Turkish Journal of Agriculture - Food Science and Technology, 11(10): 1839-1846, 2023
DOI: https://doi.org/10.24925/turjaf.v11i10.1839-1846.6062

Turkish Journal of Agriculture - Food Science and Technology

Available online, ISSN: 2148-127X | www.agrifoodscience.com | Turkish Science and Technology Publishing (TURSTEP)

Investigation of Leaf Gas Exchange Parameters of Several Chestnut Population Seedlings at the End of the Growing Season

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ARTICLE INFO

Research Article

Received : 23-03-2023
Accepted : 15-10-2023

Keywords:
Castanea sativa
Net photosynthetic rate
Stomatal conductance
Transpiration rate
Intrinsic water use efficiency

ABSTRACT

Changes in temperature and precipitation due to global climate change negatively affect plant species' growth, development, and adaptation to new places. However, genetic structure is the most critical criterion for determining a species's potential to adapt to changing environmental conditions. Monitoring gas exchange parameters in plants is the simplest way to monitor physiological changes in plants under changing environmental factors. Among species, the Anatolian chestnut (*Castanea sativa*) is native and economically important tree species (fruit and wood production). It is naturally distributed from the north side of Turkey, Marmara, and Western Anatolia. However, the Anatolian chestnut is one of the most affected tree species by global climate change. In this study, numerous Anatolian chestnut populations (3 years old) were used to determine leaf gas exchange parameters at the end of the growing season in Düzce. Stomatal conductance (*gs*), transpiration rate (*E*), net photosynthetic rate (*Anet*), and other parameters were measured. As a result, the leaf gas exchange parameters of chestnut populations changed significantly based on the populations. Marigoule population seedlings had 2-fold *Anet* values compared to the Ibradı population. Regarding *gs*, the differences between populations (Erfelek and Ibradı) changed approximately 2.5 folds and the differences (Erfelek and Ibradı) increased more than 3 folds in terms of *E* values. It can be said that Marigoule and Erfelek populations can adapt more to Düzce climate conditions than other populations. In contrast, Ibradi population seedlings have a low adaptation mechanism in terms of gas exchange traits.

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Introduction

Temperature and precipitation are the two main drivers for plant distribution around the world. With the Industrial Revolution, people have been heavily using natural resources, such as coal, gases and some other elements, resulting in increased air pollution (Çobanoğlu et al., 2022; Isınkaralar et al., 2022; Key et al., 2022; Koç et al., 2022), water contamination (Demir et al., 2021; Kutlu and Mutlu, 2021; Tokatli et al., 2021; Mutlu and Uncumusaoglu, 2022) and temperature on a regional and global scale (IPCC, 2014), and therefore a change occurs in the climate (Koç, 2022a). The temperature has risen around 1 ºC in the previous century (IPCC, 2014), and the mean annual air temperature may increase by 2.5 and 5.4 °C by 2050 and 2100, respectively, in the world (IPCC, 2014), and Türkiye (Cantürk and Kulaç, 2021). The temperature increases cause some adverse effects on plant species, such as drought (Seleiman et al., 2021; McDowell et al., 2022; Koç, 2022a) and cold stress (Yildiz e al., 2014; Raza et al., 2019; Chaudhry and Sidhu, 2021), which negatively affect tree growth, development, and physiology (Koç and Nzokou, 2022; Koç and Nzokou, 2023). All these changes are related to the genetic variation of plants.

Genetic diversity is the fundamental component that enables species to survive in changing ecosystems. In addition, genetic diversity is the most important criterion that determines the potential of a species to adapt to different environmental conditions (Sevik et al. 2010). This situation has become much more important for plants, especially with global climate change and global warming, the effects of which are increasing daily. Therefore, it is crucial to determine how different species populations behave under these changing environmental stress factors (Koç, 2022a). Identifying the most resistant populations or adaptable to these changing stress factors is vital and encourages their use. Genetic variation may play an essential role during the photosynthetic process, especially in diverse environments.

As a physiological parameter of plants, leaf photosynthetic gas exchange directly affects plant growth, and therefore scientists have been aware of this subject recently. However, similar plant species differ even under the same environmental conditions (Bhattacharjee and Saha, 2014; Koç and Nzokou, 2022). Species have various abilities to respond to environmental fluctuations (Allen et al. 2010; Koç et al., 2022). All the response mechanism to environmental alterations is linked to species' genetic structure (Koç and Nzokou, 2022). Plant species' morphological, anatomical, and photosynthetic traits are formed by the interplay of genetic codes and environmental situations (Ozel et al. 2021).

Photosynthetic gas exchange from leaves, using the LI-COR photosynthesis method (LI-COR Biosciences, Lincoln, NE, USA), is one of the common, reliable, and robust methods to determine plant status instantly. The LI-COR 6800 is worked based on a unit area on the plant leaf and a closed system that maintains IRGA, relative humidity, light intensity, and CO_2. The portable LI-COR 6800 is the latest version that provides a series of measurements, such as transpiration rate, net assimilation (photosynthetic) rate, stomatal conductance, intrinsic CO_2 concentration, and many more. Using some of these measurements, water use and intrinsic water use efficiency are also calculated. Water use efficiency has reflected the percentage of net photosynthetic ratio and transpiration, while intrinsic water use efficiency indicates the percentage of net photosynthetic ratio and stomatal conductance (Lambers et al. 2008; Koç, 2022a).

