A STUDY OF THE IMPACT OF THE CHANGES IN WINTER PRECIPITATION PATTERN ON THE WINTER CROPS YIELD IN SOUTH CENTRAL REGION OF BULGARIA

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Abstract. The paper discusses the impact of winter seasons climate change on crop yields in the South Central Region of Bulgaria. Twenty-two years long field observations show a progressive increase in air temperature and a decrease in snow cover in the winter seasons. The reduction of snow and the air temperature rise are supposed to lead to reduction of water availability in the spring for the winter crops and respectively to lowering their yield. By compiling observed climatic data and those obtained through a spatially distributed climatic model for the region area analysed is the relationship between these climatic parameters and the respective harvest of the winter crops for the last 5 winter seasons. The observed in the analysed period winter crops yield does not show distinctly the supposed dependence on the decrease of the snowfall amount and snow cover residence time. The yields of the last winter season 2019/2020 with the least snow cover and 2°C higher air temperature exceeded those of all other seasons. This effect is explained with the favourable combination of the high air temperature with the amount and monthly distribution of the precipitation in the season.
Keywords: *climate change, snow cover, winter crop yield, hydrological simulations, snow to precipitation ratio*

Introduction

Wheat, barley and oats are one of the most important agricultural crops in Bulgaria - they occupy great part of the country land and provided 62% of the production of cereals in 2019 (MAFF, 2021).

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A study conducted by Bonchev (2020) on a test field in the town of Sadovo (South Central Region) for 6 sorts of wheat in years with different climatic conditions (2016/2017 and 2017/2018) showed that for the formation of the yield of different sorts the influence of the genotype is not so significant, as the hydro-climatic conditions are. Shrestha et al. (1999) also consider that climate change will have significant impact on water availability by changes in the temperature and precipitation patterns, thus affecting the crop yield (Fodor and Pasztor, 2010). The temperature increase leads to diminishing or lack of snow cover in winter, which creates favourable conditions for drought in spring (Brázdil et al., 2015).

The snow cover has a regulating role on the hydrological cycle, recharges groundwater and plays a very important role in solving irrigation problems (Petkova, 2014). Snow to precipitation ratio controls the catchment water storage and the summer runoff (Meriö et al., 2019). The snow cover maintains water balance and creates proper conditions for overwintering of field crops as it protects them against low temperatures (Wimmerová et al., 2017). According to Watson (2020) snow is more beneficial than rain for the wheat crop in several ways. Moisture from snow does not evaporate immediately because of the cold weather. So it moves down into the soil and remains there keeping the soil warmer during winter as it takes much longer for wet soils to get cold than dry soils. Also, moisture from snow helps the roots to continue growing even when the top growth of crops is dormant during the cold periods. Third, snow cover keeps the soil from blowing, thus preventing wind erosion. Snow cover insulates the soil from the low air temperatures and protects the crown of the wheat plant from cold injury.

Climate change decreases the fraction of precipitation falling as snow and the timing of snowmelt as well. This may have negative effects on food production in basins with agriculture depending heavily on snowmelt runoff (Watson, 2020). Therefore, having information about snow cover formation processes is important in order to know the expected water availability and thermal regime in the region agriculture, respectively the winter crops yield. The soil and climatic conditions in Bulgaria are favourable for growing winter crops. Studying the changes in snow hydrology parameters during the latest years are of great importance for development of resilient agricultural practices.

The main objective of the present study is to assess the impact of climate change, which has already been identified in recent decades on the winter crops. This in particular relates to the change of the amount of the total precipitation, snow-rain ratio and air temperature. The study was done at a regional level in Bulgaria.

To achieve this goal, an analysis of the available information on winter precipitation, air temperature, snow cover and thickness, related to the yield of selected crops, was performed. The above noted hydrological data was obtained from field observations or by use of on-going spatial climatic databases. Due to the lack of sufficient field measurements, the area distributed snow data as snow part of the total precipitation were estimated using hydrological model.

Incomplete data concerning the above discussed information is available for the study area of the South Central Region of Bulgaria at a few hydro-meteorology observation stations. This however does not enable a correct enough assessment of the changes in agro-climatic conditions for the whole territory of the region for implementation of the above targeted studies.

