SZENT ISTVÁN UNIVERSITY

THE CLIMATE CHANGE EFFECT ON SOME CULTIVATED PLANTS FROM HORTICULTURE, AGRICULTURE AND FORESTRY

Arion Turcsán

Gödöllő

2017.

Doctoral school name: Landscape Architecture and Landscape Ecology

field: Agricultural Technology

head: László Bozó, Dsc MHAS
professor
Szent István Univesity,
Faculty of Horticultural Science,
Department of Soil and Water Management

supervisor: Éva Erdélyi, PhD
associate professor
Budapest Business School
College of Commerce, Catering and Tourism

expert advisor: ir. Kristine Vander Mijnsbrugge, PhD
senior scientist
Research Institute for Nature and Forest, Belgium

The candidate met the requirement of the PhD regulations of the Szent István University and the thesis are accepted for the defence process.

....
Head of PhD School Supervisor

1. Background and aims of the research

Climate change leads to Mediterranean climatic effects in the Carpathian basin such as average temperature increase, slightly yearly precipitation decrease and shifts. The number and intensity of extreme weather events (drought, flood, heatwave, frost…) will increase. I studied the effect of climate change on horticulture, agricultural and forest plants, which play an important role in the Hungarian economy. I was guided by the question how climate change effects the production of the selected plants in the future.

The warming climate will positively affect Hungarian rice (*Oriza sativa*) cultivations. Hungarian rice was farmed in large scale in the 50st.However, the area drastically decreased until the early 90st. Nowadays only a small area is used for rice production. The big scale system of the flooded rice production is still present in Hungary and the revitalization of these rice fields in the future has a high economic potential (Simonné, 2007a). Besides, the flooded conventional rice production technique, the bio-rice farming and the mixed aquaculture are gaining more attention from farmers (Jancsó et al., 2009). The mixed aquaculture has a high potential to improve soil conditions and it has a positive environmental impacts. The short growing period restricted the rice variety use in the past. These restrictions will lessen in the future.

The current research focuses mostly on the effect of climate change on grain and fruit production. I was curious how climate change affects some important vegetables which are widely used in the Hungarian kitchen such as Hungarian onions (*Allium cepa*) and Hungarian red paprika (*Capsicum annuum*).

The aim of my research was also to adapt the “adaptation turning point” method to Hungarian wine production (*Vitis vinifera*). I focused on the Kunság and Eger wine regions. The climatic parameters have a strong influence on the grape, wine quality and quantity. I based my research on the observations for the Hungarian wine gene reserve in Helvecia.

Regarding forestry, I studied the drought effect on sessile oak seedlings. Climate change affects more and more tree species. I hope that the developed methods and results within my research will be adapted to other tree species and improve the knowledge to understand the ongoing changes in the forest.

I based my climate prognoses on the Regional Climate Model, RegCM3 developed by the Department of Meteorology, Eötvös Loránd University. The RegCM3 based on SRES A1B climatic scenario (Torma et al.;2011), which is published in the IPCC (2007). My aims were to understand and describe the effect of climate change on the selected plants. Results take us one step closer to work out the necessary actions scenarios and define action points to avoid future production losses in the future. Findings provide a better understanding of the changing growing conditions as well as hints to improve plant productions. These results aid to answer one of the main business questions nowadays: “How can we deal with the changing conditions?” (Rónavári-Kedves and Varga, 2013).

2. Material and Methods

I modelled the future climate with the RegCM3 regional climatic model, which is based on the ECHAM5 global climatic model(Torma et al., 2011). I used a 10 km^2 resolution and three different timeslots (1961-1990, 2021-2050 and 2071-2100). I developed plant specific methods during my work. I will present them in separate sub-chapters.

2.1 Hungarian rice growing conditions

I focused on rice production in Szarvas and Kisújszállás regions. The success of the rice production mostly depends on the cumulative heat during the growing period (Simonné, 2007a). In a first step, I defined the timing of the different growing states for the rice. I based my method on the literature (Chaudhary and Ghildyal, 1970;Yoshida, 1981;Simonné, 1983), and consultations with Ibolya Kiss, who is a well-known rice breeder in Hungary.

