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Estimating impact of weather factors on wheat yields by using panel model approach — The case of Serbia

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ABSTRACT

In Serbia irrigation is not widely utilized to reduce water scarcity in crop production. Therefore, wheat yields largely depend on weather factors. Over the past two decades, there has been recorded a significant change in weather conditions in Serbia. Such change produces concerns about Serbia's food security and exports since wheat is among the most important agricultural products. In this paper authors analyze and quantify the impact of weather factors on the achieved wheat yields, using a set of panel data on selected Serbian municipalities in fourteen years (2000–2013). The multidimensional regression was conducted as a sort of quasi-experiment, combining data on achieved yields in selected municipalities, with data on weather factors: temperature, precipitation, extraterrestrial radiation, and evapotranspiration. Utilizing the Hargreaves method of determining reference evapotranspiration, average daily water deficit was computed as a single representative indicator of weather conditions. Testing was conducted on four predefined sub-periods within the vegetation season of wheat, and the impact of average daily water deficit on wheat yields was estimated for each of these sub-periods. Results show a robust, statistically significant impact of change in average daily water deficit on decreased wheat yields. Growth of water deficit by 0.1 mm, in the period November 15th to April 1st results with 175 kg/ha lower yields, while in the period April 1st to May 15th results in 45 kg/ha lower yields. Impact shows to be conditional on the altitude, rapidly losing on intensity and significance above 100 m.

1. Introduction

Wheat production in Serbia plays an essential role in the development of the food industry and the foreign trade balance of the national agrarian sector, covering nearly 20% of total arable land (Jeločnik et al., 2017). Wheat production is highly dependent on water availability. During the past hundred years, global warming increased the average temperature by 0.8 °C. Projections for further growth are around 2.8 °C for Britain, 3.8 °C in Central Europe, and 4–5 °C in the region of Southern Europe by the end of the 21st century (Ratknić et al., 2017). Change in weather conditions has a direct impact on the sustainability of wheat production.

The paper aimed to evaluate the statistical significance of the impact of weather factors on wheat yields from the aspect of replacing the effects of irrigation, i.e., the adequate presence of water available to plants in the soil.

Research related to the impact of weather factors on agricultural productivity can be divided into processes-based modeling (mathematical expression of one or several processes that characterize the functioning of a biological system of general or economic interest of humanity) and statistical approach (Buck-Sorlin, 2013; Moore et al., 2017). Variability of weather factors was tested by mathematical - statistical models, which most frequently relied on a stochastic approach (Mihailović et al., 2004). In recent years, new models have offered a more detailed analysis of the interaction of the variability of weather factors on yields (Nelson, Shively, 2014).

Establishment of integrated climate models for projections of their impact on the economic activities using harmonizing the values of selected weather parameters collected over a long period was limited by the width of the territory covered and the number of analyzed factors (Stute et al., 2001; Slingo et al., 2009). A high correlation between yields and precipitation or intensity of irrigation has been confirmed in a study on maize (Klocke et al., 2011).

Research carried out on field crops in California (USA), identified the availability of water, soil fertility and the availability of energy as the most essential factors in achieving the potential yields of a crop, from the aspect of the evapotranspiration potential of the soil. The model considered the estimation of the scarcity of available precipitation versus the price of water for irrigation. Where water is not deficient intensifying irrigation is feasible to a level that ensures maximum

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Table 1
Municipalities covered by the sample according to the altitude.
Source: Zubović et al., 2017.

Group	Municipality	m
Up to 100 m	Negotin	42
	Zrenjanin	80
	Kikinda (Čoka)	81
	Sremska Mitrovica	81
	Alibunar (Banatski Karlovac)	89
100-200 m	Subotica (Palić)	102
	Loznica	121
	Ćuprija	123
	Zaječar	144
Over 200 m	Kragujevac	200
	Kraljevo	215
	Leskovac	230
	Požega	310
	Vranje	432

possible crop yields (Hargreaves, Samani, 1984).

The optimization and sustainable implementation of irrigation measures at the daily level initiated the creation of a smart system (ENORASIS platform), transforms weather, hydrological and land parameters into an adequate decision related to the dynamics and intensity of irrigation in a farm (Chatzikostas et al., 2013; Cannata, Antonović, 2015).

Climate-crops models are mainly oriented towards testing the impact of precipitation and temperature on crop yields. Results in such models show a highly positive correlation of yields with precipitation levels, as well as precipitation distribution and temperature levels (Vidal, Wade, 2009; Lee, Kim, 2013). Spatial differentiation by weather factors, confirms the impact on yield and sustainability of crop production as a result of expansion or intensification of irrigation (Kang et al., 2009; Challinor et al., 2018). Cross-section and time-series research on the impact of precipitation resulted in the classification of areas primarily suitable for crop production (Tozer et al., 2014).

The research conducted in the Netherlands shows that extremely high temperatures and excessive or lack of precipitation are indicated as the leading causes of wheat yields decline (Powell, Reinhard, 2016).

The research of the impact of weather factors on the results of crop production in Serbia has so far been based on long-term experiments with sugar beet (Maksimović, Dragović, 2002), in cultivation of common crops, such as winter wheat, maize, sugar beet, soya beans, sunflower and alfalfa (Maksimović, Dragović, 2004; Dragović, 2012), or soybean production (Pejić et al., 2012; Kresović et al., 2016). Some authors have confirmed the positive impact of irrigation using specialized software packages (Cropsyst, Aquacrop or DSSAT), (Stričević et al., 2014; Kresović et al., 2014). On the other hand, besides mathematical-statistical estimates with a reduced number of parameters, regional distribution and a lower level of methodological complexity, the long-term comparative analyses of the spatial and seasonal effects of weather change on the yields of certain crops have not been yet carried out extensively (Munćan, 2016).

2. Materials and methods

The assessment was carried out by analyzing the data panel covering different weather factors, altitude, yields, and share of land under wheat in total utilized agricultural land in selected Serbian municipalities in fourteen years.

The panel represents a multidimensional regression in space and time harmonized with the weather parameters defined by the Hargreaves method of determining reference evapotranspiration (ET_o). The panel covered a sample of 14 selected municipalities (Table 1), in the long-term time cross-section. The sample size and the quality of the dispersion of municipalities in Serbia were determined by the extent of

Table 2
Saturation of soil moisture on the wheat planting day (in %) and average daily water deficiency (in mm) by sub-periods in municipalities up to 100 m.
Source: Jeločnik, 2017.

