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Changes of drought indices in relation with the geographic altitude of the crop site

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The water availability of the crop site is a determining factor regarding plant growth and development. An assessment study has been done at the MATE University, Gödöllő to evaluate the magnitude of aridity in relaion with the geographic location of the crop site. Field crop species (Sugar beet Beta vulgaris, winter barley Hordeum vulgare, winter wheat Triticum aestivum, maize Zea mays, potato Solanum tuberosum, and alfalfa Medicago sativa) were examined in the study. Long term data of twelve meteorological stations (Békéscsaba, Budapest, Debrecen, Miskolc, Mosonmagyaróvár, Nagykanizsa, Nyíregyháza, Pécs, Siófok, Szeged, Szolnok, Szombathely) representing all regions of Hungary were used as a basis of evaluation. PAI indices of each station were processed with vulnerability indices of the field crops studied. The results obtained suggest, that of cereals proved to be the least susceptible, while potato and maize were proved to be highly influenced by aridity x vulnerability interactions. Strong climatic impact could be detected in the case of alfalfa and sugar beet. The geographic altitude of the crop site has shown negative correlation with the magnitude of drought indices.

KEY WORDS: drought, field crops, altitude, crop site, vulnerability

Introduction

Water availability provides bases for all live systems. Water availability of crop sites is a determining factor regarding plant growth and development. The two main factors determining that are the temperature and the precipitation of a certain crop site (Fig. 1). Land use patterns highly impact water availability of certain crop site. Quantifying the influence of land use changes on water and energy fluxes, it is necessary to evaluate their quantitative characteristics (Novák, 2023). Water deficiency of crops is labelled as aridity, however the physiological state my range from water scarcity to drought (Várallyay, 2006). All physiological processes are dedicated to the presence of moisture, like photosynthesis, osmosis, turgor, transpiration, respiration, as well as growth and development, and propagation. Water supply may have an influence in all of them. Aridity in general may obstruct growth and development, however drought is the most crucial from among all types of water scarcity.

Definition of droughts can be assessed in three main ways (Jolánkai et al., 2012):

(1) Meteorological drought is defined when there is a prolonged period with less than average precipitation. Meteorological drought usually precedes the other kinds of drought.
(2) Agricultural droughts affect crop production or the ecology of the area. This condition can also arise independently from any change in precipitation levels when soil conditions and erosion triggered by poorly planned agricultural endeavours cause a shortfall in water available to the crops. Drought is a phenomenon when a plant suffers irreversible physiological damages.
(3) Hydrological drought is defined when the water reserves available in sources such as aquifers, lakes, and reservoirs fall below the statistical average. Hydrological drought tends to show up more slowly because it involves stored water that is used but not replenished. Like an agricultural drought, this can be triggered by more than just a loss of rainfall.

There are various assessments for quantification of water scarcity. Aridity indices are numerical indicators of the degree of dryness of the climate at a given location. A number of indices have been used in various parts of the world, like Köppen and Thornthwaite indices (UNEP, 1992). Values of the aridity index are indicators of the water conditions of certain areas have been developed by researchers for water scarcity assessment (Rattayova et al., 2022). These indicators serve to identify, locate or delimit regions that suffer from a deficit of available water, a condition that can severely affect the effective use of the land for such activities as agriculture or stock-farming. In Hungary the Pálfai Drought Index (PAI) is extensively used in agrometeorology (Pálfai, 1990; Lakatos and Szalai, 2010). In all aridity indices climatic

components are expressed in mathematical formulas. Geographic locations in this context are very seldom examined upon the basis of crop site altitude, however the elevation may have a profound role in the utilization of natural water resources by the vegetation and so by the crop plants produced. Fig. 2 presents geographic altitude data of the Carpathian basin.