The optimal growing conditions of rice are reached when the soil scale at a stable average temperature of 11 °C for four days. In Hungary these climatic circumstances can be found in mid or end of April. For the calculation this period is fixed at the 20th April. I defined the important growing phases based on the showing date of rice (germination, 3-4 leaf development, tillering, panicle development and flowering) (Chaudhary and Ghildyal, 1970;Yoshida, 1981;Simonné, 1983). I studied the rice growing phases in light of climate change. Based on experiments of Ipsits (1993) and Kiss (1980) I used the effective cumulative heat model instead of the active cumulative heat model, which leads to more accurate results for the Hungarian rice varieties (Simonné, 1983;Ipsits, 1993).

The effective cumulative heat model uses +8 °C as basis threshold value and sums only the values above the threshold. In my model, the rice needed 767-842 °C cumulative heat to reach the flowering stage. From the flowering stage, the plant needs 500-600 °C cumulative heat to reach the optimal harvesting stage. I researched the future changes for the rice production using the RegCM3 regional climatic model (Turcsán and Erdélyi, 2011).

2.2 Bulb production

During my research, I focused on the Makó and Fertőd regions. The climatic conditions are colder in Fertőd compared to Makó. The bulb production technology did not change a lot compared to the first description of the technology by Mihály Szőke from 1888 (Tóth, 1961). In the first year, small onions are produced, which stop growing in the summer. During wintertime, an optimal warm temperature has to be kept. During the second year, after the onions were put back to the soil the onion growing phase begins and ends with the harvest (Tóth, 1961;Balázs, 1994). The temperature plays an important role during this technique. If the temperature drops drastically the onion gets the cold effect, called "vernalisation" effect, which leads to flowering and reduces the quality of onions.

I investigated the vernalisation effect based on the modelled climatic parameters generated by the RegCM3 model in Makó and Fertőd regions between 1960-2100. I defined the optimal temperature above +12 °C, I defined also the cold temperature value (under +6 °C) based on the literature (Botost and Füstös, 1987;Balázs, 1994;Szabó, 2002). I analysed the temperature changes between middle of March until end oy May. In the next step, I studied the high temperature in light of onion production. The optimal growing temperature for the onion is +19 °C and the plant can cope without growing disturbances up to ± 7 °C temperature changes. At the same time, the growing of the onion stops above +33 °C (Balázs, 1994;Szabó, 2002). Based on the RegCM3 regional climatic model, I studied how the number of the hot days changes in the future. During my experiments, I focused on the full growing period of the onion (Turcsán and Erdélyi, 2012).

2.3 Red pepper production

The vegetation period of the red pepper in Hungary is between May 15th and September 15th (Erdős, 1992). I based my calculations on the temperature parameters generated by the RegCM3 model. I focused on the two most important red pepper growing regions in Hungary (Szeged and Kalocsa). In the first step, I defined 8 half month periods within the growing season of the red pepper. In the second step, I defined the optimal daily average growing temperature for every half month period based on literature (Márkus és Kapitány, 2001). Deviation of ± 5°C from the optimal growing average daily temperature leads to growing disturbances (Márkus és Kapitány, 2001).

2.4 Application of the adaptation „turning point" method in wine and grape production

I used the adaptation turning point method to study the climate change effect on wine production in Hungary. The adaptation turning point method includes not only the climate change effect on plant production, but it is integrating also the climate change effect on economy, society and the farmers (Werners, 2012).

2.4.1 Monitoring of the Hungarian wine production – in-depth interviews

First, I conducted in-depth interviews with stakeholders which are involved in wine and grape production in Hungary to monitor the societal and ecological systems. All interviewees were experts in wine production and employed by the National Food Chain Safety Office, Eszter Balikó and András Bodor (supervisors), György Pernesz (Head of the Department) and Judit Sárkány (head of the food control labour, Helvécia). To guide the interviews, I set up 53 questions in four groups. The first group consisted of basic demographic questions, the second group focused on the precipitation, temperature and plant protection relations to grape and wine production. The goal of the third group questions was to define important thresholds for the grape and wine production. The last groups focused on the effect of state and EU subsidies on grape and wine production.

2.4.2 The influence of meteorological parameters on grape and wine production

The recorded meteorological data was provided by the Hungarian Meteorological service from the Kecskemét station, the modelled meteorological data was provided by the RegCM3 model. In my calculations I used the daily average, maximum and minimum temperatures, and daily precipitations.