Among broad-leaf species, the Anatolian chestnut (*Castanea sativa*) is native tree species in Turkey and is distributed from the north side of Turkey from Bulgaria to the Caucasus, besides Marmara and Western Anatolian provinces (Orman Genel Müdürlüğü (OGM), 2013). Anatolian chestnut is the main tree species and is economically significant in Turkish forestry due to its fruit and wood production. It has a smooth and plump trunk that has been used in many areas, such as decorative, furniture, and other construction purposes (Conedera et al. 2004; Kakava et al. 2018; Mirela, 2020). Türkiye has around 39-40 thousand ha chestnut production areas, which ranks third in the world and earns more than $40 million from its export (about 60 thousand tons) worldwide in 2018 (Food and Agriculture Organization of the United State (FAO), 2019).

Türkiye is among the "countries at risk" against climate change (UNDP, 2019), and the most adverse impact of global climate change will manifest itself in the Mediterranean region in the form of increased temperatures and decreased precipitation (Giorgi and Lionello, 2008). It is estimated that these changes will significantly affect chestnut forests as in many species (Talu et al. 2011). Species that do not have an adaptation mechanism to these rapid climate changes will suffer the most (Lindner et al. 2010), and therefore some local populations will be in danger of extinction (Keenan, 2012).

For these reasons, various studies have been conducted on the possible effects of climate change on the adaptation of different species populations and plant species in different ecosystems. Most such studies harm plant species; however, plant species' have some mechanisms against climatic changes in the regions that affect plants' morphological and physiological parameters. The most harmless method to determine the changes in these physiological structures is the examination of the leaf gas exchange parameters of the plants. Therefore, seeds were collected from chestnut populations adapted to different regions of Turkey, seedlings were grown, and the differences between gas exchange parameters of these populations in the same environment (Düzce province) were tried to be determined.

Material and Method

Seed Collection, Sowing, and Containerization Substrates

The chestnut seeds were collected from at least 10 different trees in each population from September to October 2017. The information about populations is given in Table 1. The seeds were subjected to wet, cold stratification for about 28-45 days for germination, and then germinated seeds were sown into 18x25 cm polyethylene plastic bag where the potting mix consisted of peat moss, forest soil, and perlite (1:1:1 volume). The seedlings were placed outside on the concrete floor and watered once every week when it was no rain for the following years. In the warmer summer (July-September), the top was covered with a shade of material to prevent sunburn on leaves and water on hot days. This experiment was conducted at the Düzce University Forestry Department nursery in 2021. The stem height and diameter growth (± S.D.) for each chestnut population during the measurement period are given in Table 1.

Table 1. The origins of chestnut populations and their seedling growth parameters

Codes	Origin	Height (cm)	Diameter (mm)
IBR	Ibradı (Akseki-Antalya)	90.50 ± 19.21	16.20 ± 3.73
OVA	Ovacık (İzmir)	87.20 ± 19.92	12.95 ± 2.95
DSA	Deli Sarnıç (Antalya)	96.70 ± 22.43	11.18 ± 2.17
SEL	Selge (Antalya)	84.50 ± 22.23	10.76 ± 2.20
BUR	Bursa	106.50 ± 19.57	14.22 ± 2.41
DKAB	Kabalak (Düzce)	98.70 ± 24.29	11.76 ± 1.54
ERF	Erfelek (Sinop)	79.10 ± 25.54	11.30 ± 2.28
AOM	Oluk Mahallesi (Antalya)	85.00 ± 24.32	11.81 ± 2.22
DKAP	Kaplandağı (Düzce)	95.10 ± 20.99	11.66 ± 1.59
MAR	Marigoule	60.50 ± 15.76	8.07 ± 0.82