This tract of Europe is a part of the Danube river catchment area covering about ¼ million square kilometres, where over 60 percent of that area forms lowlands. The basin begins by Devin, Slovakia with an elevation of 134 m, and the lowest point of that is at the South-Eastern part of that, Portile de Fier, Romania with 61 m outflow level. Majority of the lowland areas are in the territory of Hungary, from which data of 12 meteorological stations have been used in this study.

Agricultural crops have diverse reactions to water availability conditions. According to their taxonomy, life cycle, evapotranspiration patterns and the crop site characteristics, crop plants can be clustered to various vulnerability groups. The present study is dealing with the interaction between aridity and climatic vulnerability of some of the major field crop species of Hungary, as well as to evaluate changes in the aridity indices in relation with the geographic altitude of the crop site.

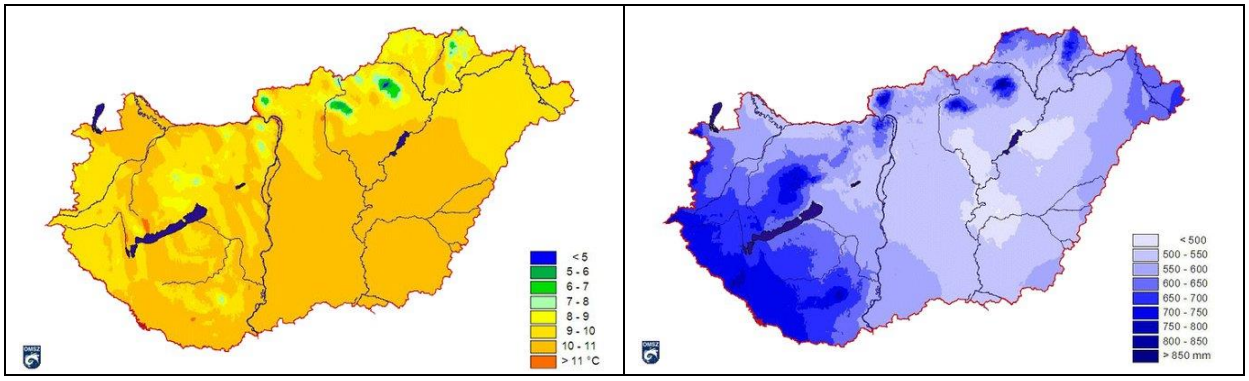

Fig. 1. Annual mean temperature and average precipitation in Hungary on a 30 years' timescale (OMSZ, 2022).