The observed grape and wine parameters were provided by the National Food Chain Safety Office, Plant production and Horticulture department. The institution recorded the different phenological states (bud brust, flowering, ripening and harvest), must and grape parameters ("Hungarian sugar degree" and acidity "g/l" content) and wine parameters (alcohol degree „% vol" and acidity "g/l" content) of every important grape variety at the research station of the institution in Helvécia. I studied the following white and red wine varieties: *Nemes Olaszrizling, Olaszrizling B. 20, Zenit, Zala gyöngye* and *Cabernet sauvignon*, *Kékfrankos*.

I studied the relationship between the observed wine, grape parameters and temperature as well as precipitation. First, I grouped the daily average temperature following the different phenological phase of the vine. Within the different groups, I calculated the cumulative temperature and precipitation parameters. Second, I linked the observed grape and wine parameter in every year to the observed meteorological parameters. Third, I used linear regression to model the wine and grape parameter changes in light of climatic parameters.

I based the future meteorological prognosis on the RegCM3. I used the modelled regression line based on the observed data and the modelled future climate to study the future climatic change effect on the grape and wine parameters. I investigated ”*Olaszrizling B20”* grape and climate change relations.

2.5 Measuring the drought effect on sessile oak seedlings

2.5.1 Source material

I conducted the forest plant experiment at the INBO (Research Institute for Nature and Forest in Geraardsbergen (Belgium). Acorns were collected at three different locations in Belgium in autumn 2013. The first location was a small relict of oak coppice wood growing on inland sand dunes within a former heath land near Klaverber (KLA). The second location was close to Voeren (VOE), which was defined by an average oak forest growing on nutrient-rich soil. The third forest was close to Borgloon (BOR) representing a similar forest as the second study location.

2.5.2 Experimental design

In autumn 2013, the collected seeds – 664 from Klaverber, 744 from Voeren and 154 from Borgloon – were sown in forestry trays (two seeds per cell) using standard nursery potting soil. The seedlings were kept without any additional fertilization during the experiment and were watered manually. The seeds were kept in a frost-free greenhouse during the wintertime, but without additional heating. 1015 seeds germinated perfectly

(486 KLA, 431 VOE és 145 BOR). The germinated seedlings were transferred in April 2014 to 1-l pots (12 cm × 11 cm × 11 cm). Non-germinated seeds were removed and double plants in one tray cell were kept together. The seedlings were divided into two equal groups (stress and control).

The seedlings of the stress group were exposed to an early summer and a late summer drought period. The first drought period took place from 15 of May 2014 until 1 of July 2014. All plants were re-watered on July 2, 2014 by soaking the two groups of plants in the same water basin in the same way. The late summer drought took place from 6 of August 2014 until 17 of October 2014. The stress period ended after a high amount of seedlings died.

2.5.3 Measurement and scoring of the oak experiment

During the drought treatment all pots were weighed every week with a normal kitchen scale. The weight loss expressed the strength of the drought during the statistical calculations. Leaf stomatal aperture in terms of leaf resistance to water vapour was measured with a diffusion porometer (Model AP4, Delta-T Devices, Burwell, Cambridge, UK) during first drought period. The stomata located on the leaf are sensitive to meteorological changes especially to drought stress.

The height of the seedlings was measured three times during the growing period (1 of July, 4 of September and 17 of October in 2014). During the stress period, the angle of the edge of the leaf was observed continually using a special developed protocol (1-4 scale). The apical bud of the highest plant per pot was scored on August 28, 2014. At the end of the second drought period, the number of dead seedlings was recorded. To monitor the autumn leaf senescence, a 1-8 point scale was used at the end of the growing period. Low numbers indicate leafs with active photosynthetic activity. Increasing numbers sign represent a decreasing photosynthetic activity. The observations were recorded in 1st of December and 8st of December, 2014.

2.5.4 Statistic calculations

The open source software R 3.1.2 (R development Core Team, Vienna, Austria) was used for all statistical analyses. The following models were created to describe the seedlings behaviours under drought stress:

- Modell I., describing the growing tendencies of the seedlings
- Modell II., describing the growth of the reshooting seedlings
- Modell III., describing the apical bud development
- Modell IV., describing the chance of surviving
- Modell V., describing the autumn leaf senescence

3. Results

3.1 The rice production in the future

Szarvas and Kisújszállás are located close to each other, which was most likely the reason, why the results of the two study areas did not show major differences. The effective cumulative heat model showed a growing phase shortening with time. For example, the flowering is predicted 3 weeks earlier in the end of the year-hundred. Not only the growing phases, but also the harvest will take place much earlier in the future. In the past, the time of harvest was long, unpredictable, sometimes even the rice did not reach the optimal stage for the harvest at the end of the growing season, because the weather was relatively bad. However, based on my model, the varieties used nowadays will reach the optimal harvest stage already in the middle of August at the end of the year hundred.