Year	Variable*	Negotin	Zrenjanin	Sremska Mitrovica	Banatski Karlovac – Alibunar	Kikinda – Čoka
	Altitude (in m)	42	80	81	89	96
2000	f_0	22,5%	52,0%	35,2%	53,0%	50,8%
	$ff_{1\ avg}$	0,51	0,50	0,69	0,48	0,54
	$ff_{2\ avg}$	0,13	0,06	0,09	0,08	0,08
	$ff_{3\ avg}$	1,62	1,44	1,70	1,55	1,50
	$ff_{4\ avg}$	4,25	3,94	4,43	4,22	4,25
2001	f_0	41,2%	13,2%	28,0%	30,4%	10,8%
	$ff_{1\ avg}$	0,87	1,30	1,17	1,10	1,34
	$ff_{2\ avg}$	0,35	0,47	0,25	0,53	0,51
	$ff_{3\ avg}$	0,90	0,63	0,45	0,60	0,62
	$ff_{4\ avg}$	2,20	1,36	0,89	1,21	1,59
2002	f_0	47,5%	69,1%	74,0%	76,3%	68,3%
	$ff_{1\ avg}$	0,73	0,42	0,39	0,38	0,42
	$ff_{2\ avg}$	0,53	0,18	0,18	0,20	0,20
	$ff_{3\ avg}$	2,12	2,08	1,75	1,93	2,02
	$ff_{4\ avg}$	3,70	3,78	3,14	3,11	3,26
2003	f_0	100,0%	70,0%	100,0%	100,0%	60,0%
	$ff_{1\ avg}$	0,04	0,35	0,03	0,03	0,46
	$ff_{2\ avg}$	0,10	0,12	0,12	0,10	0,12
	$ff_{3\ avg}$	1,13	2,02	2,30	1,95	2,03
	$ff_{4\ avg}$	2,19	4,18	3,83	4,01	4,27
2004	f_0	40,6%	66,5%	48,3%	68,6%	76,9%
	$ff_{1\ avg}$	0,17	0,14	0,24	0,12	0,12
	$ff_{2\ avg}$	0,06	0,05	0,06	0,05	0,04
	$ff_{3\ avg}$	0,94	0,56	0,54	1,07	0,45
	$ff_{4\ avg}$	2,00	1,79	1,75	2,07	2,29
2005	f_0	39,9%	63,5%	80,0%	62,2%	57,6%
	$ff_{1\ avg}$	0,58	0,40	0,12	0,52	0,50
	$ff_{2\ avg}$	0,07	0,04	0,05	0,04	0,03
	$ff_{3\ avg}$	0,52	0,94	0,70	0,73	0,55
	$ff_{4\ avg}$	2,23	1,94	1,54	1,85	1,62
2006	f_0	81,5%	70,2%	47,5%	84,2%	69,0%
	$ff_{1\ avg}$	0,34	0,48	0,81	0,33	0,51
	$ff_{2\ avg}$	0,04	0,07	0,11	0,05	0,07
	$ff_{3\ avg}$	0,93	0,59	0,63	0,50	0,54
	$ff_{4\ avg}$	1,96	2,03	2,33	2,25	2,24
2007	f_0	37,6%	43,3%	58,5%	38,0%	39,4%
	$ff_{1\ avg}$	0,97	0,83	0,72	0,90	0,84
	$ff_{2\ avg}$	0,38	0,20	0,18	0,19	0,25
	$ff_{3\ avg}$	2,12	1,52	1,51	1,70	1,45
	$ff_{4\ avg}$	3,87	2,45	2,72	3,17	1,69
2008	f_0	49,8%	52,1%	70,4%	67,3%	55,0%
	$ff_{1\ avg}$	0,24	0,22	0,13	0,14	0,27
	$ff_{2\ avg}$	0,13	0,07	0,08	0,05	0,09
	$ff_{3\ avg}$	1,33	1,27	0,88	0,70	1,35
	$ff_{4\ avg}$	3,46	3,27	3,19	2,87	2,64
2009	f_0	71,1%	38,5%	48,8%	52,6%	42,8%
	$ff_{1\ avg}$	0,41	0,93	0,88	0,76	0,83
	$ff_{2\ avg}$	0,04	0,11	0,10	0,07	0,09
	$ff_{3\ avg}$	1,53	1,92	1,74	1,59	1,78
	$ff_{4\ avg}$	3,04	2,38	2,98	1,80	2,71
2010	f_0	56,5%	48,8%	47,3%	45,5%	46,3%
	$ff_{1\ avg}$	0,29	0,43	0,41	0,46	0,41
	$ff_{2\ avg}$	0,05	0,06	0,06	0,05	0,05
	$ff_{3\ avg}$	0,74	0,91	0,86	1,11	0,81
	$ff_{4\ avg}$	2,54	0,82	1,15	1,75	0,68
2011	f_0	47,4%	70,0%	71,2%	50,8%	78,7%
	$ff_{1\ avg}$	0,12	0,23	0,23	0,36	0,18
	$ff_{2\ avg}$	0,04	0,05	0,08	0,08	0,04
	$ff_{3\ avg}$	1,19	1,19	1,41	1,46	1,19
	$ff_{4\ avg}$	3,89	3,33	2,87	2,91	3,33
2012	f_0	13,6%	30,4%	24,4%	30,2%	30,4%
	$ff_{1\ avg}$	1,09	0,77	0,87	0,78	0,81
	$ff_{2\ avg}$	0,41	0,22	0,26	0,23	0,22
	$ff_{3\ avg}$	1,72	1,34	1,16	1,35	1,29
	$ff_{4\ avg}$	2,76	3,22	3,18	3,13	3,44

(*continued on next page*)

Table 2 (*continued*)

Year	Variable*	Negotin	Zrenjanin	Sremska Mitrovica	Banatski Karlovac – Alibunar	Kikinda – Čoka
	Altitude (in m)	42	80	81	89	96
2013	f_0	14,8%	36,7%	26,7%	51,0%	32,2%
	$ff_{1\ avg}$	1,01	0,82	1,06	0,58	0,83
	$ff_{2\ avg}$	0,06	0,07	0,12	0,06	0,06
	$ff_{3\ avg}$	1,18	0,96	1,13	1,10	0,93
	$ff_{4\ avg}$	2,88	2,16	1,74	2,20	2,33

f_0 – planting day.
ff_1 –ff_4 - subperiods.

wheat distribution, grouping them by altitude and the wheat production intensity.

One of the prerequisites for creating the panel was the definition of four sub-periods (several phenophases) within the vegetation season of winter wheat. The division is based on the scientific and practical experience of persons oriented to the field of crop farming (information collected through in-depth interviews with the scientific-teaching staff of the Faculty of Agriculture and research staff of the scientific institute) and generally available literary sources. Consequently, the defined sub-periods were derived from an adequate grouping of all morphological stages of growth and 12 stages of organogenesis of winter wheat, which characterizes the agro-ecological conditions of Serbia (Đorđević et al., 1965; Jevtić, 1977; Glamočlija, 2012; IAE, 2016):

1) the first defined sub-period, lasting from October 15th to November 15th, covered the phenophases initiated by the planting process, i.e., the period from germination to the emergence of wheat, which is in a time overlap with the first stage of organogenesis (characterized by the undifferentiated vegetative cone);
2) the second sub-period covers the period from November 15th to April 1st and includes the morphological phases of tillering and seedling. These include the second stage (differentiation of the lower part of the vegetative cone to the stem and leaf buds, as well as the differentiation of the tillering node), the third stage (differentiation of the upper part of the vegetative cone, i.e. the differentiation of the ear fusiform spike) and the fourth stage (differentiation of spikelets, i.e., budding of spikelet glume) of winter wheat organogenesis;
3) the third defined sub-period covers the period from April 1st to May 15th and involves jointing and heading phases. These are the fifth stage (differentiation of flower buds, i.e., flower sheath), the sixth stage (differentiation of reproductive parts), the seventh stage (characterized by gametogenesis and dimensional enlargement of the differentiated parts) and the eighth stage (overlaps with the phenolic phase of heading) of organogenesis; and
4) the fourth determined sub-period lasts from May 15th to July 1st and implies phenological phases of flowering and pollination, fertilization and grain forming, and the stage of its ripeness until reaching full ripeness. These are the ninth stage (it coincides with the morphological phase of flowering and pollination), the tenth stage (it coincides with the morphological stage of fertilization and grain formation), the eleventh stage (the stage of ripeness as a transition between milk and wax ripeness) and the twelfth stage (the stage of ripeness as a transition between wax and full ripeness) of wheat organogenesis.

