WATER BALANCE OF THE CZECH CROP MIX IN 1961 – 2019

Karel MALEC, Department of Economics, Faculty of Economics and Management, Czech University of Life Sciences in Prague, 16500 Prague, Czech Republic. maleck@pef.czu.cz (*corresponding author*)

Zdeňka GEBELTOVÁ, Department of Economics, Faculty of Economics and Management, Czech University of Life Sciences in Prague, 16500 Prague, Czech Republic. gebeltova@pef.czu.cz

Pavel KOTYZA, Department of Economics, Faculty of Economics and Management, Czech University of Life Sciences in Prague, 16500 Prague, Czech Republic. kotyza@pef.czu.cz

Mansoor MAITAH, Department of Economics, Faculty of Economics and Management, Czech University of Life Sciences in Prague, 16500 Prague, Czech Republic. maitah@pef.czu.cz

Changing climatic conditions raised the question of sustainability of current agriculture practice which is based mostly on the intensive farming. This approach requires high inputs including water. The major part of crop production in the Czech republic is depending on precipitations.

The aim of this paper to evaluate precipitation balance for the most common 10 crops planted in the Czech Republic in period 1961 – 2019. To achieve this aim we used the Czech technical norm and so called „optimal rainfalls" for crop production. These optimized precipitation in planting season should ensure optimal yield for each crop. These optimal values are based on the observed temperatures and soil type and quality. We have calculated the optimal rainfalls for 10 most common crops which represents 94,52 %, resp. 92,8 % of the total crop production in the Czech Republic.

The obtained results show deficit of precipitation in the whole observed period, except the years 1965 and 2001. These findings can be interpreted in both ways, precipitations for optimal yield was recorded only in 2 cases out of 59. And at the same time there is a question if the missing precipitation is used from the ground water which increase the problem of droughts of past years.

Keywords: Czech agriculture, water, balance, precipitation, crop mix, deficit

INTRODUCTION

Water balance in the Czech Republic is heavily based on the precipitations (Rožnovský 2019). With the increasing temperatures and different distribution of rainfalls over the year the role of the agriculture procedures as crop mix and crop rotation, soil quality management and farmers approach to the land is very often highlighted and discussed (Možný et al., 2020; Trnka et al. 2020; Gebeltová et al., 2020; Zahradníček, 2020).

The agriculture land represents 53,3 % of total area in the Czech Republic (MoA, 2019) and the intensive farming is prevailing form (Kolářová et al., 2013; Špička et al., 2020). For conventional farming water is one of the inputs which can heavily affect the final yield. But this type of farming also increases the risk of soil degradation and which can result to the loss of water. This issue was very topical in recent years as several years of drought have been recorded (Žalud et al., 2017; Trnka et al., 2012; Maitah, et al, 2021).

Even thought new approaches as organic farming or buying local products are getting popular they still represent a marginal part of total crop production (Chalupová et al., 2021; Lazíková et al., 2021; Zámková et. al., 2020 and 2021; Hronovski et al., 2020).

Thus this paper aims to determine precipitation balance for the most common 10 crops planted in the Czech Republic in period 1961 – 2019. The selected crops are wheat, barley, rye, oats, maize, legumes, rapeseed, Sugar beet, potatoes, and fodder crops. They represent 94,52 % (1961), resp. 92,8 % (2019) of total crop production in the Czech Republic (CSO, 2020).

MATERIALS AND METHODS

The drought calculation comes from the methodology given by the standard ČSN 750434 (Technor, 2017) and data from the Czech Hydrometeorological Institute on average monthly temperatures and precipitation in the Czech Republic during the years 1961 – 2019 serves as input data (CHMI, 2020).

Data on acreage of individual crops is then based on a survey by the Czech Statistical Office (CSO, 2020) Requirements for precipitation bringing optimum yield of selected crops are based on recalculations according to the

representation of individual types of soil for a given region according to Evaluated Soil Ecological Units (ESEU) code, also called BPEJ in Czech (ESEU, 2020).