That is why here a physically based Community Land Model (CLM) (Oleson et al., 2004) to study and monitor the processes of snow hydrology has been applied. The

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model is calibrated for the soil and climatic conditions of Bulgaria. As source of its input information - climate, land cover and soil data used is the developed gridded NCEP / NCAR and IGBP database (Kalney et al., 1996). The output of the CLM model is also represented in a gridded format, which facilitates the preparing averaged regional hydrological assessments during the winter season.

By employment of the model, maps of the monthly values (from November until March) of rain and snow, snow depth, snow cover and air temperature for 5 winter seasons have been prepared. They show an increase in the air temperatures, varying snow part of the total precipitation and decrease of the snow cover area and residence time.

Materials and methods

Study area and winter crops characteristics

The South-Central Planning Region of Bulgaria was selected as the study area. The territory includes a large part of the mountain chain of Central Balkan, part of the Rila mountain and the entire massif of the Rhodopes. The north border follows the ridge of Central Balkan - Sredna Stara Planina (*Fig. 1*). The southern boundary of the region reaches the frontier with the Republic of Turkey and the Hellenic Republic. The region’s area is 22 400 square kilometres, which represents 20.1% of the country’s territory. The relief consists of valleys, lowlands, hills and mountains. It contains the most fertile part of Bulgarian land – the Thracian valley.

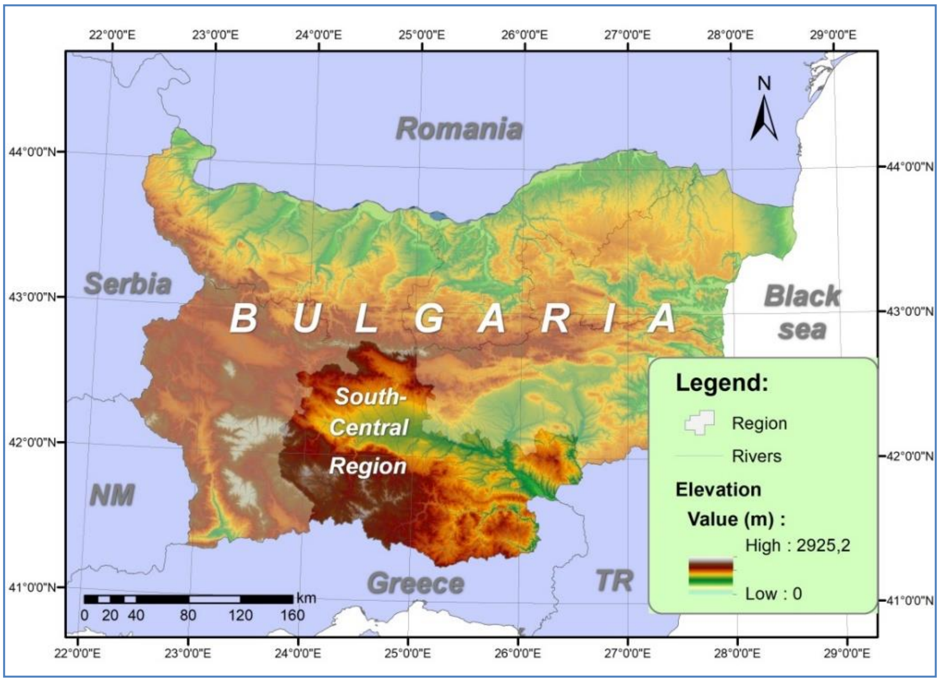

Figure 1. *Map of Bulgaria and South Central Region of Bulgaria*

The climate is predominantly temperate-continental with influence from the Mediterranean Sea in the south-eastern part of the region. It is characterized by long frost-free periods, relatively warm winter and summer and high total temperatures. 1/5

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of the country's surface water resources and about 1/4 of the country's groundwater are concentrated in the region. The main river is Maritsa with about 100 tributaries, more significant of which in the region are Arda and Vycha. The Maritsa River springs from Rila Mountain at 2378 m above sea level The mountains in the South Central Region provide water for downstream agriculture activities along the Maritsa and Arda rivers. In the flat part the precipitation is between 450 and 500 mm/a, while in the mountain and hilly parts it is between 1000 – 1200 mm/a (Santourdjian, 2000).