I was also curious how the sowing time will change based on my models in the future. The model shows temperature increases towards the end of the year hundred. In the same time, the number of extreme weather events will increase, which leads to a high uncertainty related to the optimal sowing time for the rice. In some years, the soil temperature will reach the optimal threshold for the sowing in middle of March. However, in some years the optimal conditions will occur just in the middle of April.

3.2 The climate change effect on bulb production

My model shows warm temperatures, above +12 °C from end of April for both locations (Makó, Fertőd). The number of days with optimal growing temperature (+12 °C daily average temperature) for the bulb will increase in Makó. The rate of days with cold, optimal and warm temperature was similar in the past during middle of April. Slowly increasing temperature can be seen in the model towards 2100. Similar tendency was observed during end of March in the future. Also the difference is higher between the near future and faraway future.

The models show the same tendency in Fertőd. However, the number of days with +10-12 °C average temperature is most likely between middle and end of during the near future and also the faraway future. My results shows clear warming also in Fertőd, but less intense compared to Makó.

I also studied the number of hot days – daily average temperature above + 33 °C – changes in the future at both locations. The hot days were concentrated in July in the past at Makó already. In the near future, the number of hot days will stay almost similar compared to the past. However, my model shows three times more hot days in the far away future at Makó location. The number of hot days will be four times more in June and double in July. The model does not show high increases in the number of hot days at Fertőd in the near future. However, the number of hot days in the far away future will be three times more compared to the past. The increase is strongest in June.

3.3 Climate change effect on red pepper

I based the future temperature changes in my calculation on the data provided by the RegCM3 model at the two study locations (Kalocsa, Szeged). The temperature parameters stay close to the optimal growing temperature in the past and the near future at both locations. The model shows even better growing conditions during the near future for the red pepper. However, the spring temperatures will increase compared to the optimal temperature parameters in the near future. The temperature parameters show strong increases in faraway future. The temperature increase will reach the critic threshold (+5 °C) compared to the optimal temperature end of May and the first part of July. The temperature increase will be stronger at Szeged compare to Kalocsa, but the difference did not reach higher value than 1°C.

3.4 Climate and grape, wine production relations

The in-depth interviews point on frost and drought problems at both study locations. Also, the farmers were facing unusual conditions during the last years. For example, downy mildew infected the vine during the flowering period in Eger in 2010, which was never observed before. Extreme frost damage occurred in the Kunság wine region in 2011. The intensity of the frost was so strong that the older woody part of the vine died off. The resistant and fragrant wine varieties are gaining more and more place at both wine regions. Those varieties show a stronger sensitivity against drought and heat stress. However, the warm years also had plenty positive effects on the wine production. For example, the farmers produced excellent quality red wines with a slightly Mediterranean character in 2011.

The red wine varieties show different sensitivity for climatic parameters compared to the white wine varieties. The precipitation and temperature differences between the years did not affect the local variety (*Kékfrankos*). In the same time the *Cabernet sauvignon* -not local variety-, shows higher sugar and alcohol content during a warmer dryer year.

Also, the local white wine varieties (*Zala gyöngye „Egri csillagok 24", Zenit „Badacsony 7"*) did not show strong sensitivity for temperature and precipitation changes during the growing season. However, a warm dry year leads to high sugar and low acidity content of the grape for the *Nemes olaszrizling* és *Olaszrizling B20* varieties. My model is based on the date from the RegCM3 model and shows quality problems (the must acidity decrease under 5 g/l) from 2030 at the *Olaszrizling B20.* varieties at Kunság wine region. The same problem will occur at Eger wine region from 2070. The number of hot and dry days will increase at both wine regions. The critical threshold (more like 5 hot and drought year within 10 years) will be reached in 2030 at Kunság wine regions and in 2070 at Eger wine region.

