Agricultural Water Management 188 (2017) 126–135

Contents lists available at ScienceDirect

Agricultural Water Management

journal homepage: www.elsevier.com/locate/agwat

Impacts of water availability and drought on maize yield – A comparison of 16 indicators

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ARTICLE INFO

Article history:
Received 1 October 2016
Received in revised form 7 April 2017
Accepted 10 April 2017

Keywords:
Precipitation
Drought
Water balance
Soil water holding capacity
Water use efficiency
Hybrids

ABSTRACT

Agricultural drought causes serious yield losses for rainfed crops (including C_4 crops) and is a cause of higher costs incurred by irrigation use. Drought episodes have been more frequent in Central Europe in recent years and have caused problems in terms of crop and livestock production due to a lack of available feed. The main aim of this study is to examine 16 water availability indicators (suitable for the evaluation of agricultural drought) to help explain maize silage yields. A parallel aim is to determine the period during which current maize hybrids for silage are the most vulnerable to water availability shortages. These aims reflect a current need for accurate drought impact assessment methods that can be applied as an early warning system or as part of a decision making protocol. For the purposes of this study, data from rainfed silage maize field experiments conducted between 2011 and 2015 in 4 locations (throughout the Czech Republic) were used. Relatively high correlations were found using precipitation totals for July alone, as this simple indicator explained 64% of the observed variability in the average silage yields of maize. Overall, the highest R^2 (coefficient of determination) of 0.77 was obtained when the sum of actual evapotranspiration (ETa) for May to August was applied as an independent variable. This indicator also gave the most consistent response for all of the individually assessed months. The lowest ETa totals from May to August occurred during an extremely dry year (2015). The significance of this drought episode was exacerbated by its spatial extent and severe impacts on regional maize silage yields throughout the entire Czech Republic. The selection of hybrids according to FAO numbers has not been proven (based on included data) to serve as an adequate adaptation measure for severe episodes of drought, although higher FAO values should provide slightly higher yields in such cases. The recommendation for farmers is not to rely on one hybrid alone, but instead use hybrids with different FAO values for a given year.

1. Introduction

Water availability and drought episodes have become one of the main factors affecting field crop yields and variability in the Central European region, including in the Czech Republic (Hlavinka et al., 2009; Kolář et al., 2014; Brázdil et al., 2015; Potopová et al., 2015). This situation has been caused by climatic trends leading to drier conditions (e.g., Brázdil et al., 2008; Trnka et al., 2014a, 2015a) and is due to the changed relationship between drought occurrence and its impacts on field crop yields (Trnka et al., 2012). Mentioned study on these trends reveals the potential impacts of ongoing climate change, and according to predictions for Central Europe, it will change agricultural conditions (Zalud et al., 2009) and will spur more frequent, severe, and likely prolonged episodes of drought (Trnka et al., 2013, 2015b). This trend is problematic not only for C_3 plants but also for C_4 plants as shown by, e.g., Hlavinka et al. (2009) and Potopová et al. (2015). Drought conditions are expected to worsen, and even according to optimistic climate change scenarios (Trnka et al., 2014b). Maize production is threatened by this phenomenon, and this will come with serious repercussions for Central Europe and globally, as maize is one of the most important cereal crops grown worldwide. Maize is widely grown throughout the world in tropical, subtropical, and temperate climatic zones, is an important staple crop in many countries, and is used in animal feed and for many industrial applications (as a raw material;

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http://dx.doi.org/10.1016/j.agwat.2017.04.007
0378-3774/

as a source of starch; as a sweetener; in oil, drinks, glues, alcohol, and fuel and as a source of biogas). Consequently, it is important to determine constraints on maize production, including the sensitivity of current hybrids to water availability and drought occurrence. This need is highlighted by the fact that almost all maize production in the Czech Republic is rainfed (without irrigation). The impacts of an extreme summer drought episode occurring in 2015 when maize yields were significantly reduced throughout the Czech Republic forced the government and EU to approve of compensation payments to afflicted farmers. Maize was cultivated on approximately 325 thousand hectares, of which 80 thousand hectares of maize was grown for grain while the remainder was grown for silage and green materials in the Czech Republic in 2015. The historical development of total maize acreage correlates with the number of cattle, which has declined significantly. Currently, due to new biogas station operations, this situation has partly stabilized. Compared to yields for 2014, maize grain yields were approximately 34% lower in 2015 with an average yield of 5.54 t/ha (Czech Statistical Office). Furthermore, the harvested maize silage yield was approximately 30.0% lower relative to the previous year, was the lowest since 2003 and was related to lower levels of nutrient quality (based on the total starch content). This drop in 2015 partly occurred due to the occurrence of an extreme summer agricultural drought in the Czech Republic when a severe dry episode occurred in the beginning of July and ended throughout much of the area on August 18th, 2015 due to the emergence of a cold front. The drought episode negatively affected biomass accumulation within the reproductive phenological stages. This period is particularly sensitive to stress due to the occurrence of intensive growth (e.g., Sirisampan and Zoebisch, 2005; Tolk et al., 2016). A second important feature of this episode involved a high number of very warm days. Additionally, another important feature pertained to the episode's spatial dimension, as the drought affected the entire Czech Republic territory (with the exception of mountainous regions).