Econometric model in this study follows the work of Zubović et al. (2017), who proposes the application of a spatial panel model to assess the impact of weather factors on maize yields in Serbia. The methodology is primarily designed to analyze the impact of the presence of water in the soil, as the main determinants of evapotranspiration, on wheat yield using the regression model with composite error, shown by the following equation (subscript *i* refers to the municipality, while *t* refers to the year):

$$Y_{i,t} = \alpha + X_{i,t}\gamma + Z_{i,t}\delta + \eta_i + \varepsilon_{i,t} \quad (1)$$

Variables in the equation have the following meaning:
$Y_{i,t}$ - average wheat yield expressed in kilograms per hectare;[1]
$X_{i,t}$ - measurement of water scarcity in soil by subperiods (phenophases) for wheat;
$Z_{i,t}$ - control variables;
η_i – individual effects of the municipality; and
$\varepsilon_{i,t}$ – random error, $\varepsilon_{i,t}\tilde{}N(0, \sigma^2)$

Measurements of water scarcity[2] $X_{i,t}$ are defined for each phenophase m ($m = 1,\ldots, 4$), $X_{i,t} = \{\bar{ff}^m_{i,t}\}$, where $\bar{ff}^m_{i,t}$ represents the average daily deficiency of water in the phenophase *m*. If l^m marks the duration of the phenophase *m* in days, the calculation of the average daily water scarcity $\bar{ff}^m_{i,t}$ in the phenophase *m,* can be mathematically explained in the next three steps:

1) for each day in the given phenophase, the difference between the daily potential evapotranspiration $et^{m,p}_{i,t}$ and actual daily evapotranspiration $et^{m,r}_{i,t}$ is calculated

$$\Delta et^m_{i,t} = et^{m,p}_{i,t} - et^{m,r}_{i,t} \quad (2)$$

2) for each phenophase, total water deficit $ff^m_{i,t;j}$ is calculated by summing up the difference between daily potential and actual evapotranspiration

$$ff^m_{i,t;j} = \sum_j^{l^m} \Delta et^m_{i,t;j} \quad (3)$$

3) the total water scarcity is averaged by its length expressed in days l^m

$$\bar{ff}^m_{i,t} = ff^m_{i,t}/l^m$$

Potential and actual evapotranspiration are calculated using the Hargreaves formula.[3]

Saturation of soil moisture on the wheat planting day (15^{th} October) $ff^0_{i,t}$, the share of harvest areas under wheat in the total arable area $P_{i,t}$, as well as the annual change in harvest areas under wheat $\Delta P_{i,t}$, expressed in percentage points, were used as control variables. Soil moisture saturation $ff^0_{i,t}$ is calculated as the moisture ratio on the day of planting $\omega^0_{i,t}$ and field water capacity $\omega^*_{i,t}$.

$$ff^0_{i,t} = \omega^0_{i,t}/\omega^*_{i,t} \quad (4)$$

The purpose of using this variable as a control variable is based on the expectation that a higher water concentration in the soil on the day

[1] The impact of higher yields achieved by irrigation on the value of average yields is eliminated by the fact that the share of irrigated areas in the total agricultural land used is below 3% (Pavlović et al., 2017), with only about 1.5% of these areas in the intensive irrigation system (Kljajić et al., 2013).

[2] Reference evapotranspiration is an essential element in determining plant's needs for water (satisfying the level of transpiration and evaporation of water from the soil) in certain agro-ecological conditions, designing norms and optimal irrigation regimes, dimensioning irrigation systems, etc. (Bezdan et al., 2017). Therefore, it can be used to determine the impact of weather factors on the level of fulfillment of crop's water demand requirements, as well as the deficient quantities of water that would be compensated from precipitation, irrigation or water reserve in the soil. In other words, based on the calculated value for reference evapotranspiration corrected by the appropriate coefficient for specific crop, an estimate can be performed for the daily water scarcity to be added to the crop through irrigation (Trajković, 2009).

[3] On a world scale, in terms of precision, the use of methods for determining the reference evapotranspiration by Penman-Monteith (FAO56-PM) model is suggested. At the level of Serbia, a simplified Hargreaves model is used (one of the globally most commonly used methods), where daily calculations are based on maximum, minimum and average temperature, extraterrestrial radiation of the sun and the length of the day at a certain location (RHSS, 2016).

of planting (if not excessive) can stimulate germination and sprouting of wheat. The ratio between the yield of wheat and share of land $P_{i,t}$ theoretically it can be positive (if the land is suitable for cultivation of wheat, a greater share of areas and higher yields will be achieved at the same time), but also negative (if wheat is cultivated on the arable land margins, which are characterized by lower fertility and thus reduced average yield). The above mentioned suggests an inverse ratio between changes in the share of surfaces $\Delta P_{i,t}$ and yield of wheat, as a consequence of wheat not being planted on arable land where lower yields are realized.

Municipality's altitude Alt_i is a time-invariant variable that has an impact on wheat yield. Since the explicit impact of altitude on the yields is an issue of particular importance for research, the categorical variable Alt_i is defined, based on the grouping of municipalities in the following three categories according to their altitude:

$$Alt_i = \begin{Bmatrix} 1;\ Alt_i < 100 \\ 2;\ 101 \le Alt_i < 200 \\ 3;\ Alt_i \ge 201 \end{Bmatrix}$$

This grouping was carried out according to the same matrix used for the stratification of municipalities given the criteria of altitude for creating a sample. Using the variable Alt_i a pooled regression model (pooled - because it does not take into account the individual specificities of the observation units when analyzing the impact on the dependent variable) is evaluated as a benchmark for comparison with the model with a composite error. Subsequently, three particular models with the composite error were assessed for each sub-sample of municipalities by categories of altitude, to analyze potential differences in the intensity and significance of the impact of explanatory variables on wheat yield.