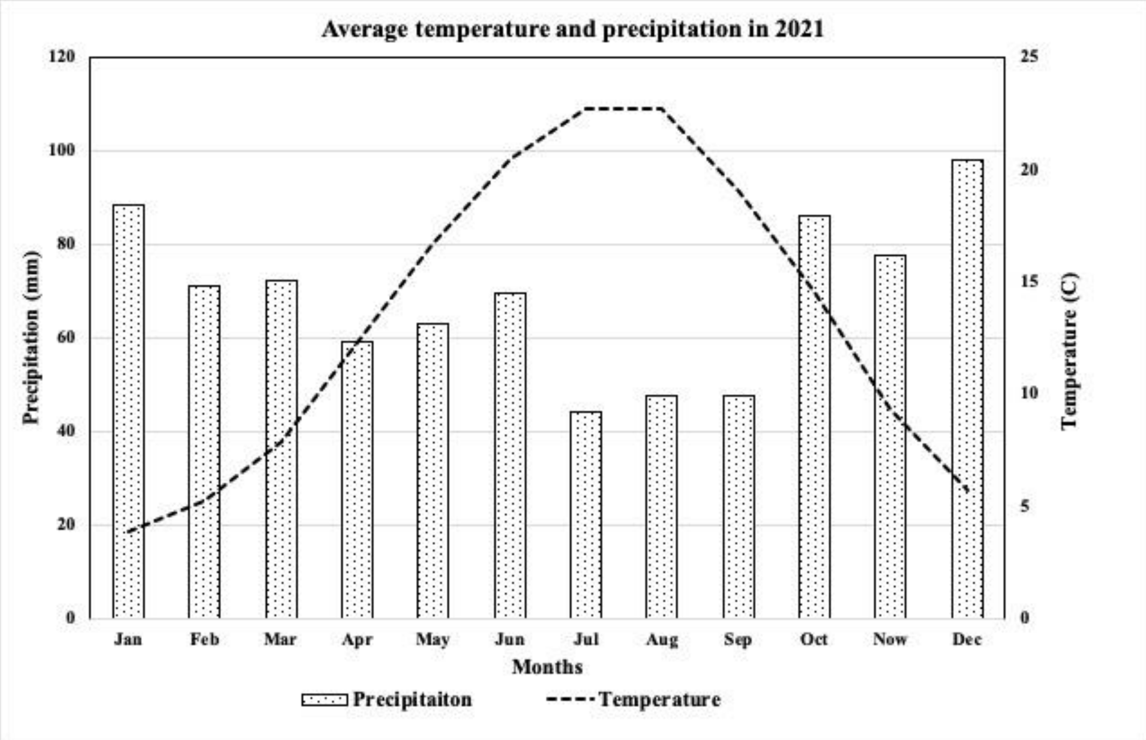

Figure 1. The mean monthly temperature and precipitation

The seeds were subjected to wet, cold stratification for about 28-45 days for germination, and then germinated seeds were sown into 18x25 cm polyethylene plastic bag where the potting mix consisted of peat moss, forest soil, and perlite (1:1:1 volume). The seedlings were placed outside on the concrete floor and watered once every week when it was no rain for the following years. In the warmer summer (July-September), the top was covered with a shade of material to prevent sunburn on leaves and water on hot days. This experiment was conducted at the Düzce University Forestry Department nursery in 2021. The stem height and diameter growth (± S.D.) for each chestnut population during the measurement period are given in Table 1.

Temperature and Precipitation

The meteorological data (temperature and precipitation) was obtained from Düzce Meteorological Station for 2021. The city's average monthly temperature and precipitation are given in Figure 1.

Growth Parameters and Gas Exchange Measurements

The height growth was measured with a wooden tape measure, while diameter growth was measured using a caliper in 10 seedlings for each population.

The gas exchange parameters measurement was performed on eight different seedlings (a single reading was taken from each seedling) from each population using a broad leaf chamber (9 cm^2) of LI-COR (LI-6800, Lincoln, NE, USA) with an attached light source (6800-02 – red/blue/light). The calibration was done as recommended by the producer. Then, the airflow rate, PPFD (photosynthesis photon flux density), and reference CO_2 were set and held automatically at 500 µmol s^{-1}, 1500 µmol s^{-1}, and 400 µmol mol^{-1} s^{-1}, respectively. The measurement was taken on September 29, 2021.

The stomatal conductance (*gs*, µmol H_2O m^{-2} s^{-1}), transpiration rate (*E*, mmol m^{-2} s^{-1}), net photosynthetic rate (*Anet*, µmol m^{-2} s^{-1}), and intercellular CO_2 (*Ci*) within gas exchange parameters were directly measured when the intercellular CO_2 to ambient CO_2 (*Ci*/*Ca*), intrinsic water use efficiency (*iWUE=Anet/gs*), water use efficiency (*WUE=Anet/E*), parameters were calculated.

Data Analysis

This experimental design was a complete randomized consisting of 10 populations, and each population had eight seedlings (replication) subjected to gas exchange measurement. Data analysis of all gas exchange parameters was done using SAS 9.1 statistical software (SAS Institute Inc., Cary, NC, USA). PROC MIXED function was used to perform analysis of variance (ANOVA), and mean separation of populations was done using Tukey's adjustment.

Result

Height Growth (HG) and Diameter Growth (DG)

The growth parameters (HG and DG) of populations are given in Table 1. The populations of Bursa seedlings had the highest HG (106.50 ±19.57 cm), followed by the Kabalak population (98.70 ±24.29 cm), while Mariguole population seedlings had the lowest HG (60.50 ±15.76 cm). The other populations averaged HG values are close to each other. The highest DG was observed in the seedlings of the Ibradı population (16.20 ±3.73 mm), followed by the Bursa population (14.22 ±2.41 mm) and Ovacık population (12.95 ±2.95 mm), while the seedlings of the Mariguole population s had the lowest DG (8.07 ±0.82 mm). The rest of the population seedlings means DG is almost the same.

Table 2. F-values of ANOVA for leaf gas exchange traits of chestnut populations

Source of variation	df	Anet	gs	E	iWUE	WUE	Ci	Ci/Ca
Population	9	6.25***	4.75 ***	12.61 ***	8.92***	26.28***	6.27***	6.40***

*** P≤0.0001. Df = Degrees of Freedom.

Table 3. The Average Values of Gas Exchange Parameters among Chestnut Populations

Population	Anet	gs	E	iWUE	WUE	Ci	Ci/Ca
AOM	6.08 bc	0.051 abc	0.0017 bc	113.62 d	3350.37c	188.17 a	0.485 a
BUR	8.50 ab	0.068 ab	0.0020 ab	126.81 cd	4131.22 c	164.04 ab	0.430 ab
DKAB	6.21 bc	0.056 abc	0.0019 abc	114.8 d	3469.88 c	186.64 a	0.484 a
DKAP	6.47 bc	0.049 abc	0.0017 bcd	146.97 bcd	4135.37 c	135.16 abcd	0.350 abc
DSA	7.37 abc	0.048 abc	0.0012 cde	155.54 abc	5937.99 b	123.89 abcd	0.320 abc
ERF	8.79 ab	0.075 a	0.0024 a	126.6 cd	3893.91 c	163.00 abc	0.425 ab
IBR	4.71 c	0.029 c	0.0007 e	175.78 ab	6715.03 ab	98.02 cd	0.251 c
MAR	10.07 a	0.070 ab	0.0016 bcd	143.58 bcd	6238.45 ab	138.30 abcd	0.363 abc
OVA	7.64 abc	0.043 bc	0.0011 de	187.46 a	7538.61 a	84.94 d	0.220 c
SEL	8.80 ab	0.054 abc	0.0016 bcd	157.4 abc	5568.49 b	116.98 bcd	0.305 bc

Note: Different letters, such as a, b, c means that the parameters of gas exchange significantly (p<0.05) differed among chestnut populations.