Classification of agricultural land in the Czech Republic according to grain size (soil type) is based on the ESEU codes. The soil ESEU codes registered in the LPIS database were used. Its scope is in accordance with the records of sown areas kept at the Czech Statistical Office (CSO; Annex No. 3 to Decree No. 227/2018 Coll, On the characteristics of rated soil ecological units and the procedure for their management and updating).

In each climatic region (code 0-9), HPJ (code 1-78) was software filtered for each region of the Czech Republic, depending on the characteristics of the type of agricultural land, ie with regard to its grain size (particle content <0.01 mm). The representation of individual grain classes (fractions) in agricultural soil is evaluated. The three groups of soils are: Light soils, medium-heavy and heavy (light = sandy, loamy; medium-heavy soils are sandy loam and loamy; heavy soils are loamy, loamy and clays.). The soil types distribution is represented by table 1.

Classification of HPJ into soil categories:

a) light soils (sandy, loamy): 4, 13, 17, 21, 22, 27, 31, 32, 34, 37, 39, 40, 51, 55

b) heavy soils (clayey clay, clayey, clay): 6, 7, 20, 23, 41, 49, 54, 57, 59, 61, 63, 64, 66, 69, 70, 71, 72, 73, 74, 75, 76, 77, 78

c) soils lighter and heavier medium (sandy loam, loamy): other HPJ in the interval 1-78 (Gebeltová et al., 2018; ESEU in: Decree No. 227/2018 Coll., representation of ESEU in LPIS internal database of MOA, 2019).

Table 1. Soil types according to ESEU.

Region	Light	Heavy	Soils lighter heavier medium	Area [m2]
Zlínský	5.51	36.22	58.27	1 496 554 673
Jihočeský	27.73	6.52	65.75	4 278 019 596
Královehradecký	18.88	18.42	62.70	2 363 852 816
Jihomoravský	14.27	14.35	71.8	3 640 079 362
karlovarský	34.78	6.78	58.44	1 009 716 160
Liberecký	22.04	6.36	71.60	1 035 909 257
Moravskoslezský	15.88	6.21	77.92	2 167 042 574
Olomoucký	20.55	7.86	71.59	2 448 397 226
Pardubický	19.59	11.79	68.62	2 331 780 137
Plzeňský	23.09	6.23	70.68	3 279 684 157
Středočeský	18.47	9.74	71.79	5 579 411 040
ústecký	14.38	15.84	69.78	2 225 243 682
Vysočina	34.03	2.81	63.17	3 610 309 781
Praha	7.50	3.17	89.33	109 972 672
Total (m2)				35 575 973 132
Total (%)	21.00	10.00	69.00	

Authors based on LPIS, 2021

This soil type structure is taken into account and the standard (CSN 750 434) indicates the needed water for each crop according to the one of the three soil type category.

The water balance was calculated for the 10 crops most frequently represented on Czech agricultural land during the time period 1961 – 2019. These are wheat, barley, rye, oats, maize for silage, legumes, rapeseed, sugar beet, potato and fodder. Their share on agriculture land was 94,52 % in 1961 and 92,8 % in 2019 (CSO, 2020).

Precipitation deficit is presented in mm for individual crops. Water deficit for given crops is based on the Czech technical norm (Technor, 2017). The norm uses the standardized temperatures (ST) according to the long term averages. Optimal rainfalls (OR) were determined for these standardized temperatures. These optimal rainfalls (in mm) are stated for the vegetation period (April – October) and they represent the sum of monthly rainfalls which ensure maximal yield for the given commodity. They differ for each individual crop and calendar month. They are also adjusted according to the observed temperature to involve the effect of evapotranspiration. Thus this method does not require precipitation standards as an input, as the required precipitation are calculated in respect to the temperatures standards adjusted to the observed temperatures and soil type in the given region.

The water demand of a plant (Wd in m3 / ha, mm) is water that the plant consumes for the expected development in the growing season to physiological processes in the given climatic conditions.

Optimal rainfalls (OR in mm) represents monthly total precipitation in the growing season at which optimal yields are achieved in the given climatic conditions.