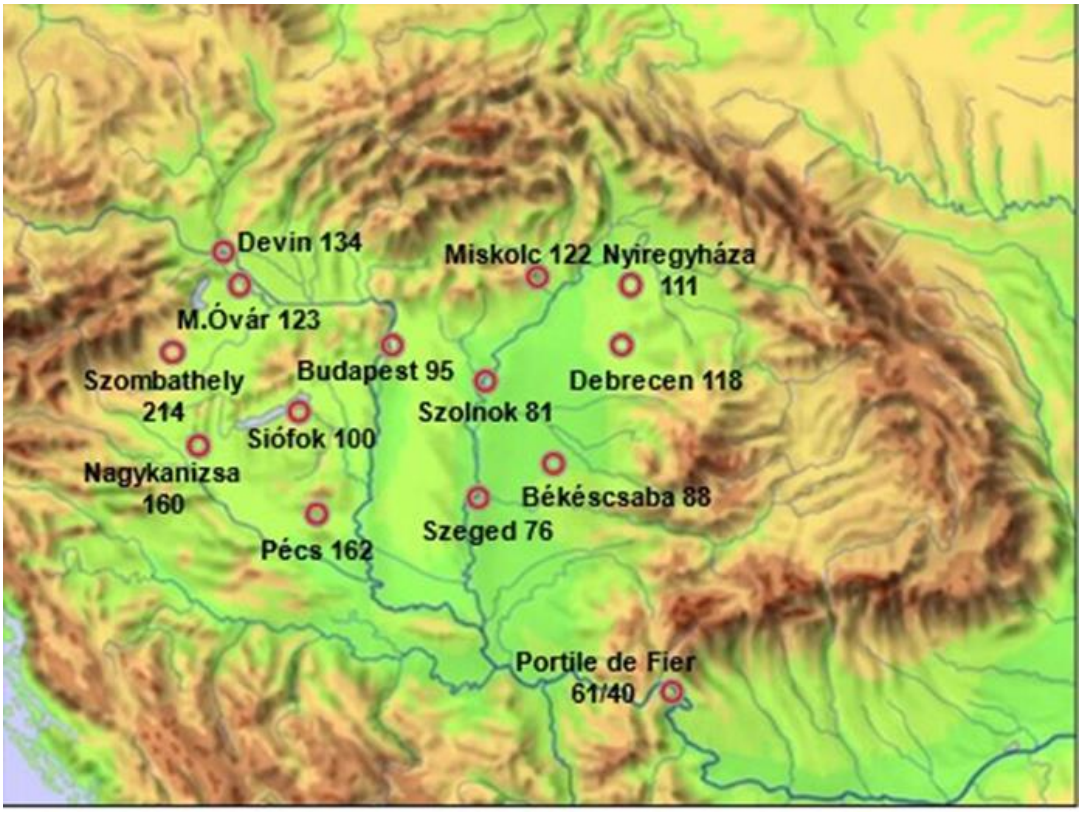

Fig. 2. Geographic altitude data of some meteorological stations in the Carpathian basin [m a.s.l.].

Material and methods

An assessment study has been conducted at the MATE University, Gödöllő to evaluate and identify the main factors of aridity. Almost all major field crop species were involved in the study, from which six species (Sugar beet *Beta vulgaris*, winter barley *Hordeum vulgare*, winter wheat *Triticum aestivum*, maize *Zea mays*, potato *Solanum tuberosum*, and alfalfa *Medicago sativa*) have been evaluated and presented. Crop vulnerability values were based on the mathematical model of Tarnawa et al. (2010). In the survey databases of the Hungarian Meteorological Service (OMSZ) and the Ministry of Agriculture (AM) have been used (KSH, 2022; OMSZ, 2022). The use of Pálfai Drought Index has been applied during the survey (Pálfai, 1990; Bihari et al., 2012). PAI values have been evaluated in a context of long-term databases. Regional evaluations were done respecting the databases of 12 meteorological stations chosen randomly to represent most of the regions of the territory of Hungary (Vermes, 2011; Tarnawa et al., 2012).
Evaluating the long-term data bases the methodology of the state of the World's land and water resources for food and agriculture – Systems at breaking point (FAO, 2021) was used. For statistical evaluations standard methods were applied; correlations, regression analysis, offered by Microsoft Office 2006.

Results and discussion

Pálfai Drought Indices of certain meteorological stations of the OMSZ Hungarian Meteorological Service (Békéscsaba, Budapest, Debrecen, Miskolc, Mosonmagyaróvár, Nagykanizsa, Nyíregyháza, Pécs, Siófok, Szeged, Szolnok and Szombathely) calculated on 50 years' averages were processed for each crop species studied. The results presented in Table 1 verify detectable differences between locations.
The twelve meteorological stations that were randomly chosen to represent various levels of drought probability. The highest PAI indices were found in the case the central and the South-eastern part of Hungary, while in the mountainous locations westward smaller figures were observed.
Studying the interactions between drought and vulnerability the data suggest that crop species in accordance with their water consumption patterns and physiological characteristics may have a rather diverse performance in relation with the crop site PAI values.
Fig. 3 presents data of the survey where the crop sites belonging to the certain meteorological stations were evaluated by the geographic altitude of them.
Yield performance of the six crop species had a reducing trend due to the geographic elevation of the crop site. PAI x VI interactions have shown constant reduction of the crop yields. The trend line of this reduction was labelled by a strong linear regression. The lowest altitude was that of the Szeged crop site with 76 m above sea level, while the highest one of Szombathely had a geographic elevation of 214 m. The reason of this trend may be due to the annual mean temperature and the average precipitation of the location as this can be detected by the data of Fig 1. Central part of the lowland proved to have a higher temperature mean belonging to the annual 10–11°C isotherm range, while the same locations received an annual 500–550 mm precipitation over the long term.