The most important soil resources are Chromic Luvisols, Chromic Cambisols, Planosols, Vertisoils, Fluvisols; there are also sandy light soils on deforested slopes. The region includes five Bulgarian administrative districts – Pazardzhik, Plovdiv, Smolyan, Haskovo, and Kardzhali with Plovdiv being the regional capital (*Fig. 2*). As of 2016 farmland covers 840 650 hectares, of which the utilized agricultural area is 650 190 hectares and arable land covers 358 860 hectares (Eurostat, 2021).

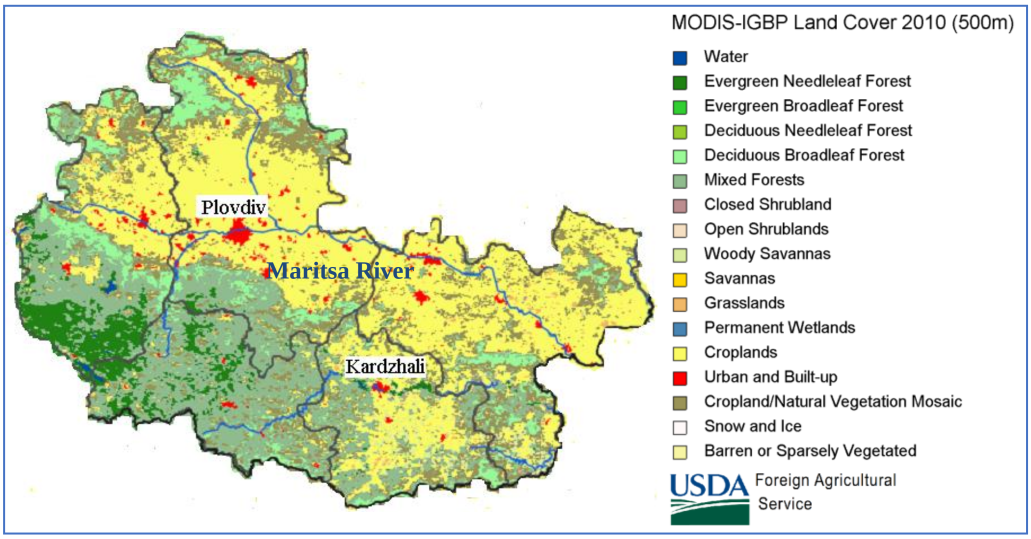

Figure 2. *Land Cover map of the South-Central Planning Region of Bulgaria*

Wheat and barley are sown mainly in late September and early October. Thus, they use autumn moisture in the soil to germinate and develop in their initial stages (Savova, 1994). These phases are essential for their overwintering. The main phase is tillering, during which up to 3 tillers develop on one root. The number of tillers is basic to the high yields of these crops. Decreased tillering and spring tillering lead to a strong decrease in yields (Yanchev and Tahsin, 2000; Kolev et al., 2004). Soil moisture in May-June, combined with high temperatures (above 25^{o}C) during grain maturing (June) are also favorable for good yields.

Of the three crops, oats yield is the lowest because oats are most susceptible to frost. That is why it is grown mainly as a spring crop. It is sown usually in March. This leads to much lower yields because of possible dry periods in the end of May and in June. In such a case the autumn development of the crop is lost and there is an accelerated development in the spring in not always favorable temperature and humidity conditions (Savova, 1994; Georgieva, 1995). With global warming, oats will be able to be sown mainly as a winter crop in September and October and this would increase its yields (Forsberg and Reeves, 1992; Savova, 1994).

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Data and methods

Necessary data about the atmospheric forcing for the research purposes and the modeling of the hydrology processes on the territory of the South-Central region of Bulgaria for the period 2013-2020 are available. Available are also published data about the yields of the winter crops - wheat, barley and oats (MAFF, 2021), as well as data about the number of days with snow cover for the period 2013-2020 on the area of Plovdiv and Kardzhali, and long data series (1999-2021) with measured temperatures, precipitation and the snow cover thickness for the region of Kardzhali. For assessments of the whole South-Central region hydrology applied is the Community Land Model version 3 (CLM3).