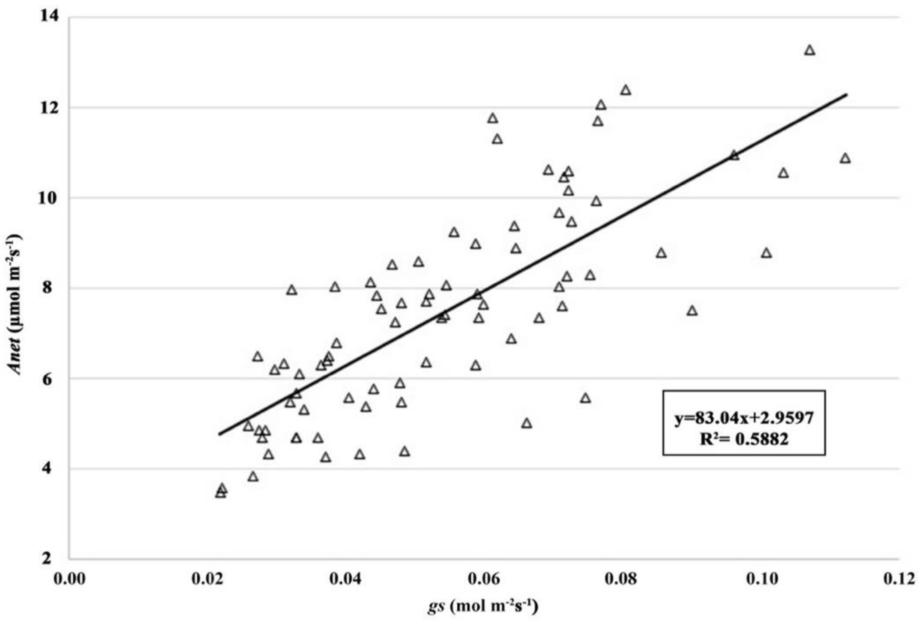

Figure 2. Relationship between gs and Anet within chestnut population

Leaf Gas Exchange Measurement

The ANOVA of leaf gas exchange measurements, such as *Anet, E, gs, WUE, iWUE, Ci, and Ci/Ca* among populations, are presented in Table 2. Chestnut population statistically differed (P≤0.0001) for each gas exchange parameter (Table 2). The averages and Tukey's test results of gas exchange parameters of chestnut populations are presented in Table 3.

When the chestnut populations are evaluated in terms of *Anet* amounts, the seedlings of the MAR population have the highest *Anet* amount. At the same time, the lowest average *Anet* value is found in the IBR population, followed by ERF and BUR populations (Table 3).

When the chestnut populations are evaluated in terms of *gs*, the seedlings of the ERF population have the highest average *gs* value, followed by MAR and BUR populations. The lowest *gs* values are determined in chestnut seedlings belonging to IBR populations (Table 3).

If we evaluate the chestnut populations in terms of *E*, the seedlings of the ERF population have the highest *E* values, followed by the BUR population. In contrast, the lowest *E* value is seen in the seedlings of the IBR population, followed by the seedlings of the OVA population (Table 3).

When the chestnut populations are evaluated in terms of *iWUE* amounts, the highest values are found in the OVA population seedlings, followed by the IBR population. The lowest *iWUE* values were determined in the AOM population, followed by the DKAB and BUR populations (Table 3).

When the chestnut populations are evaluated in terms of *WUE* amounts, the seedlings of the OVA population showed the highest value, followed by the group formed by the IBR, MAR, and SEL populations. The lowest *WUE* values were observed in a group consisting of AOM, DKAB, ERF, BUR, and DKAP populations (Table 3).