Table 1. Drought x crop vulnerability interactions regarding twelve meteorological stations and six field crop species based on 50 years' average

PAI [°C/100 mm]	VI indices	wheat	winter barley	maize	potato	alfalfa	sugar beet	mean
		5.6	5.8	7.3	6.5	7.6	7.7	6.75
Békéscsaba	5.47	5.5	5.6	6.4	6.0	6.5	6.6	6.11
Budapest	5.85	5.7	5.8	6.6	6.2	6.7	6.8	6.30
Debrecen	4.91	5.3	5.4	6.1	5.7	6.3	6.3	5.83
Miskolc	4.18	4.9	5.0	5.7	5.3	5.9	5.9	5.47
Mosonmagyaróvár	4.69	5.1	5.2	6.0	5.6	6.1	6.2	5.72
Nagykanizsa	3.79	4.7	4.8	5.5	5.1	5.7	5.7	5.27
Nyíregyháza	5.23	5.4	5.5	6.3	5.9	6.4	6.5	5.99
Pécs	4.22	4.9	5.0	5.8	5.4	5.9	6.0	5.49
Siófok	5.07	5.3	5.4	6.2	5.8	6.3	6.4	5.91
Szeged	5.88	5.7	5.8	6.6	6.2	6.7	6.8	6.32
Szolnok	6.02	5,8	5.9	6.7	6.3	6.8	6.9	6.39
Szombathely	3.79	4.7	4.8	5.5	5.1	5.7	5.7	527
mean	4.92	5.2	5.4	6.1	5.7	6.3	6.3	5.83

There were some alterations within the records since the most arid areas of the Great Plain belonging to the less than 500 mm range are located by the Szolnok station which is labelled by a higher PAI index than that of the Szeged crop site. Also, the highest altitude of this study at Szombathely with its 214 m had a medium level of PAI drought index. In the case of crop species the trends were almost consequest, but have shown detectable differences in accordance with their vulnerability. The results of the study support the postulated, that cereals were the least susceptible species, while potato and maize were proved to be highly influenced by drought x vulnerability interactions. Strong climatic impact could be detected in the case of alfalfa and sugar beet. Altitude of the crop site was in negative correlation with the magnitude of drought indices.

Fig. 4 presents the regression data of the PAI drought indices related to the altitude of the crop sites'