The water deficits have been calculated according to the following method:

The OR have been calculated for each of the 10 selected crops according to the soil type and quality. This was possible because the soil in the Czech Republic is categorized according to the ESEU, which is 5 digits code indicating the climatic region, soil type, stoniness and soil depth, slant and exposition (Gebelotová & Malec, 2019).

Based on that we could adjust the OR for each of 13 regions and each of the 10 selected crops in the Czech Republic (CSO, 2020).

The whole process is based on soil type. The ČSN 750434 distinguish there categories and OR for each of this category. Based on the percentage share in the give region was possible to use weighted average, where the weight was

share of soil type (ST), to get the final OR for our calculations. Thus the final OR for given crop, in given month, and in given region is expressed as:

$$OR = \sum_{i=1}^{n} ST_i * OR_i \qquad (1)$$

Where: ST_i = Area of individual soil type category, OR_i = Optimal rainfall for given soil type category.

1. The temperature standards (TS) have been compared with the observed temperatures (OT) for given month and year. The TS given by the technical norm are in the table 2.

Table 2. Temperature Standards.

Month	IV	V	VI	VII	VIII	IX	X
Normal temperature (°C)	9	14	17	19	18	14	12

Authors based on Technor, 2017

2. If the observed temperature is higher or lower then the TS, then the OR is needed to be adjusted to involve the effect of evapotranspiration. For each +1°C above the temperature standard, OR are increased by 5 mm; oppositely, for each -1°C below the temperature standard, OR are decreased by 5 mm. These adjusted optimal rainfalls (AOR) should ensure optimal yield, ceteris paribus. This method is based on Klatt's approach and takes the changes in evapotranspiration related to the temperatures into account (Klatt, 1958). For the Czech conditions this values were adjusted by Baňoch et al. (1980).

$$AOR = OR + (TS - OT)*5 \qquad (2)$$

3. Then the AOR have been compared with observed rainfalls (RR) to identify if there was some deficit and how much mm of rainfalls was missing. The whole procedure is represented by table 3.

$$D = AOR - RR \qquad (3)$$

Table 3. Water requirements calculation.

Line	Crop/Item/Month	Unit
1	Temperature standard (TS)	°C
2	Observed temperature (OT)	°C
3	Observed temperature rounded to whole numbers (ROT)	°C
4	Temperature difference (td); (Line2 - Line1)	°C
5	Optimal rainfall (OR)	mm
6	Adjustment for OR (AOR)	mm
7	AOR; (Line5 + Line 4), Correspond with water requirement (WR)	mm
8	Observed rainfall (RR)	mm
9	Deficit (D); (Line7 - Line6)	mm

Authors based on Technor, 2017

Water deficit (D in mm) is the sum of water deficits for observed months (d) in the given year. Water surplus in one month can affect the water balance in the following month, thus the rainfall above the stated OR is transferred to the next month in max. value of |30|mm to capture the influence of soil moisture on the total water balance (Technor., 2017).

4. Then the average for all selected crops and their vegetation months have been considered as average total rainfall deficit (TD) for given year.

The water deficit (DW) is calculated according to the following formulas:

$$DW = WB * A \qquad (4)$$

Where: DW= water deficit, WB = water balance for individual crop, A = harvest area of given crop