CLM is a physically-based hydrologic model developed in the US National Center for Atmospheric Research (Oleson et al., 2004, 2008). The energy and water fluxes are estimated through vegetation processes, energy budget calculations, and water balance calculations based on the theory of mass conservation and Fick‘s law with specified initial and boundary conditions.

The water balance for a SnowpackSlab is presented by *Eq.1* (Arsenault, 2010):

$$Qsnow = Qsnowsubl + Qsnowmelt + \Delta Qsnow(t) \qquad \text{(Eq.1)}$$

where Q_{snow} is the snowfall (kg m^{-2}) (when air temperature is <0^{o}C), $Q_{snowsubl}$ is the sublimation from snow surface (kg m^{-2}), $Q_{snowmelt}$ is the snowmelt (kg m^{-2}), $\Delta Q_{snow(t)}$ is the change in snow amount (kg m^{-2}), t is time step length.

Snow depth formation is calculated by *Eq.2*:

$$Zsnow = \frac{Qsnow}{\rho snow}.t \qquad \text{(Eq.2)}$$

where Z_{snow} is the snow depth (m), ρ_{snow} is the bulk density of newly fallen snow (kg m^{-3}), for dry new snow ρ_{snow} =50-70 (kg m^{-3}), for damp new snow ρ_{snow} =100-200 (kg m^{-3}).

The snow depth decreases along the time due to sublimation, melting and compaction.

CLM3 uses a one-dimensional vertical, multilayer snow model based on the parameterizations developed by Anderson (1976), Jordan (1991), and Dai and Zeng (1997).

The model input uses gridded climate variables such as solar radiation (W/m^2), precipitation (mm/s), air temperature (K), wind speed (m/s), atmospheric pressure (Pa), and specific humidity (kg/kg), with spatial resolution 180 x 180 km and time resolution 6 hours. Soil and plant data are presented by the information for soil texture (% of sand and % of clay), soil color and vegetation parameters (monthly leaf LAI and stem SAI indices), where the spatial resolution is 5 x 5 km. Database with the listed parameters is publicly available. These are aggregated ground-based and satellite observations from different countries and organizations, which are prepared in a uniform grid that is suitable for input of regional climate and hydrological models.

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Results and Discussion

As discussed above, the main factors responsible for the growth and development of winter crops are the amount and monthly distribution of total precipitation, snow cover thickness and residence time, respectively the average snow depth and air temperature during the winter season. As such considered is the period from November to March. Globally, one of the hitherto undisputed effects of climate change is the trend of rising air temperatures and reduction in the share of snow from total precipitation.

Confirmation of this trend for the studied area is seen in the available field data about the precipitation, air temperature and snowdepth during the last 22 winter seasons, measured near to the town of Kardzhali. The town is located in the southeast part of the regarded region at about 280 m above sea level (*Fig. 2*). Graphs of the time data series, averaged for the winter seasons (from November to March) during the period 1999-2021 are shown on *Figure 3*. Plotted are the values of the precipitation (snow plus rain), air temperature and snowdepth, together with the trendlines of their change.

