2_avg	0.5945	0.6499	0.7258	1					
ff3_avg	0.6808	0.7201	0.4859	0.5735	1				
ff4_avg	0.6298	0.6462	0.4696	0.6181	0.5665	1			
f0	-0.2835	-0.3735	-0.9045	-0.5848	-0.2533	-0.383	1		
ΔP	-0.1859	-0.15	-0.123	-0.1082	-0.1544	-0.1025	0.1311	1	
P	-0.1977	-0.1469	0.0126	-0.1369	-0.2013	-0.1604	0.0352	0.2113	1

Source: Calculated according to the received data (SORS, [31] and RHMSS, [28]).

Model (1) was estimated in several variations, in order to test the robustness of the estimated parameters under the presence of high co-linearity. The results indicated that variables *Over30* and the water deficit in phenophase 2 have the most stable coefficients and also the highest contribution in explaining the maize yield variability. Moreover, the results

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[3] It should be mentioned that hybrids from FAO maturity group 600 covered the largest part of production surfaces in former Yugoslavia (HUSIĆ & al., [13]). Currently, the situation in Serbia is generally the same, as hybrids from late FAO maturity groups (600 and 700) have also been dominant (mostly in lowlands and terrains with altitude up to 300m), (VITIĆ, [36]).

suggest the removal of variables *HW* and *P* from the final specification of the model due to the following reasons:

- Variable *HW* (hot waves counter) exhibits a negative impact on the maize yield as expected, when the model is estimated without the second measure of excess temperature *Over30*; nevertheless, in all versions of the estimation where variable *Over30* is included, the estimated impact of *HW* is positive (probably due to high co-linearity) and inferior to the impact of *Over30*, when contributions of both excess temperature variables in explaining variability of dependent variable are directly compared.
- Variable *P* (share of maize planted acreage in total arable land) in each of estimated versions of the model does not exhibit a statistically significant impact on the dependent variable, and it is also uncorrelated to other regressors.

Estimations of the model (1), with gradual adding of variables, are given in Table no. 3.

Table 3. Estimation Results

Variable	**Fixed Effects**				**Pooled**
	1	**2**	**3**	**4**	
Over30	-10.9957***	-9.0855***	-9.0905***	-9.5931***	-9.3094***
	(1.3569)	(1.6490)	(1.6723)	(1.7669)	1.8445
ff2_avg	-351.8955***	-313.8826***	-314.6448***	-342.6045***	-392.8897***
	(96.2005)	(97.2598)	(104.7584)	(109.4722)	(124.9833)
ff3_avg		-155.8883**	-156.6503**	-167.1058*	-186.3139*
		(77.8012)	(86.8764)	(87.7275)	(96.6131)
ff1_avg			6.2301	51.4668	237.8708
			(312.3773)	(316.7141)	(337.6342)
ff4_avg				79.4967	83.9852
				(89.7459)	(104.2467)
ff0	9.3396**	10.95184**	11.1423	12.7349	18.8644
	(4.5372)	(4.5705)	(10.5906)	(10.7485)	(11.8712)
ΔP	-34.4654***	-36.49929***	-36.5154***	-36.6676***	-31.2445**
	(10.6792)	(10.6379)	(10.6990)	(10.7069)	(12.5063)
Lat					-406.3888***
					(60.5323)
Const	5209.5***	5327.3***	5311.5***	5105.1***	5471.8***
	(467.4)	(467.2)	(924.5)	(953.9)	(1109.1)
R Sq	0.7183	0.7246	0.7246	0.7258	0.5863
R Sq adj	0.6913	0.6964	0.6947	0.6943	0.5685

Source: Calculated according to the received data (SORS, [31] and RHMSS, [28]).
Note: Standard errors in the parenthesis. Levels of significance: * p<0.1, ** p<0.05, *** p<0.01

The first four columns give an estimation of a fixed-effects model, while the last column provides the results of a pooled estimation with an altitude dummy to explicitly shed the light on the impact of altitude on the maize yield. All versions of the estimated models give high values of both R-squared and R-squared adjusted. Regardless of the version, the coefficients for variables *Over30*, *ff1_avg* and ΔP are stable, significant for relevant levels of significance and can be interpreted as follows (interpretations are illustrated using the estimations from version 4 of FE model):

- temperature growth of one degree Celsius, on the day in which the temperature is exceeding 30 degrees (within the vegetative period of maize) implies around 9.6 kg decrease in maize yield per hectare;
- daily increase in the water deficit in phenophase 2 by 1 mm leads to around 342.6 kg decrease in maize yield per hectare;

- increase in maize planted acreage for one percentage point leads to around 36.7 kg decrease in maize yield per hectare; this can be explained by a conjecture that lower maize yield on marginal arable land diminishes the average yield.