RESULTS AND DISCUSSION

The obtained results are represented by figure 1. There were recorded only two years with no deficit for the whole 59 years long period. Although there was not possible statistically determine trend from the figure 1 is obvious increasing tendency to achieve higher values (deficit higher than 60 mm) since nineties.
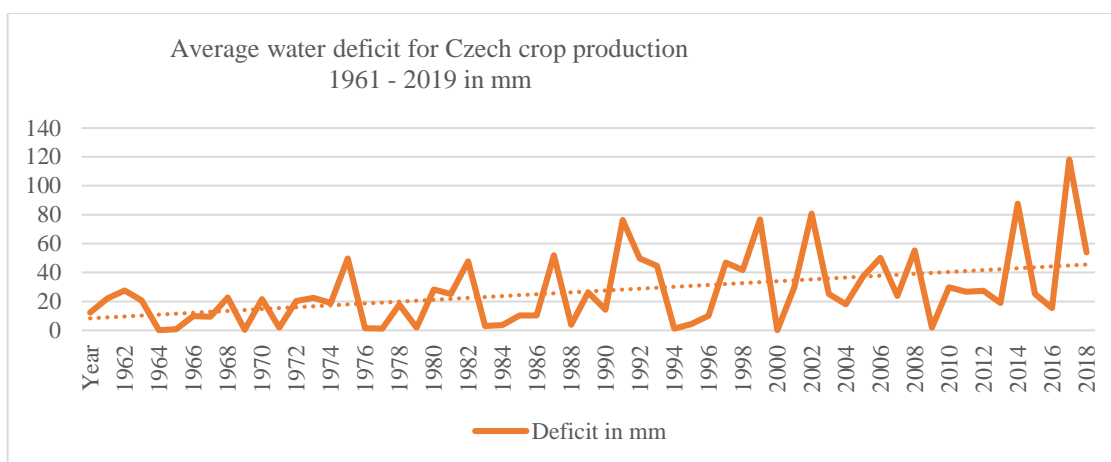
Figure 1. Average water deficit for Czech crop production 1961 - 2019 in mm

The figure 2 brings histogram for all calculated deficits. From all 58 averages 29 of them belongs to the category 0 – 22 mm missing precipitation to have the condition for optimal yield. Category 22 – 44 mm average water deficit for crop production was found in 16 cases and 44 -66 mm in 9 individual years. More severe deficits represented by category 66 – 88 mm were found in 4 cases (76,2 mm in 1991; 76,7 mm in 1999; 80,7 mm in 2002; 87,65 mm in 2014), then there are no values in the category 88 – 110 mm and one outlying value in category 110 – 132 (118,05 mm) was found for year 2017.
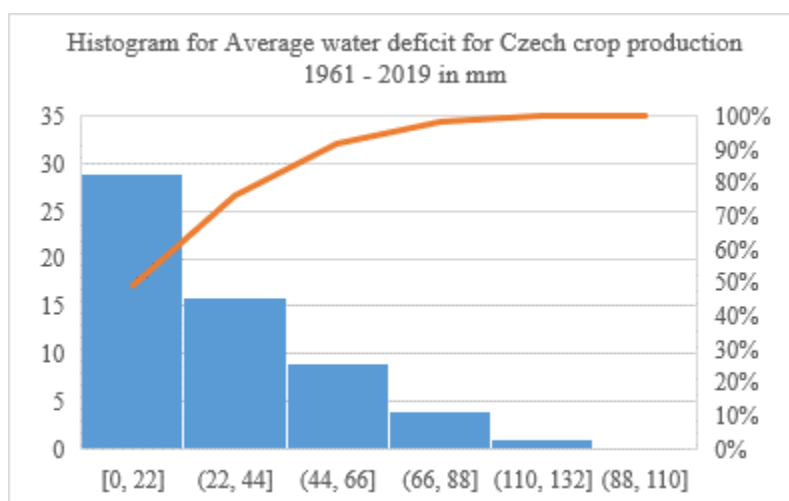

Figure 2. Histogram for Average water deficit for Czech crop production 1961 - 2019 in mm

The total deficit is represented by figure 3 and the development corresponds with the average values, as there were not found significant changes in the total area of agriculture land. The blue line in the figure represents the total deficit in m3. The highest total deficit has been recorded in 2018 and reached almost 260 millions of cubic meters. No deficits have been found for years 1965 and 2001 in accordance with average deficits in mm.

Our calculations show that Czech crop production brings requirements on the surface water and lead to its consumption. Although the situation is very variable based on the temperature and precipitations in given year the question of sustainability of this practice is reasonable. But it is not only the impact of weather or climatic conditions. Also, the crop mix, area of individual crops will affect overall water balance of the Czech crop production. The selected crops differ in their requirements for precipitation and thus further research analyzing the changes in crop production structure should follow.

The employed method offers large scale comparison, and it is suitable for bigger areas as regions, as it is not so demanding on inputs. But there are needed data about the soil quality which specific for the Czech Republic that this type of data are available. The other methods for water balance or irrigation requirements are more complex and it is usually quite complicated to apply them large scale, but they can bring more detail results.