The methodological limitations of the conducted research include conceptual limitations (coming from the model simplification of reality) and estimation limitations (arising from the general limitation of the statistical methods used for the analysis). The main conceptual limitations of the conducted research were:

- Only ordinary mercantile winter wheat was considered;
- Defined phenophases are of general significance for all observed municipalities, regardless of potential differences in the locality. Also, the beginning and end dates of individual phenophases in specific years may vary depending on weather conditions, which is not taken into account due to the lack of specific data from previous years;
- The lack of data has caused the neglect of the influence of mineral fertilizers and pesticides (by type and quantity) on the realized yield of wheat.

The basic estimation limitations in evaluating the created model are related to the limited possibilities of statistical analysis methods to eliminate the following problems often present in the analysis of actual data:

- The presence of high collinearity i.e., a pronounced correlation between independent variables that prevent precise delineation of the influence of individual independent variables on the dependent variable;
- The presence of unobserved heterogeneity due to influential factors that are not explicitly covered by the model;
- Measurement errors in variables, as a direct consequence of the conceptual limitations, stated above.

Each of these limitations is a potential source of the unreliability of regression assessment, so we address them later in the analysis.

Table 3
Saturation of soil moisture on the wheat planting day (in %) and average daily water deficiency (in mm) by sub-periods in municipalities. 100-200 m
Source: Jeločnik, 2017.

Year	Variable* Altitude (in m)	Palić –Subotica 102	Loznica 121	Ćuprija 123	Zaječar 144
2000	f_0	58,6%	49,2%	43,4%	18,7%
	$ff_{1\ avg}$	0,45	0,56	0,63	0,71
	$ff_{2\ avg}$	0,06	0,04	0,10	0,19
	$ff_{3\ avg}$	1,15	1,33	1,24	2,09
	$ff_{4\ avg}$	4,12	3,21	4,29	5,13
2001	f_0	12,0%	54,5%	37,4%	36,7%
	$ff_{1\ avg}$	1,28	0,83	1,05	0,97
	$ff_{2\ avg}$	0,39	0,16	0,48	0,47
	$ff_{3\ avg}$	0,43	0,44	0,64	0,88
	$ff_{4\ avg}$	1,07	1,31	1,84	1,98
2002	f_0	66,6%	74,1%	73,5%	43,3%
	$ff_{1\ avg}$	0,43	0,43	0,53	0,89
	$ff_{2\ avg}$	0,17	0,11	0,19	0,63
	$ff_{3\ avg}$	1,68	0,51	0,97	2,07
	$ff_{4\ avg}$	3,03	1,65	2,34	3,97
2003	f_0	44,0%	100,0%	95,8%	100,0%
	$ff_{1\ avg}$	0,63	0,03	0,09	0,09
	$ff_{2\ avg}$	0,18	0,10	0,11	0,11
	$ff_{3\ avg}$	2,04	2,12	1,89	1,20
	$ff_{4\ avg}$	4,20	3,80	3,92	3,13
2004	f_0	68,3%	72,4%	54,3%	52,5%
	$ff_{1\ avg}$	0,14	0,12	0,19	0,10
	$ff_{2\ avg}$	0,04	0,06	0,05	0,06
	$ff_{3\ avg}$	0,48	0,42	1,17	0,91
	$ff_{4\ avg}$	1,86	1,10	2,27	2,77
2005	f_0	63,4%	83,2%	60,9%	46,8%
	$ff_{1\ avg}$	0,33	0,18	0,58	0,55
	$ff_{2\ avg}$	0,03	0,03	0,04	0,06
	$ff_{3\ avg}$	0,61	0,48	0,53	0,97
	$ff_{4\ avg}$	1,21	0,76	1,85	2,36
2006	f_0	77,0%	85,3%	87,0%	84,6%
	$ff_{1\ avg}$	0,38	0,29	0,31	0,34
	$ff_{2\ avg}$	0,05	0,04	0,03	0,05
	$ff_{3\ avg}$	0,40	0,36	0,64	1,15
	$ff_{4\ avg}$	1,01	1,55	2,82	2,93
2007	f_0	40,1%	84,8%	38,2%	52,5%
	$ff_{1\ avg}$	0,79	0,37	0,93	0,83
	$ff_{2\ avg}$	0,29	0,09	0,15	0,46
	$ff_{3\ avg}$	1,49	1,50	1,96	2,38
	$ff_{4\ avg}$	1,94	2,70	2,68	3,55
2008	f_0	37,0%	95,4%	64,6%	83,0%
	$ff_{1\ avg}$	0,37	0,03	0,21	0,10
	$ff_{2\ avg}$	0,06	0,03	0,08	0,13
	$ff_{3\ avg}$	0,82	0,67	0,90	1,15
	$ff_{4\ avg}$	1,52	1,66	3,89	3,93
2009	f_0	50,9%	66,3%	52,9%	62,1%
	$ff_{1\ avg}$	0,69	0,66	0,82	0,58
	$ff_{2\ avg}$	0,09	0,06	0,08	0,07
	$ff_{3\ avg}$	1,84	1,27	1,52	1,40
	$ff_{4\ avg}$	2,55	1,82	2,44	3,39
2010	f_0	60,3%	75,9%	54,5%	68,6%
	$ff_{1\ avg}$	0,32	0,10	0,32	0,19
	$ff_{2\ avg}$	0,04	0,03	0,07	0,06
	$ff_{3\ avg}$	0,77	0,61	0,96	0,76
	$ff_{4\ avg}$	1,03	0,69	1,60	2,26
2011	f_0	83,2%	87,4%	37,1%	37,2%
	$ff_{1\ avg}$	0,09	0,08	0,56	0,51
	$ff_{2\ avg}$	0,03	0,07	0,10	0,08
	$ff_{3\ avg}$	1,15	0,92	1,19	1,30
	$ff_{4\ avg}$	2,58	2,54	3,65	3,62
2012	f_0	33,8%	31,3%	30,9%	23,8%
	$ff_{1\ avg}$	0,72	0,82	0,93	0,95
	$ff_{2\ avg}$	0,19	0,20	0,27	0,41
	$ff_{3\ avg}$	1,47	0,74	0,91	1,85
	$ff_{4\ avg}$	3,23	2,20	3,12	2,66
2013	f_0	40,3%	42,0%	24,7%	12,1%
	$ff_{1\ avg}$	0,68	0,90	1,04	1,12
	$ff_{2\ avg}$	0,04	0,05	0,08	0,09
	$ff_{3\ avg}$	0,91	0,86	1,26	1,26
	$ff_{4\ avg}$	2,06	1,27	2,56	3,39

f_0 – planting day.
ff_1 –ff_4 - subperiods.

Table 4
Saturation of soil moisture on the wheat planting day (in %) and average daily water deficiency (in mm) by sub-periods in municipalities over the 200 m.
Source: Jeločnik, 2017.