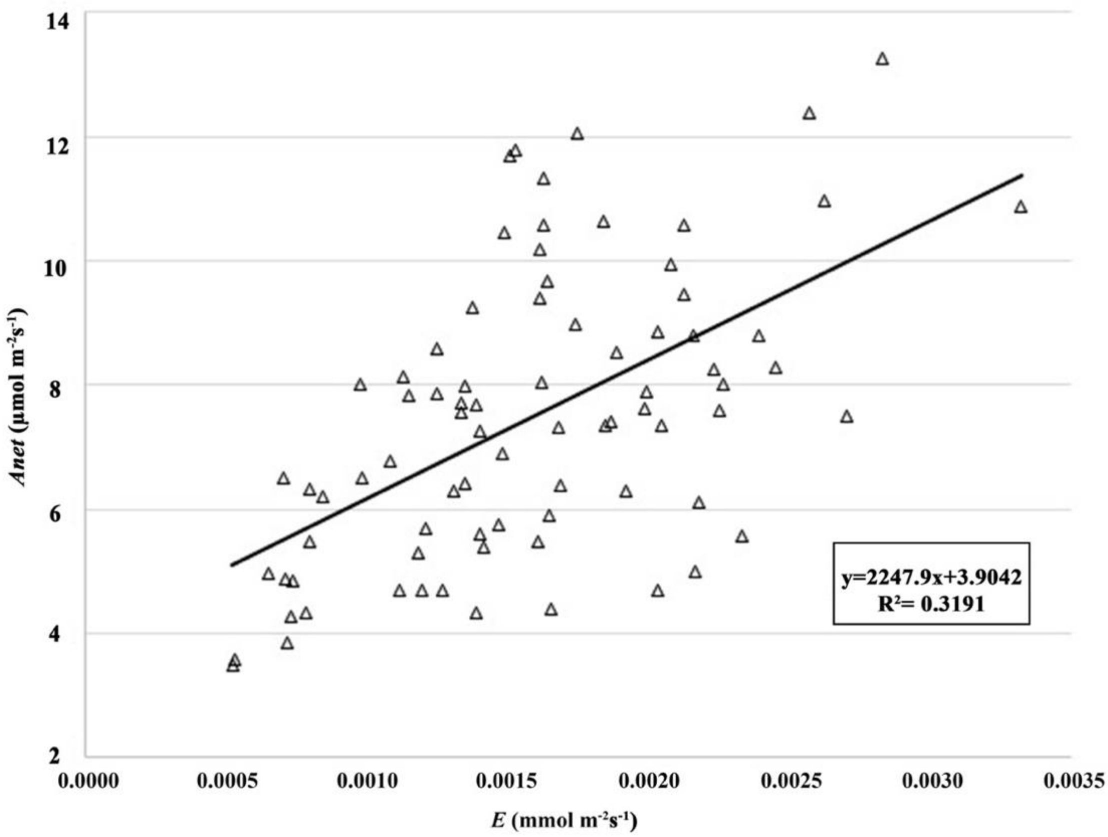

Figure 3. Relationship between E and Anet within chestnut population

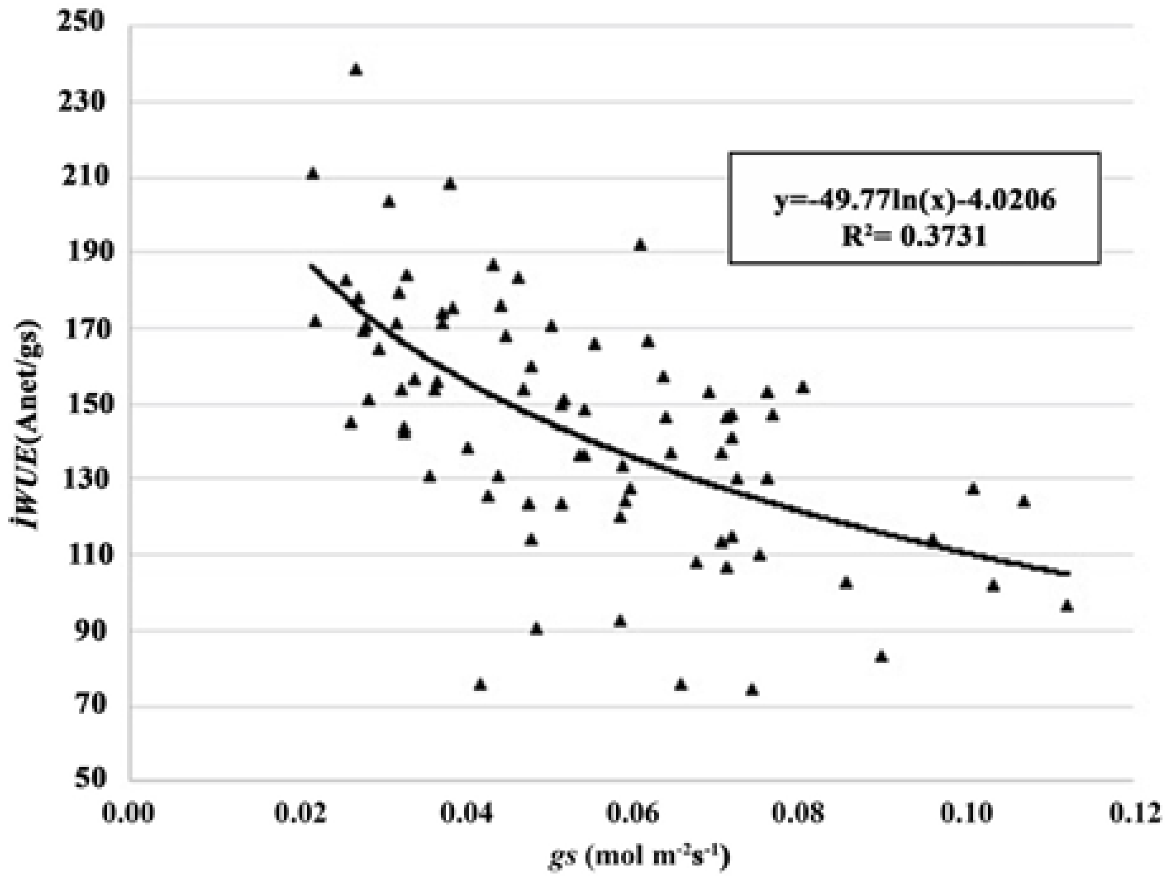

Figure 4. Relationship between gs and iWUE within chestnut population

When Ci values of chestnut populations were examined, AOM and DKAB populations had the highest values, whereas OVA and IBR showed the minimum *Ci* values (Table 3). When the *Ci/Ca* values of the chestnut populations are examined, the seedlings of the AOM and DKAB populations have the highest *Ci/Ca* values. In contrast, the OVA and IBR populations have the lowest values (Table 3).