3.5 Results of drought effect on sessile oak seedlings

To monitor the stress symptoms of the seedlings, stomatal resistance and weight of pots were measured during the first drought period. The average value of the drought-treated group strongly increased from June 10, 2014 onward indicating a response to drought. At the same time, the average weight loss of the pots increased confirming the drying process. Among the treated seedlings a small group of plants (23%) showed visual “wilting or curling of leaves” compared to the control group. Model I., shows high probability for extra shoot growth at the drought treated seedlings after the first drought period in the summer. However, seedlings from VOE origin show lover probability for extra shoot formation during the summer period within the stressed and within the control group. Furthermore, higher probability for extra shoot was observed within the double planted seedlings effected drought in the late spring period compare to the single planted seedlings.

Model II revealed that the height at the end of the drought treatment negatively related to the probability of extra shoot growth. Model III. describes that the drought-treated seedlings significantly showed less well-developed apical buds in higher plants end of the summer period. Both in drought-treated and control seedlings, VOE had a lower probability on a fully developed apical bud on the measurement day compared to the other provenances.

Model IV shows that the surviving chance depends on the height of the seedlings before the second drought period, the number of seedlings per pot and on the weight loss. The surviving chance was much lower along the double planted high seedlings. The origins did not show significant relation with the surviving chance, however higher number of dead seedlings was documented from KLA and BOR origins compared to seedlings originated from VOE.

Model V shows the earliest autumn leaf senescence at seedlings originated from KLA at the treated and the control groups, followed by seedlings from KLA and from BOR. However, the seedlings from the treated groups kept their leafs longer. The single seedlings from the stress group lost 18,8 days later their leafs compare to the control group. 6,7 days different was observed between seedlings from KLA and VOE, furthermore, 14,7 days different between KLA and BOR independent from the treatment.

4. Discussion and conclusion

The climate change will lead to better growing and farming conditions for the Hungarian rice production. The longer growing period allows including varieties with longer growing period in the future, which would lead a better rice productivity.

A slow temperature increase was observed also at the bold production areas, which could allow for an earlier planting of the small onions at Makó region. The temperature increase is less intense at Fertőd region towards end of the year hundred, in case if we take into consideration to adapt the bulb production technique from Makó in this region. The same tendency was observed in the number of hot days in Fertőd region. The number of hot days will increase drastically towards 2100 at Makó region. However, further investigations are necessary to give a better picture of the climate change effect on the special bulb production technique in Makó.

The model did not show significant differences between Szeged and Kalocsa in light of red pepper production. The growing conditions stay close to the optimal in the near future. However, the number of bad weather conditions will increase in the faraway future for the red pepper. It would be necessary to enlarge the model with other parameters such as radiation or sunburn as well as conducting experiments on the field.

The climate change will challenge the grape farmers and the wine producers. Irrigation system use can help to reduce the drought stress during the summer period, however the topic still need deeper economic investigation. The variety use plays important use to avoid the economic losses caused by climate change in the future. The average temperature increase will also positively impact the wine production, especially for the red wine varieties. It would be important to take into consideration the old varieties and also old farming techniques (covering the vine during the winter with soil), to avoid the negative effect of climate change.

From 2030 on, the farmers will face quality problems with the white wine varieties with the present farming technique in the Kunság wine region. Those changing growing conditions will lead to an earlier harvest and quality problems. The same circumstances will occur only from 2070 at Eger wine region. One of the adaptation strategies could be to move the production to higher and therefore colder elevations in Eger region. A similar strategy is impossible in the Kunság region because of the geological character of the wine region.

After an early summer drought event re-watering augmented significantly the probability to form an extra shoot in oak seedlings. Simultaneously, drought retarded the apical bud development significantly in larger seedlings. Competition for water experienced by seedlings that grow together in a pot further increased the chance of extra shoot formation. There was no clear significant difference between the three origins, however the proportion of dead seedlings from KLA and BOR origins was higher compared to seedlings from VOE locations. The repeated drought lead to a delay of autumn leaf senescence. For future research it is important to include other origins and to use other technique (example: wood anatomical analyses) to evaluate the drought effect on the seedlings and give a better understanding the future drought events effect on seedlings and work out possible adaptation strategies.

5. New scientific results

1. I defined the critical temperature thresholds for the Hungarian rice (*Oriza sativa*). I investigated the climate change effect on the Hungarian rice in the future using regional climate model (RegCm3). My model shows better growing conditions for the Hungarian rice in the future. I defined two week earlier sowing time in the future than usual and the harvest will take place one month earlier with the current technology.