Year	Variable* Altitude (in m)	Kragujevac 200	Kraljevo 215	Leskovac 230	Požega 310	Vranje 432
2000	f_0	46,5%	53,5%	22,4%	59,4%	17,1%
	$ff_{1\ avg}$	0,60	0,44	0,86	0,36	0,88
	$ff_{2\ avg}$	0,11	0,05	0,11	0,05	0,11
	$ff_{3\ avg}$	1,88	1,53	1,44	1,38	1,32
	$ff_{4\ avg}$	4,40	3,88	4,01	3,46	4,44
2001	f_0	49,5%	52,9%	33,9%	51,5%	19,9%
	$ff_{1\ avg}$	0,89	0,66	1,14	0,76	1,23
	$ff_{2\ avg}$	0,44	0,24	0,44	0,18	0,59
	$ff_{3\ avg}$	0,56	0,42	0,59	0,52	0,81
	$ff_{4\ avg}$	1,96	1,79	2,59	1,92	2,72
2002	f_0	75,8%	75,8%	38,9%	78,0%	31,3%
	$ff_{1\ avg}$	0,45	0,46	1,11	0,38	1,19
	$ff_{2\ avg}$	0,17	0,14	0,30	0,15	0,39
	$ff_{3\ avg}$	1,13	0,46	0,96	0,55	1,06
	$ff_{4\ avg}$	3,00	2,09	2,70	2,69	2,24
2003	f_0	100,0%	100,0%	99,0%	100,0%	100,0%
	$ff_{1\ avg}$	0,06	0,11	0,13	0,11	0,10
	$ff_{2\ avg}$	0,11	0,10	0,11	0,11	0,12
	$ff_{3\ avg}$	1,88	1,95	1,58	2,14	2,09
	$ff_{4\ avg}$	3,36	2,62	3,63	2,42	3,64
2004	f_0	33,1%	43,9%	56,2%	26,8%	54,8%
	$ff_{1\ avg}$	0,46	0,29	0,17	0,51	0,17
	$ff_{2\ avg}$	0,11	0,07	0,05	0,12	0,05
	$ff_{3\ avg}$	0,99	0,91	0,98	0,86	0,75
	$ff_{4\ avg}$	2,41	1,54	2,58	1,71	2,24
2005	f_0	63,9%	67,7%	68,3%	60,1%	71,5%
	$ff_{1\ avg}$	0,54	0,49	0,54	0,58	0,50
	$ff_{2\ avg}$	0,05	0,04	0,04	0,04	0,06
	$ff_{3\ avg}$	0,43	0,65	0,53	0,93	1,37
	$ff_{4\ avg}$	1,91	1,20	1,58	1,80	2,81
2006	f_0	85,6%	86,6%	67,6%	77,3%	73,8%
	$ff_{1\ avg}$	0,35	0,28	0,60	0,34	0,50
	$ff_{2\ avg}$	0,03	0,03	0,07	0,02	0,05
	$ff_{3\ avg}$	0,55	0,46	0,51	0,45	0,65
	$ff_{4\ avg}$	2,40	1,89	2,11	1,49	1,86
2007	f_0	65,0%	65,7%	71,7%	68,7%	54,3%
	$ff_{1\ avg}$	0,64	0,58	0,55	0,53	0,78
	$ff_{2\ avg}$	0,16	0,11	0,15	0,11	0,21
	$ff_{3\ avg}$	1,63	1,47	1,67	1,48	1,60
	$ff_{4\ avg}$	2,88	2,53	3,03	2,41	2,90
2008	f_0	54,8%	73,8%	53,8%	90,2%	50,1%
	$ff_{1\ avg}$	0,36	0,12	0,30	0,05	0,41
	$ff_{2\ avg}$	0,07	0,05	0,14	0,08	0,13
	$ff_{3\ avg}$	1,04	0,51	0,96	0,81	0,88
	$ff_{4\ avg}$	3,74	2,70	3,56	2,42	3,23
2009	f_0	50,6%	76,5%	55,2%	57,5%	76,5%
	$ff_{1\ avg}$	0,82	0,43	0,98	0,67	0,59
	$ff_{2\ avg}$	0,13	0,05	0,08	0,06	0,07
	$ff_{3\ avg}$	1,34	1,34	1,33	1,35	1,07
	$ff_{4\ avg}$	2,32	2,14	2,66	2,17	2,35
2010	f_0	69,9%	79,9%	54,6%	70,7%	59,3%
	$ff_{1\ avg}$	0,19	0,06	0,34	0,20	0,34
	$ff_{2\ avg}$	0,05	0,05	0,05	0,05	0,06
	$ff_{3\ avg}$	0,66	0,68	0,80	1,14	0,70
	$ff_{4\ avg}$	1,13	1,06	2,23	1,60	2,10
2011	f_0	48,1%	41,7%	37,2%	48,7%	51,4%
	$ff_{1\ avg}$	0,38	0,37	0,73	0,43	0,31
	$ff_{2\ avg}$	0,09	0,07	0,11	0,09	0,10
	$ff_{3\ avg}$	1,17	0,73	1,32	1,04	1,50
	$ff_{4\ avg}$	3,14	2,14	3,35	2,69	3,69
2012	f_0	39,7%	34,4%	47,8%	41,6%	49,9%
	$ff_{1\ avg}$	0,83	0,90	0,87	0,73	0,84
	$ff_{2\ avg}$	0,25	0,22	0,22	0,20	0,22
	$ff_{3\ avg}$	1,31	1,07	1,53	1,33	1,33
	$ff_{4\ avg}$	2,72	2,82	2,80	2,59	2,68
2013	f_0	20,7%	21,5%	13,0%	21,3%	20,9%
	$ff_{1\ avg}$	1,10	1,15	1,41	1,22	1,24
	$ff_{2\ avg}$	0,10	0,10	0,14	0,08	0,13
	$ff_{3\ avg}$	1,18	1,07	1,22	1,20	1,08
	$ff_{4\ avg}$	2,10	1,43	2,78	1,74	2,47

f_0 – planting day.
ff_1 –ff_4 - subperiods.

3. Results

Data on saturation of soil moisture on the planting day (f_0), as well as the average daily water scarcity in the four previously determined sub-periods (ff_1-ff_4) in the wheat vegetation season for selected municipalities for the altitudes 0–100 m is given in Table 2, for 100–200 m in Table 3, and above 200 m in Table 4. Wheat annual yields and changes in the size of harvested areas is given in Table 5 for the altitudes 0–100 m, in Table 6 for 100–200 m, and in Table 7 for the altitudes 200 m and above. Observed municipalities are grouped according to altitude delimitation, as explained in the previous section.

Table 8 shows a correlation matrix of the explanatory variables. Estimated correlation coefficients do not indicate the problem of too high multicollinearity in the model. In addition to simple correlation analysis, we consulted more formal collinearity diagnostics in the form of Variance Inflation Factor (VIF) analysis. Collinearity tolerance indicator shows portion of variations in the particular variable that cannot be explained by variations in other variables on the explanatory side of the regression equation. The usual interpretation of the collinearity diagnostic is that values of the VIF (VIF is inverse of collinearity tolerance) higher than 10 indicates a problem with collinearity (Craney and Surles, 2002). In our case, the values of the VIF are quite low, so we can conclude that the problem of excessive collinearity doesn't affect our explanatory variables. Results of collinearity diagnostic are presented in Table 9.