In the current study, *Anet* correlated with *gs* that increasing stomatal conductance increased *Anet* in chestnut populations (Figure 2). However, there was not a strong correlation between *Anet* and *E* in the seedlings of chestnut populations (Figure 3). There was a negative correlation between *iWUE* and *gs*, which was not robust (Figure 4).

Discussion and Conclusion

As a result of the study, it was determined that the leaf gas exchange parameters changed significantly based on the population, and even this change was determined to be approximately 2 times higher in terms of the *Anet* values amount among some populations (MAR and IBR). Regarding *gs*, the differences between populations (ERF and IBR) changed approximately 2.5 times, and the differences (ERF and IBR) increased more than 3 times in terms of *E* values. These differences in *iWUE* and *Ci/Ca* values were determined as 1.5 (OVA and DKAB) and 2 (AOM and OVA) folds, respectively. Reduced water content in the soil causes a decline in plant organs' water potential, causing a reduction in *gs*, *Anet*, and *E*. Similar results were observed in *Acer negundo* and *Acer pseudoplatanus* (Koç, 2022a) and some conifer species seedlings (Koç 2021; Koç and Nzokou, 2022). A decline in *gs* caused a reduction in *Anet* and *E*, which led to plants having different *WUE* and *iWUE* traits. The different traits may play an essential role in plant growth and development (Xu et al. 2020).

Today, global climate change is one of the most critical glitches on a global scale, and this problem is considered irreversible (Varol et al. 2021; Tekin et al. 2022). It is estimated that global climate change will directly or indirectly affect all living things and ecosystems (Varol et al. 2022; Varol et al. 2022). Because the phenotypic features of all living things are shaped under the influence of genetic structure and environmental factors, the most apparent effects of global climate change will affect the climate parameters (Koç, 2022a; Yayla, 2022). It is estimated that the main effect of global climate change on climate parameters will manifest itself in the form of precipitation regime and temperature increase (Koç, 2022b; Koç, 2022c).

In this process, it is stated that factors such as fertilization deficiency, especially in marginal regions (Shults et al., 2018), increased temperature, more prolonged summer drought, and increased UV-B will significantly affect plant growth (Cantürk and Kulaç, 2021; Ozel et al. 2021). Because these factors, especially drought, are among the most critical stress facets affecting the development and growth of plants (Seleiman et al. 2021; Chaudhry and Sidhu, 2021; Koç, 2022a; Koç et al., 2022).

Summer temperatures and drought that will be prolonged due to global climate change will affect plant growth and may cause significant species and population losses (Varol et al. 2021). However, it is predicted that these impacts will have different levels of effects on a species basis, and while some species have significantly narrowed their distribution areas, the appropriate distribution areas of some species will increase (Dyderski et al. 2018; Ning et al. 2021).

It is estimated that species resistant to drought conditions will be less affected in this process. Studies reveal that the drought tolerance of different species differs significantly (Sevik and Cetin, 2015; Yigit et al. 2016). In addition, it has been determined that different populations of the same species have different levels of drought tolerance (Sevik and Erturk, 2015; Koç and Nzokou, 2022). Therefore, less resistant species and population losses are inevitable due to the effects of global climate change. In order to minimize these losses, necessary measures should be taken without delay.

In order to diminish possible species and population losses in the global climate change process, it is necessary to determine the climatic changes that will occur in advance. Studies on the subject it has been tried to determine both the change of climate parameters (Koç, 2022b; Koç, 2022c) and how this change will change the appropriate distribution areas of various species (Canturk and Kulaç, 2021; Tekin et al. 2022). It is essential to continue and diversify these studies to determine the climatic changes that may occur, which species will be affected by these changes, and to what extent.

Suggestions

In order to diminish the outcomes of climate change globally, especially species and population losses, these effects must be determined in advance. For this reason, projected model studies on the subject, determining the variables affecting this process, and determining possible changes in advance are priority issues.

In the next stage, to prevent deforestation, it is recommended to determine the most drought-resistant species and plant these species in appropriate areas, at least to include them in the mixture of the stands. Thus, although species and population losses are experienced in forested areas, at least the effects of deforestation and related erosion, loss of water resources, and large-scale loss of fauna can be reduced. Drought-resistant species in landscaping in urban areas are critical in preventing plant loss and saving water use.

One of the most critical measures that can be taken on the subject is the use of drought-resistant plant origins. Determining and using drought-resistant origins in the forest, agriculture, and landscape studies is very important in adapting to global climate change. In the studies to be carried out in this area, it is crucial to determine the drought-resistant origin and even individuals. For this purpose, the method used in the study can be recommended as a method that can be used to evaluate a large number of individuals in a short time, giving fast, cheap and reliable results.

Competing Interest / Conflict of Interest

The authors declare no conflict/competing interests.

Author Contribution

We declare that all authors equally contribute.

References

Allen CD, Macalady AK, Chenchouni H, Bachelet D, McDowell N, Vennetier M, Cobb, N. 2010. A global overview of drought and heat-induced tree mortality reveals emerging climate change risks for forests. Forest Ecology and Management, 259(4): 660-684.

Bhattacharjee S, & Saha, AK. 2014. Plant water-stress response mechanisms. In Approaches to plant stress and their management. New Delhi: Springer, pp. 149-172.