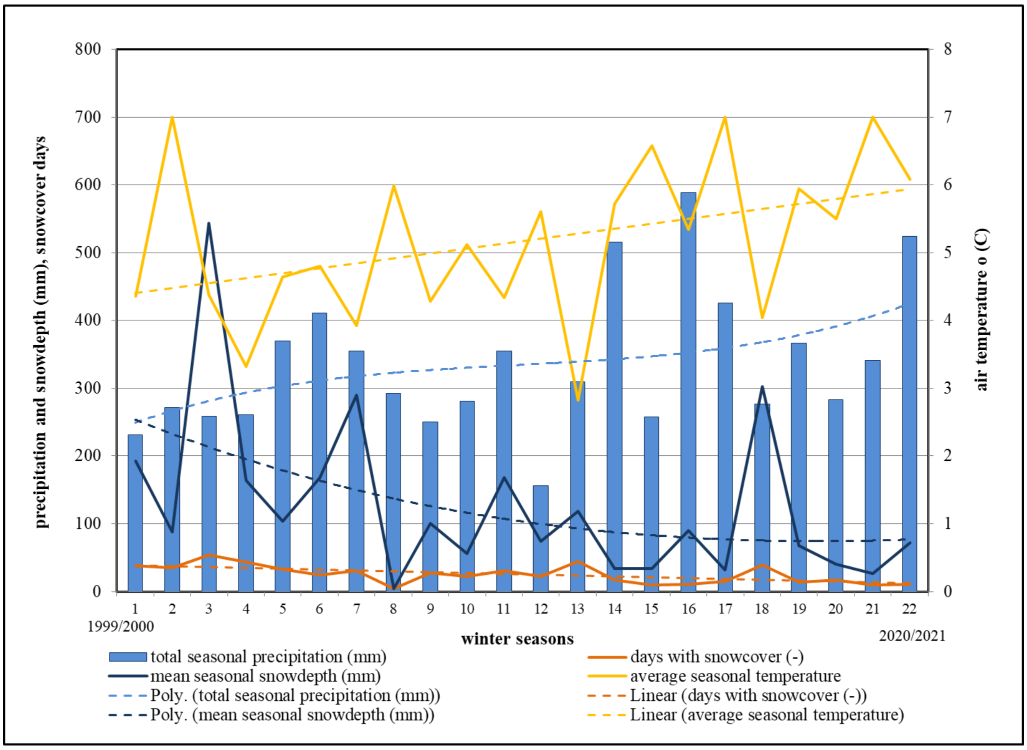

***Figure 3.** Trends of the seasonal total precipitation, air temperature and snowdepth at Kardjali station from 1999/2000 to 2020/2021, (for months Nov, Dec, Jan, Feb and March)*

This was prepared using the public databases STRINGMETEO (2021) and National Institute of Meteorology and Hydrology (NIMH) monthly bulletins (2021). However, they don’t provide information about the part of the snow from the total precipitation. From the measured average monthly snowdepth it is very difficult to recover the amount of precipitation in the form of snow.

The time distribution of winter precipitation and temperatures presented on *Figure 3* shows an increasing trend for the period 1999-2021, while the snowdepth measured in the field decreases during the same period. Temperature rise leads to accelerating of the

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snowpack melting. This shortens the time of water availability due to winter precipitation. The decrease of snow cover normally is supposed to worsen winter agro-climatic conditions.

Checking the degree of validity of these considerations on the importance of the amount of snow and the time of its retention for the development and the yield of winter crops, a comparative assessment of their values during the winter seasons of 5 years with rather different climatic characteristics has been done. For the purpose selected were the last 4 winter seasons – the period 2016-2020, including the months from November to March. The winter season 2013/2014 was additionally added to them as being with a similar scarce amount of rain and snow as the season 2019/2020.

The observed climatic data at the Kardzhali station, as well as the similar at the stations at Plovdiv have local character and do not allow accurate enough hydrological and climatic estimates for the whole area of the region. They don't show the snowfall part from the total winter precipitation either. An estimate covering the entire area is necessary for a well based and reasonable assessment of the considered climatic parameters value and their influence on the region winter crops yield.

This was achieved by employment of the hydrological model CLM to study and supplement the hydrological description of the winter conditions for analysis and comparisons on the considered area, half of which is agricultural land. Mathematical simulations have been made for evaluation of the snow part of the total precipitation and the average monthly snow depth during the five selected years.

For demonstration purposes the model computed monthly averaged snowdepth spatial distribution in December 2018 is presented on *Figure 4*. The highest average monthly values of 5 cm are calculated for the mountainous and hilly parts of the studied region, the lowest values of 1-2 cm are along the Maritsa River, where the agricultural lands are situated.