The issue of unobserved heterogeneity in econometric analysis of panel data is usually handled using fixed effects (FE) or random effects (RE) estimators. The main difference between these two estimators is the underlying assumption on the nature of the time-invariant individual effect η_i in the model with composite error (1). While FE estimator assumes that individual effects are fixed across units (i.e.,

Table 5
Change in harvested surfaces under the wheat (in %) and annual yield (in kg/ha) in municipalities up to 100 m.
Source: Jelonik, 2017.

Year	Variable	Negotin	Zrenjanin	Sremska Mitrovica	Banatski Karlovac – Alibunar	Kikinda – Čoka
2000	ΔP	0,31%	1,39%	6,82%	−1,97%	−9,50%
	Y	2.822	3.200	3.543	3.084	2.747
2001	ΔP	−0,83%	0,04%	0,20%	2,00%	1,54%
	Y	3.571	4.072	4.237	3.666	3.198
2002	ΔP	−0,26%	0,41%	−0,63%	0,17%	0,25%
	Y	1.115	2.906	4.181	2.657	2.344
2003	ΔP	−1,81%	−0,99%	−4,94%	−3,75%	−0,68%
	Y	1.917	2.154	2.917	1.826	1.356
2004	ΔP	−0,21%	−0,44%	0,30%	−0,38%	1,36%
	Y	3.937	4.876	4.959	4.131	4.448
2005	ΔP	−0,66%	−1,20%	−3,03%	−2,74%	−2,50%
	Y	3.518	4.185	4.181	3.759	3.739
2006	ΔP	0,05%	−1,08%	−1,12%	−0,09%	1,35%
	Y	2.759	3.881	4.123	3.897	2.948
2007	ΔP	−0,62%	3,27%	1,37%	1,05%	0,81%
	Y	1.400	3.917	4.038	3.335	3.104
2008	ΔP	−0,60%	−5,27%	−3,92%	0,70%	−5,04%
	Y	3.594	4.832	4.868	4.881	3.805
2009	ΔP	1,19%	4,79%	5,37%	−0,72%	3,47%
	Y	3.404	3.956	4.198	4.146	2.812
2010	ΔP	−0,52%	−4,56%	−2,10%	−2,50%	0,88%
	Y	3.036	3.795	3.604	3.768	3.425
2011	ΔP	0,43%	0,82%	−1,31%	−1,05%	−2,04%
	Y	3.574	5.043	4.267	4.155	4.652
2012	ΔP	13,29%	0,00%	1,72%	−0,43%	5,17%
	Y	3.427	4.330	4.422	3.654	3.799
2013	ΔP	3,77%	3,84%	4,90%	1,79%	2,84%
	Y	3.841	5.849	5.469	5.333	5.121

ΔP - annual change in harvested areas under wheat.
Y - yield.

Table 6
Change in harvested surfaces under the wheat (in %) and annual yield (in kg) in municipalities. 100-200 m
Source: Jeločnik, 2017.

Year	Variable	Palić-Subotica	Loznica	Ćuprija	Zaječar
2000	ΔP	5,27%	0,62%	1,61%	0,30%
	Y	2.805	3.333	2.780	2.030
2001	ΔP	−5,07%	1,41%	1,51%	−0,61%
	Y	3.464	2.809	3.765	3.273
2002	ΔP	1,91%	7,46%	−0,78%	−0,08%
	Y	3.559	3.203	3.891	1.511
2003	ΔP	−2,94%	−10,49%	0,04%	−2,33%
	Y	1.586	2.347	2.579	1.934
2004	ΔP	0,59%	2,06%	2,63%	1,06%
	Y	4.445	3.558	4.583	3.567
2005	ΔP	−4,26%	−1,24%	−4,03%	−0,23%
	Y	4.054	3.162	3.303	3.681
2006	ΔP	1,49%	−0,11%	−0,07%	−1,13%
	Y	4.646	2.937	2.886	2.557
2007	ΔP	0,65%	−0,25%	0,55%	0,73%
	Y	3.622	3.220	3.035	1.536
2008	ΔP	−1,43%	−1,05%	−0,06%	−1,38%
	Y	5.094	3.353	4.438	4.021
2009	ΔP	1,48%	0,77%	1,38%	0,97%
	Y	3.695	3.230	3.952	3.226
2010	ΔP	−3,78%	−0,63%	−3,18%	−1,72%
	Y	3.613	2.567	3.669	2.899
2011	ΔP	−0,85%	−1,36%	2,47%	0,58%
	Y	5.451	3.458	3.833	3.313
2012	ΔP	1,62%	3,85%	13,46%	9,46%
	Y	3.949	4.005	3.685	3.389
2013	ΔP	5,07%	3,72%	0,79%	1,28%
	Y	5.559	3.968	4.078	3.217

ΔP - annual change in harvested areas under wheat.
Y - yield.

Table 7
Change in harvested surfaces under the wheat (in %) and annual yield (in kg) in municipalities over the 200 m.
Source: Jeločnik, 2017.

Year	Variable	Kragujevac	Kraljevo	Leskovac	Požega	Vranje
2000	ΔP	2,20%	0,13%	1,37%	0,06%	−0,28%
	Y	2.557	2.494	2.468	2.887	1.808
2001	ΔP	0,45%	0,22%	−0,44%	0,03%	−0,12%
	Y	3.790	3.311	2.853	2.863	2.638
2002	ΔP	−0,05%	0,09%	0,30%	−0,37%	−0,37%
	Y	3.430	3.237	2.813	2.542	2.970
2003	ΔP	−0,68%	−0,46%	−1,21%	−0,21%	−0,68%
	Y	2.153	2.320	2.387	2.323	1.913
2004	ΔP	0,90%	0,22%	0,52%	0,20%	0,50%
	Y	4.156	3.845	3.667	3.396	3.462
2005	ΔP	−1,36%	−0,60%	−0,74%	−0,13%	−0,18%
	Y	2.847	3.454	2.992	3.190	2.998
2006	ΔP	−1,81%	0,06%	−0,30%	−0,47%	−0,32%
	Y	3.127	3.594	2.880	2.919	2.799
2007	ΔP	0,34%	0,19%	−0,46%	0,07%	−0,23%
	Y	3.080	3.961	2.655	2.884	2.731
2008	ΔP	−0,88%	−0,82%	−0,38%	−0,51%	−0,23%
	Y	3.827	4.211	3.611	3.388	3.469
2009	ΔP	0,34%	0,17%	0,01%	0,26%	−1,72%
	Y	3.387	3.763	2.970	2.986	2.800
2010	ΔP	−0,63%	−0,29%	0,47%	−0,28%	−0,35%
	Y	3.224	3.243	2.529	2.712	2.803
2011	ΔP	0,23%	0,11%	0,03%	0,01%	−0,02%
	Y	3.648	3.762	3.431	3.128	3.283
2012	ΔP	5,64%	2,54%	15,97%	0,99%	11,72%
	Y	3.895	3.417	2.909	2.777	3.255
2013	ΔP	0,98%	0,58%	0,34%	0,01%	0,68%
	Y	3.995	4.216	3.773	3.811	3.854

ΔP - annual change in harvested areas under wheat.
Y - yield.