Canturk, U, Kulaç, Ş. 2021. The effects of climate change scenarios on *Tilia* ssp. In Turkey. Environmental Monitoring and Assessment, 193: 771. https://doi.org/10.1007/s10661-021-09546-5

Chaudhry S, & Sidhu, GPS. 2021. Climate change regulated abiotic stress mechanisms in plants: a comprehensive review. Plant Cell Reports, 1-31.

Çobanoğlu H, Şevik H, Koç İ. 2022. Havadaki Ca konsantrasyonunun tespitinde ve trafik yoğunluğu ile ilişkisinde yıllık halkaların kullanılabilirliği. Icontech Internatıonal Journal, 6(3): 94-106.

Demir T, Mutlu E, Aydın S, Gültepe N. 2021. Physicochemical water quality of Karabel, Çaltı, and Tohma brooks and blood biochemical parameters of *Barbus plebejus* fish: assessment of heavy metal concentrations for potential health risks. Environmental Monitoring and Assessment, 193(11), 1-15.

Conedera M, Manetti MC, Giudici F, Amorini E. 2004. Distribution and economic potential of the sweet chestnut (*Castanea sativa* Mill.) in Europe. Ecologia Mediterranea, 30(2): 179-193.

Dyderski MK, Paź S, Frelich LE, Jagodziński AM. 2018. How much does climate change threaten European forest tree species distributions? Global Change Biology, 24(3): 1150–1163.

FAO (Food and Agriculture Organization of the United State) 2019. FAOSTAT, crops, chestnut; Retrieved from http://www.fao.org/faostat/en/#data/QC/visualize

Giorgi F, & Lionello P. 2008. Climate change projections for the Mediterranean region. Global and Planetary Change, 63(2-3): 90-104.

IPCC 2014. Climate Change 2014 Synthesis Report Contribution of Working Groups I, II and III to The Fifth Assessment Report of The Intergovernmental Panel on Climate Change. R. K. Pachauri, L. A. Meyer, Eds, Core writing team. IPCC, Geneva, 2014.

IPCC 2014. Climate change 2014: Impacts, Adaptation and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the IPCC. Cambridge: Cambridge University Press.

Isinkaralar K, Koc I, Erdem R, & Sevik H. 2022. Atmospheric Cd, Cr, and Zn deposition in several landscape plants in Mersin, Türkiye. Water, Air, & Soil Pollution, 233(4): 1-10.

Kakavas K, Chavenetidou M, & Birbilis D. 2018. Chemical properties of Greek stump chestnut (*Castanea sativa* Mill.). Natural Product Research, 6(4): 1-4.

Keenan RJ. 2012. Adaptation of forests and forest management to climate change: An Editorial. Forests, 3(1): 75-82.

Key K, Kulaç Ş, Koç İ, Sevik H. 2022. Determining the 180-year change of Cd, Fe, and Al concentrations in the air by using annual rings of *Corylus colurna* L. Water, Air, & Soil Pollution, 233(7): 1-13.

Koç İ. 2021. Examination of gas exchange parameters of *Abies balsamea* (L.) Mill. and Abies concolor saplings, grown under various water regime, exposed to extreme drought stress at the end of the growing season. Turkish Journal of Forest Science, 5(2): 592-605.

Koç İ. 2022a. Comparison of the gas exchange parameters of two maple species (*Acer negundo* and *Acer pseudoplatanus*) seedlings under drought stress. Bartın Orman Fakültesi Dergisi, 24(1): 65-76.

Koç İ. 2022b. Determining the near-future biocomfort zones in Samsun province by the global climate change scenarios. Kastamonu University Journal of Forestry Faculty, 22(2): 181-192.

Koç İ. 2022c. Determining the biocomfort zones in near future under global climate change scenarios in Antalya. Kastamonu University Journal of Engineering and Sciences, 8(1): 6-17.

Koç İ, Cantürk U, Çobanoğlu H. 2022a. Changes of plant nutrients K and Mg in several plants based on traffic density and organs. Kastamonu University Journal of Engineering and Sciences, 8(1): 54-59.

Koç İ, Nzokou P. 2022. Do various conifers respond differently to water stress? A comparative study of white pine, concolor and balsam fir. Kastamonu University Journal of Forest Faculty, 22(1): 1-16.

Koç İ, Nzokou P. 2023. Combined effects of water stress and fertilization on the morphology and gas exchange parameters of 3-yeaar-old *Abies fraseri* (Pursh) Poir. Acta Physiologiae Plantarum, 45(49), 1-12.

Koç İ, Nzokou P, Cregg B. 2022. Biomass allocation and nutrient use efficiency in response to water stress: Insight from experimental manipulation of balsam fir, concolor fir and white pine transplants. New Forests, 53(5): 915-933.

Kutlu B, Mutlu E. 2021. Multivariate statistical evaluation of dissolved trace elements and water quality assessment in the Karaca dam, Turkey. EQA-International Journal of Environmental Quality, 44, 26-31.

Lambers H, Chapin III FS, Pons TL. 2008. Plant Physiological Ecology. (2nd ed.). New York: Springer Science & Business Media.

Lindner, M, Maroschek, M, Netherer, S, Kremer, A, Barbati, A, Garcia Gonzalo, J, Seidl, R, Delzon, S, Corona, P, Kolstrom, M, Lexer, M. J, & Marchetti, M. 2010. Climate change impacts, adaptive capacity, and vulnerability of European forest ecosystems. Forest Ecology and Management, 259(4): 698-709.