The link between drought and maize growth and development can be investigated in terms of water use efficiency levels, e.g., by using lysimeters (e.g., Tolk et al., 2016), in terms of transpiration (Messina et al., 2015), or with a focus on radiation use efficiency (Earl and Davis, 2003). The sensitivities of selected hybrids have been investigated by, e.g., Kamara et al. (2003) and Spitko et al. (2014), and agronomic measures have been investigated by Sirisampan and Zoebisch (2005). Most results in this area have been obtained through field observations (e.g., Lobell et al., 2014), but crop growth models are often used as a research tool (e.g., Wu et al., 2015) and for extreme weather (heat waves and droughts) impact assessments of recent and future climatic conditions (e.g., Chung et al., 2014). This approach is limited in its high input data requirements for analyses, heavy requirements in terms of modeler skills (growth models are sophisticated tools), remaining uncertainties due to calibrations, and degrees of complexity or simplification in selected algorithms. These factors are certainly limit spatially universal, non-problematic and efficient (e.g., for the purposes of early warning systems) crop growth models for larger regions or states. On the other hand, the availability of simple, robust, and descriptive indicators for the evaluation of drought impacts is desirable.

The main aim of this study is to evaluate a set of various water availability (drought) indicators and to determine which has the strongest correlation with maize silage yields. A parallel aim is to determine the period in which current maize hybrids for silage (and under recent agroclimatic conditions) are most vulnerable to water availability shortages. These aims reflect a current need for accurate drought impact assessment methods (for the precise quantification

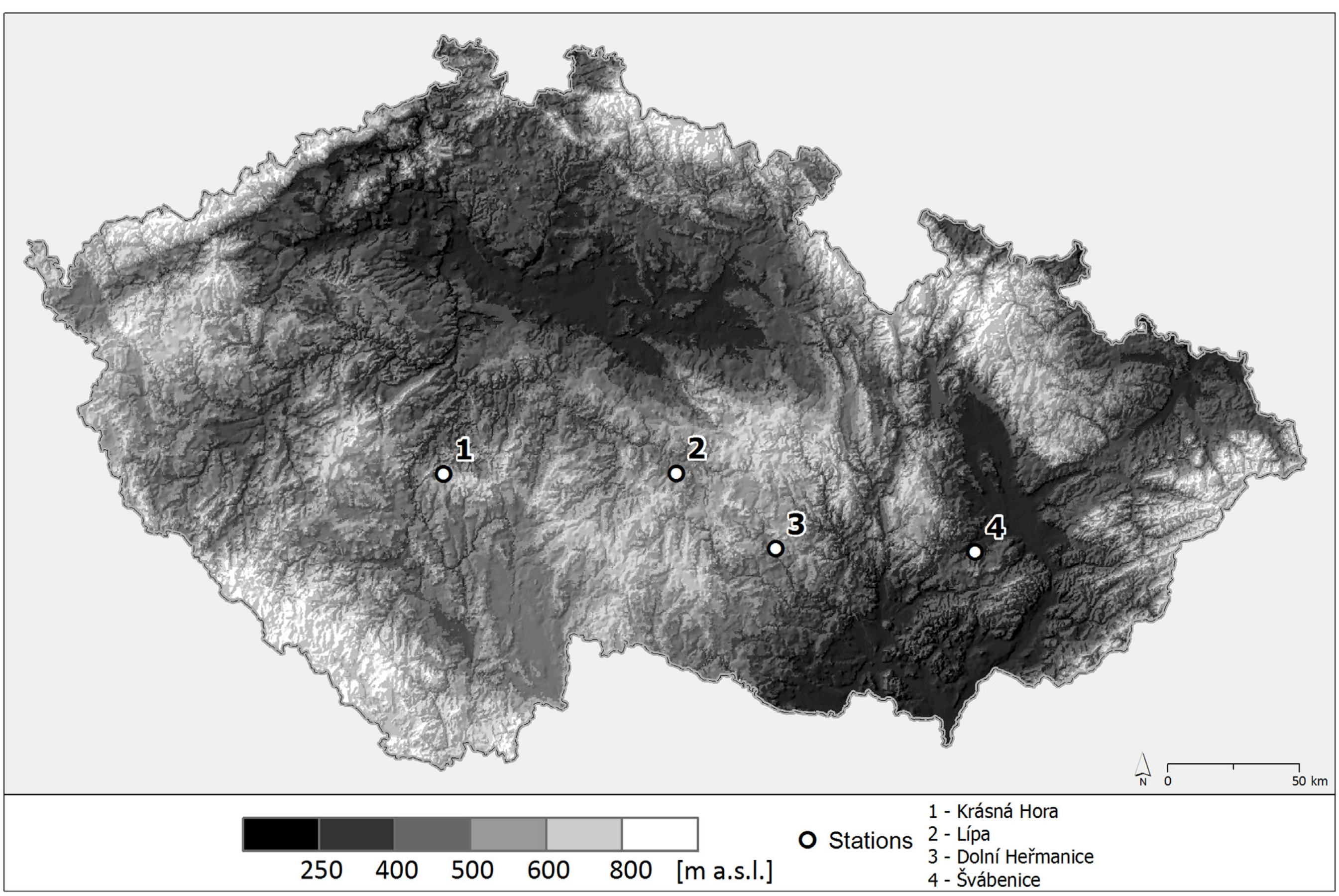

Fig 1. Locations of the stations considered throughout the Czech Republic.