Table 8
Estimated Pearson's correlation coefficients between explanatory variables in the model.

Variable	ff_{1_avg}	ff_{2_avg}	ff_{3_avg}	ff_{4_avg}	f_0	ΔP
ff_{1_avg}	1					
ff_{2_avg}	0.6035	1				
ff_{3_avg}	0.0659	0.1829	1			
ff_{4_avg}	−0.0527	0.0931	0.6784	1		
f_0	−0.7956	−0.4326	−0.0016	−0.0225	1	
ΔP	0.3779	0.2148	0.0723	0.0323	−0.3479	1

f_0 – planting day.
ff_1 –ff_4 – subperiods.
ΔP - annual change in harvested areas under wheat.
Y - yield.
Note: Pearson correlation coefficient measures level of co-variations between two numeric variables, in percentage.

Table 9
Collinearity diagnostic for explanatory variables in the model.

Variable	Collinearity Statistics	
	Tolerance	VIF
ff_{1_avg}	.258	3.871
ff_{2_avg}	.608	1.646
ff_{3_avg}	.501	1.997
ff_{4_avg}	.501	1.997
f_0	.340	2.940
ΔP	.848	1.180

f_0 – planting day.
ff_1 –ff_4 – subperiods.
ΔP - annual change in harvest areas under wheat.
Note: Tolerance measures level of variations of given explanatory variables which can not be explained by variations of other explanatory variables in the model.

having nothing in common), RE estimator assumes that individual effects originated from the common probability distribution. In order to get exact evidence which estimator is more appropriate to use, we run Hausman (1978) test, first assuming that the variance-covariance matrices are based on the estimated disturbance variance from the consistent estimator (FE) and then from the efficient estimator (RE). In both cases, the Hausman test suggests that RE is more appropriate to use, as shown in the Table 10.

By evaluating the model (Eq. (1) using the estimator of random effects, the detrimental effect of unobserved heterogeneity on the reliability of regression assessment is significantly reduced. Since there is a high probability of having heteroscedasticity in the given set of data, we also applied Huber-White estimator of heteroscedasticity-consistent standard errors within RE estimation. This improves the reliability of correct inferences about the statistical significance of the estimated coefficients.

Before econometric estimation, we apply a unit root test to check the stationarity of the data. As Birkel (2014) noticed, non-stationarity of panel data can result in multiple estimation issues: conventional estimation technics produce consistent parameter estimates only under particular circumstances, conventional estimates for standard errors do not allow valid inference and properties of estimators are dependent on cointegration. To test the presence of non-stationarity, we use two forms of panel unit root tests: a) Levin–Lin–Chu test (LLC) and b) Im-Pesaran-Shin (IPS). LLC test assumes that all panels follow the common autoregressive process, while the IPS test is based on the more realistic assumption, that each panel follows its autoregressive process. Results of panel unit root tests are presented in Table 11.

As seen from the table, almost all variables used in regressions are stationary according to both tests, at a significance level of 1%. The

Table 10
Hausman test for choice between Random and Fixed Effects estimator.

Variance-covariance matrices base	Estimated disturbance variance from the consistent (FE) estimator	Estimated disturbance variance from the efficient (RE) estimator
Test statistic (chi squared)	7.17	7.13
P-value	0.3054	0.3093

Note: H0 – "Individual effects are adequately modeled by a random effects model".

Table 11
Panel unit root tests for all variables in the model.

Variable	LLC test	IPS test
Y	−5.27***	−4.63***
ff_{1_avg}	−2.42***	−5.88***
ff_{2_avg}	−13.47***	−5.65***
ff_{3_avg}	−7.75***	−6.30***
ff_{4_avg}	−8.22***	−6.67***
f_0	−2.57***	−6.52***
ΔP	0.05	−7.01***

f_0 – planting day.
ff_1 –ff_4 – subperiods.
ΔP - annual change in harvest areas under wheat.
Note: standard errors in brackets; level of significance: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.
H0 – "Panels contain unit roots" for both tests.
H1 – "Panels are stationary" for LLC, "Some panels are stationary" for IPS.

only exemption is an annual change in harvested areas under wheat (ΔP) in case of LLC, but more reliable IPS test suggests that this variable is stationary, too.

The results of the regression model estimation (Eq. (1)) for the yield of wheat are shown in Table 12, where columns 1–4 show the results of the estimation of the random effect model by gradual extension of regression specification, while the last column shows the results of the pooled model's estimation. The gradual extension of regression specification allows monitoring of the marginal changes in the value of the regression coefficients and the coefficient of determinations and thus indicate the robustness of the estimation results.

The second part of the analysis included the estimation of the model of random effects on sub-samples (grouping of municipalities by altitude), (Table 13).

The previously discussed conceptual limitations imply that variables used in the model are most likely subject to measurement errors. Similar to unobserved heterogeneity, measurement error is a typical pitfall of non-experimental research and source of model endogeneity, which may compromise the estimation results (Antonakis et al., 2014). The model endogeneity caused by measurement errors is often addressed using non-standard estimation methods, such as the two-stage least-squares method or the generalized method of moments. Both of these procedures require the use of instrumental variables, which have two properties: high correlation with explanatory variables of interest and no correlation with random error. Because there was no possibility to identify adequate natural instruments due to the specific nature of this research, we consider Wald's, Bartlett's and Durbin's method of grouping observations of existing explanatory variables to create new instrumental variables that satisfy required properties (Gillard, 2010). Since the water scarcity in the phenophases 2 and soil moisture saturation on the supposed day of planting are two weather factors with the most persistent impact on wheat yield, we instrumentalized both of them using all available methods of grouping. The model is re-estimated using the two-stage least-squares method and random effect estimator. The results of regression estimation using instrumental variables approach, presented in Table 14, confirm the stability of estimated parameters even in the case when potential endogeneity from measurement errors is tackled.

Table 12
Econometric estimation of gradually extended model by Random Effects estimator and full model by Pooled OLS estimator, for the total sample of municipalities.

Variable	Random effects				Pooled
	1	2	3	4	
ff_{2_avg}	−2604.7627***	−2102.5805***	−1793.4160***	−1750.5763***	−2103.3754***
	(432.1977)	(312.4325)	(308.0658)	(304.5088)	(444.5704)
ff_{3_avg}		−635.8655***	−631.5058***	−449.1062***	−1424.0514***
		(104.9991)	(106.1071)	(107.5404)	(349.5853)
ff_{1_avg}			−341.4279***	−488.9886***	−335.1038
			(127.184)	(153.6249)	(13.7007)
ff_{4_avg}				−148.0775**	−177.9797**
				(70.0957)	(123.8719)
f_0	−1265.7553***	−1037.8192***	−1370.6377***	−1528.3348***	−335.7365
	(163.4748)	(170.251)	(218.6377)	(196.8302)	(236.4925)
ΔP	36.0720***	45.4019***	48.6888***	48.9096***	−172.9308**
	(11.5096)	(13.73)	(14.2737)	(15.1153)	(76.8037)
Alt					−290.8344***
					−44.3237
Const	4447.9850***	4980.2385***	5303.5067***	5638.6563***	6171.9362***
	(190.2482)	(228.2351)	(313.4955)	(357.5839)	(329.583)
R Sq	0.43	0.56	0.57	0.58	0.42

f_0 – planting day.
ff_1 –ff_4 – subperiods.
ΔP - annual change in harvest areas under wheat.
Alt – altitude.
Const – Constant.
R sq – R squared.
Note: standard errors in brackets; level of significance: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.
Since R Squared is not directly computable in case of RE estimator, it is approximated by the squared Pearson correlation coefficient between actual and modelled values of dependent variable.