On the other hand, it is obvious, that the shift of climatic conditions will affect the integrity of ecosystem, yield, growing cycles and physiological and biological rhythms (as water use, potential evapotranspiration, biomass production, drought resistance, etc. (Butcher et al., 2014). This will bring new demands on soil and water management (Mehdi et al., 2015; Teshager et al., 2016). Decreasing yields will result in changes of localization of planted crops (EEA, 2012).
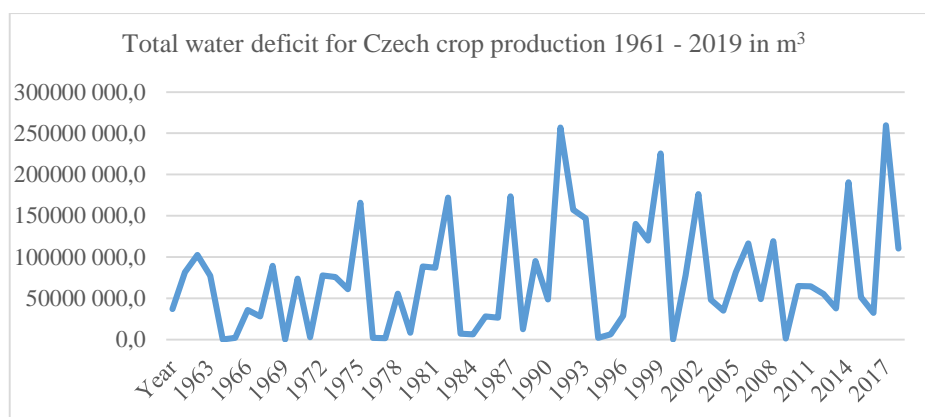
Total water deficit for Czech crop production 1961 - 2019 in m³

Figure 3. Total water deficit for Czech crop production 1961 - 2019 in m3

Farm adaptation opportunities, such as improving irrigation planning, changing crop mix, using new crop varieties and improving irrigation efficiency, will make a significant contribution to adaptation (Howden et al., 2007; Leclere et al., 2013; Gebeltová et al. 2020). However, many authors call for a reassessment of water institutions and policies currently in use and the introduction of incentive-based policies for more effective implementation of adaptation (Booker et al., 2005). Public policies that provide subsidies for investment in efficient irrigation systems (irrigation modernization) are also considered important options for adaptation to climate change (Varela et al., 2014). According to (Kahil, 2015), for example, the water market shows greater economic and social benefits compared to irrigation subsidy policies.

Rocha (2020) recommend adaptation strategies such as the implementation of state-of-the-art technologies (eg soil moisture and water stress probes, satellite imagery and drones for water stress assessment - NDVI), as well as irrigation network restoration and adequate crop selection can help mitigate effects Climate change on water resources in the region.

The vulnerability of water resources in these areas will therefore require management plans to adapt the demand for irrigation to climate change, which could consider improving water efficiency, water prices and changing crops more efficient and water-resistant (Chavez-Jimenez et al., 2014).

CONCLUSION

The aim of this paper was to determine the basic water balance for the crop production in the Czech Republic. We used data for period 1961 – 2019 and for the 10 most common crops representing more than 90 % of total sowing areas over the given period. The method itself is based on the Czech technical norm which indicates required level of precipitation for optimal yield for selected crops according to the soil characteristics and weather conditions (temperatures). The research is based on assumption that if there is a lack of precipitations during the vegetation period the crops will use the surface water or the yield will decrease. Czech republic water balance is depending on rainfalls and thus the long term water deficit in agriculture may be problematic for the water resources.

We found water deficits for the whole period except the years 1965 and 2001. But it is needed to say that these deficits vary over time and tend to be higher in the last 30 years, especially in last decade, which corresponds with the other author findings regards the climatic changes and its effects on central Europe countries. There can be more reasons causing this disbalance of water use for crop production and thus further research is needed to identify changes in the areas of individual crops, their yields, etc.

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