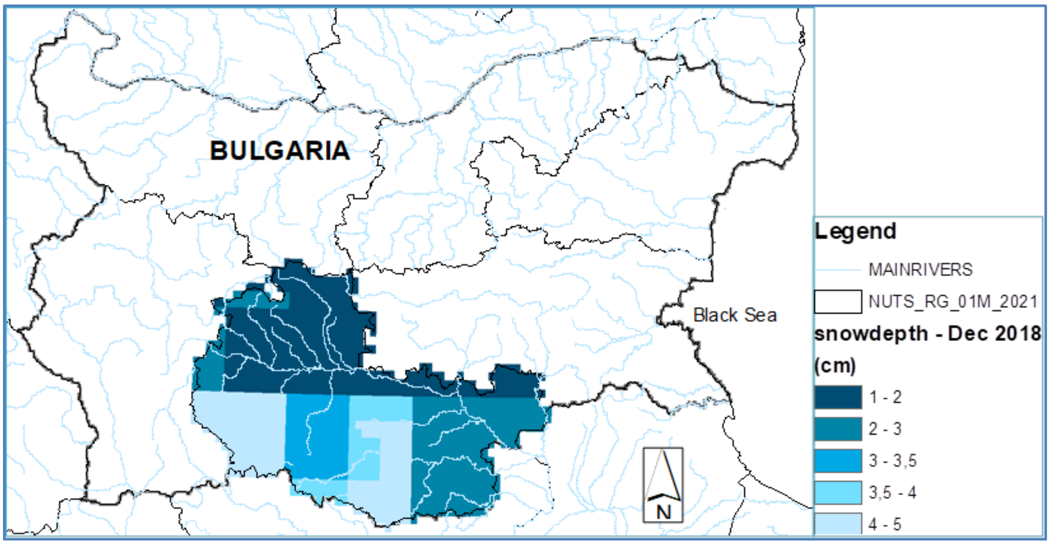

***Figure 4.** Map of CLM model calculated average snowdepth on the Bulgarian South Central Region in December 2018*

The calculated for the South-Central Region mean monthly values of rainfall, snowfall, air temperature and snow depth are shown on *Figure 5*. There is a tendency to

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progressive reduction of the snow depth and increase of the air temperature at the end of the period. The average monthly snowdepth is quite small in the last two winter seasons, being at the critical minimum in 2019/2020. Its highest value of 18 cm is in January 2017, when the air temperature is the lowest.

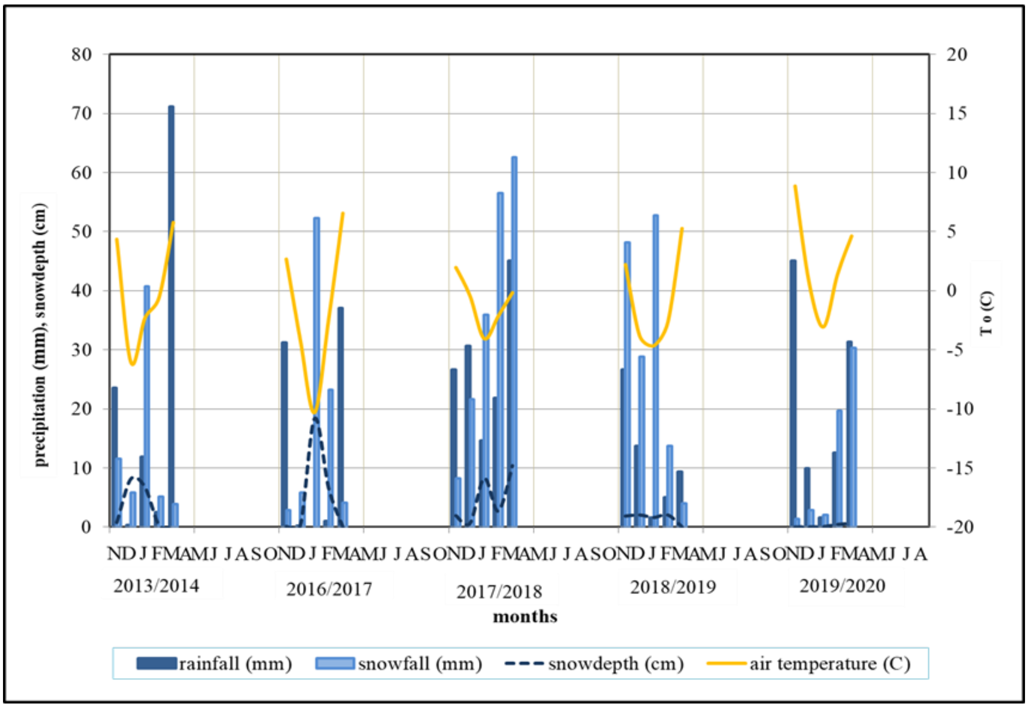

***Figure 5.** Model calculated monthly values of rainfall, snowfall, air temperature and snowdepth during winter seasons*