2. I defined a shift towards north for the optimal growing area for the Hungarian bulb (*Allium cepa*) production due to climate change in the future. My model was based on the regional climatic model (RegCM3). Furthermore, we have to take into consideration the number of hot day increase in the future. My model shows 955 hot days in the faraway future 30 years interval in Makó, which is three times more compared to the normal number of hot days.

3. The growing conditions for the red pepper (Capsicum annuum) will stay optimal in Hungary. However, the temperature anomalies during the spring time could lead to farming problem of the red pepper. I modelled high temperature values (+5 °C) compared to the optimal temperatures at the end of May, and for the first part of July in the faraway future.

4. I analysed the impact of weather (average temperature and precipitation) on the quality of grape and wine. I described the climate change effect using the RegCM3 model on some of the white and red wine varieties. I defined, that the growing conditions of the different grape varieties will improve in the future. I pointed on, that the white wine varieties with the current farming technology will face with quality problems in the future, because the must acidity content could decrease under the critical threshold (5 g/l). This effect will lead to technological changes in the future. I defined high risk possibility of wine production with the current technology in Kunság wine region from 2030, and from 2070 at Eger wine region, because of the number of hot and dry years are increasing drastically.

5. After an early summer drought event re-watering augmented significantly the probability to form an extra shoot in oak seedlings, with the highest probability in the smaller individuals. The repeated drought lead to delay of autumn leaf senescence, which can help to understand the climate change effect on seedling level. The single seedlings from the stress group lost their leafs 18,8 days later compared to the control group. 6,7 days difference was observed between seedlings from KLA and VOE, furthermore, 14,7 days difference between KLA and BOR, independently from the treatment.

6. Literature

1. Balázs, S. (1994). *Zöldségtermesztők kézikönyve.* Mezőgazda Kiadó, Budapest.
2. Botost, G., and Füstös, Z. (1987). *Hagymafélék termesztése.* . Mezőgazda kiadó.
3. Chaudhary, T., and Ghildyal, B. (1970). *Influence of submerged soil temperature regimes on growth, yield, and nutrient composition of rice plant.* Agronomy Journal 62**,** 281-285.
4. Ipsits, C. (1993). *Esőztető öntözéssel termesztett rizs agronómiai és morfológiai sajátosságainak vizsgálata.* .
5. Rónavári-Kedves, L., and Varga, I. (2013). *Tudásmenedzsment alkalmazásának lehetőségei.* Tudományos évkönyv2, Budapesti Gazdasági Fősikola**,** 75-81.
6. Simonné, I.K. (2007a). *RE: Szóbeli közlés.*
7. Simonné, K. (1983). *A rizs termesztése.* (*Rice Production)* Mezõgazdasági Kiadó, Budapest.
8. Szabó, I. (2002). *A hagymafélék termesztése.* Budapest: Szaktudás Kiadó Ház.
9. Torma, C., Coppola, E., Giorgi, F., Bartholy, J., and Pongrácz, R. (2011). *Validation of a high-resolution version of the regional climate model RegCM3 over the Carpathian basin.* Journal of Hydrometeorology 12**,** 84-100.
10. Tóth, F. (1961). *A makói hagyma történetének néhány fejezete.* Makó: Móra Ferenc Múzeum évkönyve.
11. Turcsán, A., and Erdélyi, É. (2011). *"A rizs fejlődési szakaszainak alakulása a melegedő éghajlat hatására Magyarországon,"* in LIII. Georgikon Napok nemzetközi tudományos konferencia, Fenntarthatóság és versenyképesség?, , ed. D.L. Gábor. Keszthely), 745-753.
12. Turcsán, A., and Erdélyi, É. (2012). *"Red pepper and bulb vegetables under changing climate in Hungary,"* in *1*6th International Eco-Conference, 7th Eco Conference on Safe Food: Climate and production of safe food. , ed. N. Aleksic. (Novi Sad: Ecological Movement of Novi Sad), 53-61.
13. Werners, S. (2012). *Turning points in climate change adaptation* Global Environmental Change 16**,** 253-267.
14. Yoshida, S. (1981). *Fundamentals of rice crop science.* Int. Rice Res. Inst.