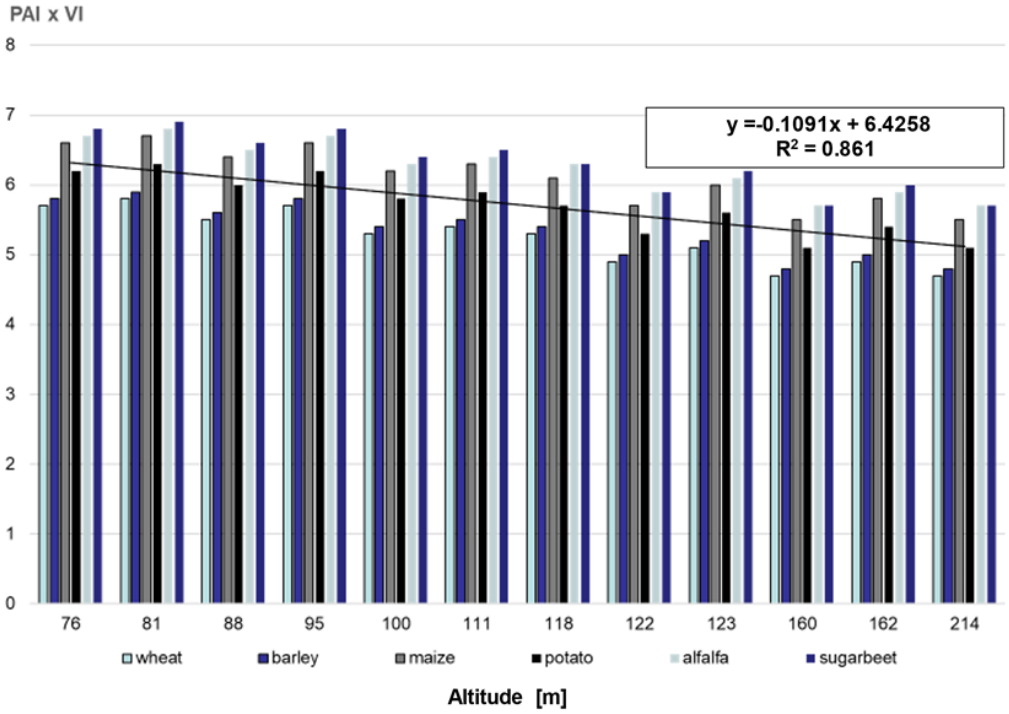

Fig. 3. Drought x crop vulnerability interactions of six field crop species by crop site altitude.

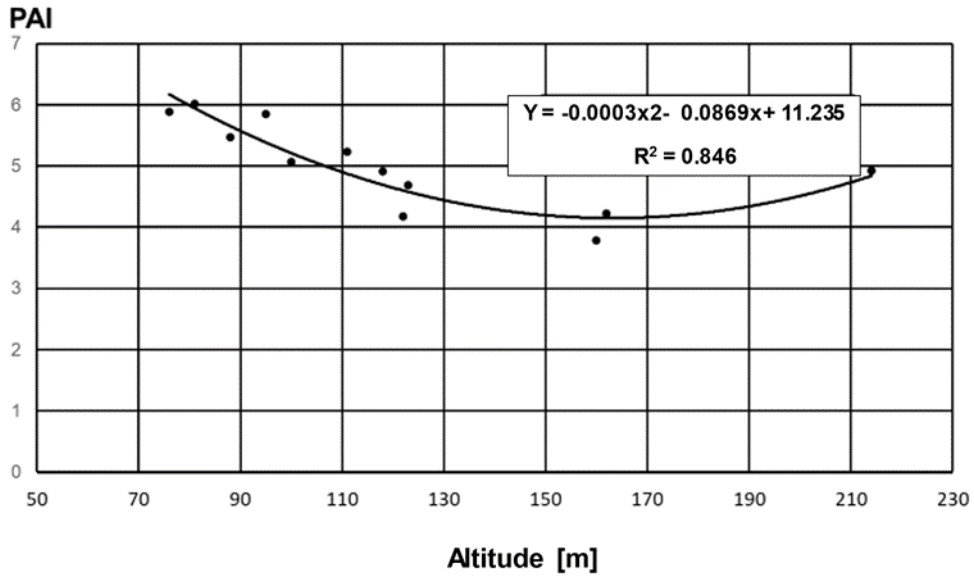

Fig. 4. Changes in the PAI indices due to the geographic elevation of crop sites.

meteorological station. The equation can be expressed by a polynomial equation that is having a rather strong statistical value.

Conclusion

As a conclusion of the study it can be stated, that the geographic location may have a strong influence for the performance of various crop plant species. Certain crops like cereals are less susceptible to crop site conditions, while others, especially those with higher water demand like maize and potato are more exposed to that. Alfalfa and sugar beet were definitely proven to be the most vulnerable crops in this study. The interaction between PAI and VI indices were proved to be useful for characterising the crop site.

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