The credibility of the results comes from comparing the trend of change of the modeled snowdepth with the trend of the number of days in the months with snow cover measured in the field and published by NIMH (NIMH, 2013-2020). The distribution of the days in the month with snow cover is in line with the calculated snowfall and snowdepth. The reliability of model results from simulation of winter conditions was tested in another study on the mountain catchment in the upper reaches of the Struma River (Nitcheva et al., 2021). The modeling of the physical and climatic processes in the South Central Region also shows good enough agreement of the calculated data for snow cover with measured one. The comparisons are made with summarized data for the whole region. The estimated degree of realism of the snow characteristics calculated according to the model is sufficient for confidence in the unambiguousness of the survey results.

To facilitate the analysis, the modeled values are averaged over the 5 season months and presented graphically on *Figure 6*. On the same figure shown are the yields of the winter crops – wheat, barley and oats. These data together with the snowfall / precipitation ratio and the annual yields of wheat, barley and oats, average estimates for the whole South Central region, are shown on *Table 1*.

Table 1 and *Figure 6* show the seasonally summarized values of the hydrological and thermal effects in the considered 5-year period, influencing the soil thermal and humidity regime during the growth of the winter crops. The total precipitation except

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for the seasons 2017/2018 is close to the normal for that part of the year but the snowfall/precipitation ratio changes significantly. For the seasons with the least snowfall 2013/2014 and 2019/2020 it is around 38-36%. The air temperature in the last season is rather positive making the snow cover depth and residence time negligible. At the same time the seasons 2016/2017 and 2017/2018 enjoy nearly normal winter climatic conditions with more snow than rain, negative air temperature and satisfactory for the current stage of climate change snow cover. Within this small span of time, these changes can be assumed as significant and they follow the typical pattern accepted as inherent to the ongoing climate conditions.

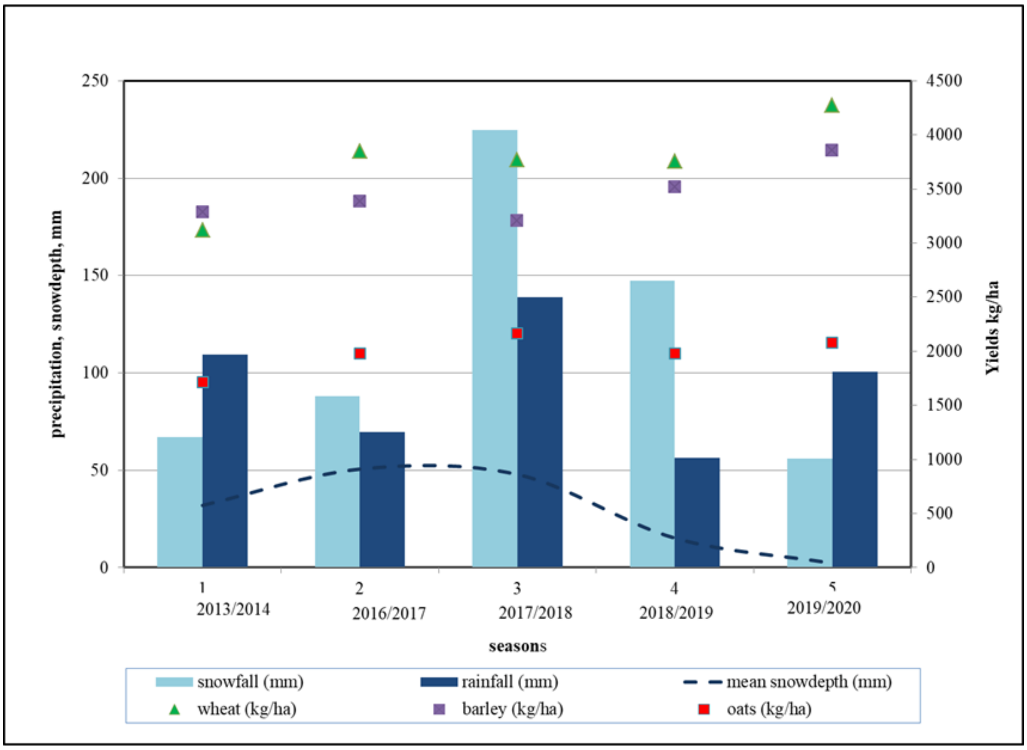

Figure 6. *Model calculated seasonal values of the total snowfall, total rainfall and average snowdepth with the crops yield*