4. Discussion

Research conducted in Kenya for 18 years shows a correlation between weather factors and yields, and linear regression pointed out that wheat yield is statistically highly dependent on several weather factors. That includes precipitation, temperature, and humidity. However, the author did not test causality (Nderitu, 2016).

Research on the production of spring wheat in Canada during the 24 years, confirms the correlation of the yields and weather factors as well. Moreover, the authors have provided the following empirical evidence. An increase in the number of days with extremely high temperature by 20% decreases average yields by 11.7 kg/ha for spring wheat (Meng et al., 2017).

In the previous research, authors have analyzed the influence of weather factors on maize yields in Serbia. Results have shown that 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 and daily increase in water deficit by 1 mm can lead to yield reduction for more than 340 kg/ha. The results confirmed that weather factors do not have a statistically significant impact on yields at the altitudes above 200 m (Zubović et al., 2017).

In comparison, our results show that there is a strong dominance of the water scarcity in the sub-periods 2 and 3, as explanatory variables with the greatest intensity, significance, and robustness, while other explanatory variables, although predominantly significant, minimally contribute to the increase in the explanatory power of the model. The increase in the average daily water scarcity of 0.1 mm in phenophase 2 reduces the yield by more than 175 kg/ha and about 45 kg/ha in phenophase 3. Statistical significance of the effect of soil moisture saturation on the day of planting with a markedly negative impact on wheat yield is evident. Changes in harvested areas under wheat in total arable land have a very positive impact on the growth of wheat yield. Therefore the marginal increment of wheat areas is mainly carried out on a better-quality soil, which ultimately results in a higher average yield. The regression coefficients obtained by estimating the pooled model corresponds with the estimation of the model with random effects, while the altitude has a significant negative impact on the yield of wheat.

The results of the estimation (Table 13) imply that the water scarcity in the phenophases 2 and 3 has a significant effect only in the lowlands, while with an increase in altitude above 100 m the effect is rapidly decreasing. Similarly, changes in the areas under wheat make the effect lose intensity and significance with the increase in altitude, which is expected, given that the availability of high-quality agricultural land at higher altitudes is reduced. The specific curiosity of the estimation is a confirmation of the robustness of the extremely negative impact of soil moisture saturation on the supposed day of planting, which manifests itself at higher and lower altitudes as well as on the entire sample.

Table 13
Econometric estimation of full model for each subsample of municipalities, by Random Effects estimator.

Variable	Random effects		
	Alt1	Alt2	Alt3
ff_{2_avg}	−3057.8019***	−1794.3879***	−820.3836
	(493.0989)	(403.0284)	(622.4601)
ff_{3_avg}	−728.1522***	−196.8755	−189.5869*
	(151.4551)	(237.645)	(110.3371)
ff_{1_avg}	−69.6693	−918.6832*	−321.3239
	(448.3952)	(491.6471)	(217.3961)
ff_{4_avg}	−91.4832	−260.1866	−219.1990**
	(91.8951)	(223.8466)	(101.645)
f_0	−1155.8621*	−1985.7989***	−1362.8579***
	(700.3312)	(567.5964)	(310.7278)
ΔP	57.8577***	49.6667	20.5296
	(16.0492)	(32.6167)	(21.9716)
Const	5873.7194***	6121.3335***	4962.1371***
	(689.6182)	(960.1427)	(350.1317)
R Sq	0.43	0.40	0.33
No of obs.	70	56	70

f_0 – planting day.
ff_1 –ff_4 – subperiods.
ΔP - annual change in harvest areas under wheat.
Alt – altitude.
Const – Constant.
R sq – R squared.
No of obs. – Number of observations.
Note: standard errors in brackets; level of significance: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.
Since R Squared is not directly computable in case of RE estimator, it is approximated by the squared Pearson correlation coefficient between actual and modelled values of dependent variable.

5. Conclusions

In order to test the statistical significance of the impact of the weather factors on yields, we used a data panel with data on weather conditions, altitude, wheat yields and share of land under wheat in total utilized agricultural land on a specific territorial unit. A multidimensional regression for fourteen municipalities in Serbia for fourteen years, harmonized with the Hargreaves method of determining reference evapotranspiration has been performed.

The results confirm that an increase in the average daily water scarcity (Δ ET) by 0.1 mm in sub-periods II (November 15th –April 1st) and III (April 1st –May 15th) initiates a potential reduction in yields of about 175 kg/ha and over 45 kg/ha respectively. Moreover, water scarcity has a significant effect on wheat yield only in the plain regions, which with the rise of the altitude above 100 m rapidly loses its intensity and significance.

Results show with a high statistical significance that change in weather conditions observed through variations in precipitation and

Table 14
Econometric estimation of the full model by instrumental variables approach, for the total sample of municipalities.

Variable	Random effects		
	Wald	Bartlett	Durbin
ff_{2_avg}	−1541.7641*	−1727.7214**	−1463.8228**
	(838.3563)	(729.2323)	(629.5273)
ff_{3_avg}	−447.9505***	−470.3919***	−471.5961***
	(127.2834)	(124.2541)	(121.8768)
ff_{1_avg}	−586.0712	−391.3046	−482.5897
	(440.5011)	(353.3202)	(301.5519)
ff_{4_avg}	−151.5509**	−138.2612**	−141.4341**
	(70.8749)	(68.9038)	(67.8455)
f_0	−1626.9988***	−1331.6704***	−1395.7583***
	(596.1523)	(469.0052)	(379.6692)
ΔP	48.8799***	50.0005***	49.9966***
	(14.7623)	(14.6999)	(14.6645)
Const	5726.3029***	5472.1811***	5532.1758***
	(547.2501)	(445.4415)	(378.0676)
R Sq	0.58	0.58	0.58

f_0 – planting day.
ff_1 –ff_4 – subperiods.
ΔP - annual change in harvest areas under wheat.
Alt – altitude.
Const – Constant.
R sq – R squared.
Note: standard errors in brackets; level of significance: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.
Since R Squared is not directly computable in case of RE estimator, it is approximated by the squared Pearson correlation coefficient between actual and modelled values of dependent variable.

temperature increase has a significant impact on wheat yields in Serbia. It is, therefore, recommendable to improve and expand irrigation systems, with the possibility of redistribution of its use only in the second and third subperiods so that they can be moved to other crops in the remaining part of the year.

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