McDowell NG, Sapes G, Pivovaroff A, Adams HD, Allen CD, Anderegg WR, ... & Xu C. 2022. Mechanisms of woody-plant mortality under rising drought, CO_2 and vapour pressure deficit. Nature Reviews Earth & Environment, 3(5): 294-308.

Mirela L. 2020. Spread and study of sp. *Castanea sativa* in Albania. International Journal of Applied Environmental Sciences, 15(2): 109-115.

Mutlu E, Uncumusaoglu A. A. 2022. Assessment of spatial and temporal water pollution patterns in Aydos River (Turkey) by using water quality index and multivariate statistical methods. Desalination and Water Treatment, 246, 196-211.

Ning H, Ling L, Sun X, Kang X, & Chen H. 2021. Predicting the future redistribution of Chinese white pine *Pinus armandii* Franch. Under climate change scenarios in China using species distribution models. Global Ecology and Conservation, 25: e01420.

OGM (Orman Genel Müdürlüğü/General Directorate of Forestry) 2013. Chestnut Action Plan 2013-2017. Orman ve Su İşleri Bakanlığı, Ankara. p. 56.

Ozel HB, Cetin M, Sevik H, Varol T, Isik B, Yaman B. 2021. The effects of base station as an electromagnetic radiation source on flower and cone yield and germination percentage in *Pinus brutia* Ten. Biologia Futura, 1-7

Raza A, Razzaq A, Mehmood SS, Zou X, Zhang X, Lv Y, Xu J. 2019. Impact of climate change on crops adaptation and strategies to tackle its outcome: A review. Plants, 8(2): 34.

Seleiman MF, Al-Suhaibani N, Ali N, Akmal M, Alotaibi M, Refay Y, Dindaroglu T, Abdul-Wajid HH, Battaglia ML. 2021. Drought stress impacts on plants and different approaches to alleviate its adverse effects. Plants, 10(2): 259.

Sevik H, & Cetin M. 2015. Effects of water stress on seed germination for select landscape plants. Polish Journal of Environmental Studies, 24(2): 689-693.

Sevik H, & Erturk N. 2015. Effects of drought stress on germination in fourteen provenances of *Pinus brutia* Ten. seeds in Turkey. Turkish Journal of Agriculture-Food Science and Technology, 3(5): 294-299.

Sevik H, Ayan S, Turna I, & Yahyaoglu Z. 2010. Genetic diversity among populations in Scotch pine (*Pinus silvestris* L.) seed stands of Western. African Journal of Biotechnology, 9(43): 266-7272.

Shults P, Nzokou P, & Koc I. 2020. Nitrogen contributions of alley cropped Trifolium pratense may sustain short rotation woody crop yields on marginal lands. Nutrient Cycling in Agroecosystems, 117(2): 261-272.

Talu N, Sinan Ö, Özgün S, Dougherty W, Fencl A. 2011. Turkey's national climate change adaptation strategy and action plan (Draft). (D. Ş. Tapan, Ed.). Ankara: Ministry of Environment and Urbanization.

Tekin O, Cetin M, Varol T, Ozel HB, Sevik H, Zeren Cetin I. 2022. Altitudinal migration of species of fir (Abies spp.) in adaptation to climate change. Water, Air, & Soil Pollution, 233(9): 1-16.

Tokatli C, Mutlu E, Arslan N. 2021. Assessment of the potentially toxic element contamination in water of Şehriban Stream (Black Sea Region, Turkey) by using statistical and ecological indicators. Water Environment Research, 93(10), 2060-2071.

UNDP. 2019. Turkey UNDP climate change adaptation. Retrieved from; https://www.adaptation-undp.org/explore/western-asia/turkey

Varol T, Canturk U, Cetin M, Ozel HB, Sevik H. 2021. Impacts of climate change scenarios on European ash tree (*Fraxinus excelsior* L.) in Turkey. Forest Ecology and Management, 491: 119199.

Varol T, Canturk U, Cetin M, Ozel HB, Sevik H, Zeren Cetin I. 2022. Identifying the suitable habitats for Anatolian boxwood (*Buxus sempervirens* L.) for the future regarding the climate change. Theoretical and Applied Climatology, 150(1): 637-647.

Varol T, Cetin M, Ozel HB, Sevik H, Zeren Cetin I. 2022. The effects of climate change scenarios on *Carpinus betulus* and *Carpinus orientalis* in Europe. Water, Air, & Soil Pollution, 233(2): 1-13.

Xu Y, Feng Z, Shang B, Yuan X, Tarvainen L. 2020. Limited water availability did not protect poplar saplings from water use efficiency reduction under elevated ozone. Forest Ecology and Management, 462: 117999.

Yayla EE, Sevik H, & Isinkaralar K. 2022. Detection of landscape species as a low-cost biomonitoring study: Cr, Mn, and Zn pollution in an urban air quality. Environmental Monitoring and Assessment, 194(10): 1-10.

Yigit N, Sevik H, Cetin M, & Kaya N. 2016. Determination of the effect of drought stress on the seed germination in some plant species. Water Stress in Plants, 43: 62.

Yildiz D, Nzokou P, Deligoz A. Koc I, Genc M. 2014. Chemical and physiological responses of four Turkish red pine (*Pinus brutia* Ten.) provenances to cold temperature treatments. European Journal of Forest Research, 809–818.