The water deficit in phenophase 3 also exhibits a stable and statistically significant impact on maize yield, but brings about a very small contribution to R-squared adjusted. The remaining explanatory variables, the water deficit in phenophase 1 and 4, are characterized by instable coefficients with disputable (positive) sign, statistically insignificant in all versions of the estimated model whenever *Over30* and *ff2_avg* are included (not presented in Table no. 3). Soil moisture saturation on the sowing day is a specific case, where the significance exhibited in the first two versions is lost after variable *ff1_avg* is included (again probably due to high co-linearity between *ff0* and *ff1_avg*), so that precise impact of variable *ff0* on maize yield remains an issue for further discussion. Finally, we estimate the pooled model equivalent to the final specification of the fixed-effects model, with explicit control of altitude impact on the maize yield. The estimated value of coefficient for an altitude range is expectantly negative and statistically significant.

Further analysis considers the differences in the level and the significance of regression coefficients with respect to the altitude of maize plants. We divided the total sample to four subsamples according to the altitude range *Alt*, and estimated separate regression equations by an FE estimator, as shown in Table no. 4.

Table 4. Estimation Results, Subsample Analysis

Variable	**FE**			
	Alt1	**Alt2**	**Alt3**	**Alt4**
Over30	-11.3494***	-6.1211*	-14.3652***	-7.7139*
	(3.2638)	(3.4214)	(3.9795)	3.9002
ff2_avg	-489.7054***	-440.375**	-9.1048	-18.6913
	(181.3053)	(208.7392)	(288.6733)	288.0021
ff3_avg	-137.2089	-486.8522**	135.5915	-225.0040
	(139.8649)	(190.7737)	(212.6039)	204.4558
ff1_avg	622.4805	409.4113	-710.6994	-140.8253
	(490.8902)	(692.6779)	(849.3849)	694.8570
ff4_avg	163.2819	88.0355	85.9999	-202.3924
	(150.3810)	(179.7364)	(198.0171)	197.8959
ff0	30.7525*	19.1659	-19.7726	10.6707
	(18.0039)	(23.3878)	(26.1684)	21.3614
ΔP	-7.7103	-27.6199**	-118.093***	-261.6932
	(25.0412)	(13.6000)	(37.0655)	182.2551
Const	3770.5**	5231.9**	6894.6***	4404.1**
	(1650.4)	(2054.7)	(2168.2)	(1850.1)
R Sq	0.7183	0.7246	0.7246	0.7258
R Sq adj	0.6913	0.6964	0.6947	0.6943
No of obs.	70	55	42	28

Source: Calculated according to the received data (SORS, [31] and RHMSS, [28]).
Note: Standard errors in the parenthesis. Levels of significance: * p<0.1, ** p<0.05, *** p<0.01

The results of the analysis indicate two important findings – that excess temperature is the only significant regressor regardless of the altitude range, while the significant impact of the water deficit on the maize yield disappears when maize is planted above 200 m. The water deficit in phenophase 2 rapidly slips away its size and significance at the altitude above 200 m. Besides, the change in maize planted acreage is significant only for the altitude range 100-300 m, while the estimated value of its regression coefficient is considerably higher for higher altitude ranges. The latter implies that in plains, where arable land is generally of higher quality, marginal increase in maize plants does not tackle the average yield, while in altitude range 200-300 m, the change in maize planted acreage for one percentage point decreases the average maize yield for 118 kg/ha. Ambiguous causality in relation between the soil moisture saturation on the sowing day and the maize yield pointed out in the total sample, is also detected in the subsample-based estimations. By summarizing the results of the subsample analysis, we can conclude that the impact of the water deficit on the maize yield fades with the increase in altitude. In addition, agricultural effectiveness of the current size of maize plants at higher altitude ranges is also disputed, as the analysis shows that small marginal decrease in maize planted leads to a tangible increase in an average maize yield.

4. Conclusion

In order to determine the impact of climatic factors on maize yields in Serbia, spatial and seasonal panel model was used that covers 14 municipalities in Serbia over a 15-year period. Among several findings derived from the established model, the following can be emphasized: statistically significant impact on maize yields is achieved by water deficit in the second phenophase; within the vegetative period of maize, temperature growth for 1 °C, during the days in which temperature exceeds 30 °C, can cause a decrease in yield by almost 10 kg/ha; during the second phenophase, daily increase in water deficit by 1 mm can lead to yield reduction for more than 340 kg/ha; implementation of irrigation, as an agro-technical measure on the used arable land at the altitudes above 200 m will not contribute to the growth of maize yield; and 1% increase of sowed surfaces under maize can result in yield reduction by almost 37 kg/ha.

According to the obtained results, the research can be continued in the direction of finding the optimal measure/instrument for decreasing the present risk of rainfall deficiency in maize production. Potential measures are recognized in the implementation of irrigation systems, crop insurance, or the use of precipitation weather derivatives. Furthermore, our research approach can be further exploited in several ways. First, it would be interesting to conduct a similar research in the countries or geographical units that have similar climatic and agricultural characteristics to Serbia, such as Romania, Croatia and Uruguay, or some continental parts of China and France. Second, our approach can be applied in the analysis of other crops. Third, it can be incorporated as an element of the wider methodology for a financial cost-benefit analysis of irrigation, as it allows the calculation of the most likely increase in quantity of maize plants as a result of decrease in water deficiency due to irrigation.

5. Acknowledgements

The paper is a part of projects III 46006, 179001 and 179015 funded by the Ministry of Education, Science and Technological Development of the Republic of Serbia, for the project period 2011-2017.

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