7. List of publications related to the thesis

IF articles:

Vander Mijnsbrugge, K., **Turcsán, A.,** Depypere, L., & Steenackers, M. (2016). Variance, Genetic Control, and Spatial Phenotypic Plasticity of Morphological and Phenological Traits in Prunus spinosa and Its Large Fruited Forms (P. x fruticans). Frontiers in Plant Science, 7. DOI: 10.3389/fpls.2016.01641

IF:4,49

https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5093327/

Vander Mijnsbrugge, K., **Turcsán, A.,** Maes, J., Duchêne, N., Meeus, S., Steppe, K., & Steenackers, M. (2016). Repeated Summer Drought and Re-watering during the First Growing Year of Oak (Quercus petraea) Delay Autumn Senescence and Bud Burst in the Following Spring. Frontiers in plant science, 7. DOI: 10.3389/fpls.2016.00419

IF:4,49

https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4814502/

Turcsán, A., Steppe, K., Sárközi, E., Erdélyi, É., Missoorten, M., Mees, G., & Mijnsbrugge, K. V. (2016). Early summer drought stress during the first growing year stimulates extra shoot growth in oak seedlings (Quercus petraea). Frontiers in plant science, 7. DOI: 10.3389/fpls.2016.00193

IF:4,49

https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4763100/

Vander Mijnsbrugge, K., **Turcsán, A.,** Boudewijn, M. Population differentiation and phenotypic plasticity in temperature response of bud brust in Frangula alnus provenances of different latitude. Plant Systematics and Evolution. Wien, (Austria) 2015. DOI: 10.1007/s00606-015-1258-2 (ISSN 0378-2697) IF: 1,42
http://link.springer.com/article/10.1007/s00606-015-1258-2

International conferences (fullpaper)

Turcsán, A., Erdélyi, É. Modelling the Effects of Climate Change on Wine Production for Kunság Region In: Nikola Aleksic (szerk.) Safe Food. Novi Sad: Ecological Movement of Novi Sad, 2014. pp. 49-56. (ISBN:9788683177479)

Turcsán, A., Erdélyi, É. Red pepper and bulb vegetables under changing climate in Hungary In: Nikola Aleksic (szerk.) 16th International Eco-Conference, 7th Eco Conference on Safe Food: Climate and production of safe food. Novi Sad: Ecological Movement of Novi Sad, 2012. pp. 53-61. (ISBN:978-86-83177-46-2)

Petz, K., **Arion Turcsán,** Éva Erdélyi Changing climate affects agro-ecosystem sevices, a positive example in Hungary In: Nikola Aleksic (szerk.) 16th International Eco-Conference, 7th Eco Conference on Safe Food: Climate and production of safe food. Novi Sad: Ecological Movement of Novi Sad, 2012. pp. 63-71. (ISBN:978-86-83177-46-2)

Erdélyi, É., Lőrincz, S., **Turcsán, A.** Correspondence between economic, social and environmental aspects in tourism development. In: Nikola Aleksic (szerk.) Environmental protection of urban and suburban settelments: XVII International Eco-Conference, Novi Sad: Ecological Movement of Novi Sad, pp. 473-482.

Conference papers

Hungarian language (full paper)

Turcsán A., Erdélyi É., Werners, S. Éghajlatváltozás, és alkalmazkodási stratégiák keresése a szőlőtermesztésben: egy új módszer bemutatása, Adaptációs "turning point" - hogy is nevezzelek? In: Hamar Farkas (szerk.) Multidiszciplináris kihívások, sokszínű válaszok - 3. kötet: BGF KVIK KÖT Tanulmánykötete - 112 p. Kereskedelmi Vendéglátói és Idegenforgalmi Kar, 2014. pp. 94-101. ISBN:978-963-7159-51-0

Hungarian language (abstract)

Petz K., **Turcsán, A**., Erdélyi, É. A változó klíma új lehetőségeket hozhat a magyarországi rizstermesztésnek. IX. Magyar Biometriai, Biomatematikai és Bioinformatikai Konferencia, Budapesti Corvinus Egyetem, 2011 p. 66. http://www.biometria.uni-corvinus.hu/2011/index.html

Turcsán A., Erdélyi É. A rizs fejlődési szakaszainak alakulása a melegedő éghajlat hatására Magyarországon, In: Dr. Lukács Gábor (szerk.) LIII. Georgikon Napok nemzetközi tudományos konferencia, Fenntarthatóság és versenyképesség?, 2011. Keszthely, p. 131. (ISBN 978-963-9639-43-0) http://sandbox.georgikon.hu/napok-old/upload/data/2011GeorgikonNapok_abstractbook.pdf