Table 1. *Seasonal precipitation components in mm and air temperature in °C calculated by the model CLM and observed winter crops yield in kg/ha for the South Central Region of Bulgaria*

Winter seasons	2013-2014	2016-2017	2017-2018	2018-2019	2019-2020
Total rainfall (mm)	110	70	139	57	101
Total snowfall (mm)	67	89	225	148	57
Total precipitation (mm)	177	159	364	205	158
Snowfall/precipitation (%)	38	56	62	72	36
Air temperature (°C)	0,3	-1,5	-1,0	-0,7	2,5
Wheat yield (kg/ha)	3479	3849	3768	3754	4272
Barley yield (kg/ha)	3283	3386	3207	3517	3858
Oats yield (kg/ha)	1716	1978	2163	1976	2078

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The yield of the winter crops, which as a rule in Bulgaria are not irrigated, depends on the thermal and moisture regime of the soil during the autumn-winter season. However, the exposed on the *Table 1* yields of wheat, barley and oats in the analyzed 5 winter seasons don't show proportional response to the considered as negative reduction of the snowfall part from the total precipitation amount. Judging from the data on the *Table 1* they are not so sensitive even to the total amount of the precipitation.

Actually the yields of the season 2013/2014 with snowfall much less than the ones in the winter seasons of 2016, 2017 and 2018 are around 10% lower than the yields in these 3 years. Although less pronounced, this result is in line with the logics of the adverse effects of snow reduction on the winter crops growth. On the other hand, noteworthy is the yield of the season 2019/2020, which exceeds the yield of all other considered winter seasons at the same time being with the least snowfall. Most probable explanation for that fact may be the significant rainfall in November (*Fig. 5*) and the positive seasonal mean air temperature, stimulating the early growth and development of the crops.

These conclusions are confirmed by MARS JRC research (bulletin March 2020), based on field and remote satellite observations and model simulations. The CLM model simulations in the present study is in line with those of the European Commission research team (Baruth et al., 2020).

Conclusions

Carried is out an overview study of the impact of the occurring changes in the winter season precipitation pattern and air temperature on the yields of the winter crops in the South Central Region of Bulgaria. The analysis is based on field measurements of climatic data such as total precipitation and air temperature and through a hydrological model estimated snow characteristics for the last 5 winters, covering the whole area.

The general understanding is that the reduction of snowfall and snow cover residence time should lead to a reduction in winter crop yields. The results of the study show that this influence is not strictly observed for the last 5 winter seasons in this region. If it is to some extent confirmed for the season 2013/2014 with little snow, then for the last winter season 2019/2020 with even less snow cover, but with 2°C higher average temperature of air, the yields exceed those of all other seasons. One of the reasons for this phenomenon is supposed to be the high mean air temperature of the season and the monthly distribution of the precipitation with significant rainfall in November.

The main conclusion from the study is that the changes in the main parameters of the climate such as the decrease in the snow part of the precipitation and the increase in air temperature, as well as their distribution in the winter months have divergent effects on winter crops. Their yield depends on the favorable combination of air temperature with the amount, type and monthly distribution of precipitation, which can reduce the role of snow as a determining factor for good yields. The conclusion is in accordance with the agricultural logic. It shows the importance of the reliability of long-term weather forecasts facilitating adequate solutions in the cultivation of winter crops.

Studies with similar purpose, using information from ground observations for precipitation and air temperature and obtained by hydrological models snow amount and residence time, should be performed for other agricultural regions of the country. They will serve for a detailed analysis of the amount and nature of changes in these basic hydro-climatic parameters and in the soil moisture and infiltration as well. As a

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result, their influence on the cultivation and harvesting of winter crops will be clarified. These assessments will be useful for improving the current agricultural practice in the country and for its adaptation to the ongoing agro-climatic changes.

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