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# Determination of pasture comfort climate index between forest and open grassland for livestock grazing

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**Abstract:**
In the summer of 2019, digitally recorded climatic data of shelterbelts and open pastures were compared to create a database. The aim of study was to clarify the extent to which the herding needs of free-range flocks in the pasture meet the climatic conditions of the shelterbelts. It is considered important to graze sheep in the grazing forest, as special attention needs to be paid during the daytime due to their low heat stress tolerance, which can increase the comfort zone of sheep, thus ensuring grassland sustainability and increasing grassland diversity. Based on investigations, it can be concluded that the shelterbelts occupy a key position in the examined area in the daily rhythm of the flock's presence on the pasture. The results showed that the soil surface temperature measured in the shelterbelt was lower on average 6.44°C (p-value: 1.36 $E^{-08}$ at 13:00 *hrs.*) and 5.18°C (p-value: 7.8 $E^{-07}$ at 15:00 *hrs.*) than in the control area. The studies also showed that the temperature in the shelterbelt was lower in the early afternoon hours than in the control area (p-value: 0.001 at 13:00 *hrs.*; and p-value: 0.0007 at 15:00 *hrs.*). Furthermore, the protective role of the shelterbelt was demonstrated, with a lower wind speed (83% avg.), humidity (13% avg.) and temperature (4% avg.) values.

**Keywords:** Shelterbelts; Weather; Database; Comparison

## Introduction

Grazing livestock plays a key role in maintaining the steppe grassland associations and biodiversity of the Pannonian Basin (Komarek, 2008). The negative effects of climate change due to the continental climate, in particular the heat stress affecting grazing animals are a major limiting factor for both the daily grazing and the rumination period, which determine the volume of animal products produced on pasture. The time spent ruminating for 6-8 hours a day should be spent with as few distractions (anthropogenic influences, heat, flies, etc.) as possible. Experience has shown that a shady grove is optimal for this purpose (Halasz et al., 2021).
Regulation 1305/2013 of the EU Rural Development Program (European Commission2013) is based on the recognition of the essential role of woody vegetation in extensive grazing, which contributes to the continuation of nature-friendly, sustainable agriculture (Fagerholm et al., 2016). It is linked to brittleness and is part of traditional extensive animal husbandry with migratory grazing all over the country. During the driveways, the forests also served as a destination and rest (Tálasi, 1939). The use of foliar fodder was widespread throughout Hungary (Andrásfalvy, 2007) as shepherds were happy to provide foliar fodder to the cattle. Sheep are born foresters as they like to consume willow and poplar when grazed at the right stocking density, leaving sheep untouched by the more commercially valuable forest tree species (*Pinus* species) (Andrásfalvy, 2007; DenHerder and AmaralPaoulo, 2021).
Based on our observations, the flora of the shelterbelts is not comparable to that of open grasslands. Due to the lack of light, the vegetation under the trees is negligible due to the high animal load and trampling, which is not a problem for woody stems. In terms of biodiversity, the shelterbelts is important for fauna rather than flora. The shelterbelts can increase the diversity of nesting songbirds, e.g. *Erithacus*

*rubecula, Columba palumbus*.

The systems consist of the combination of grass and trees: in other words, the silvopastoral systems are archaic cultivation forms of historical relevance in the international agricultural sphere in which they have also become a focus of research objectives as elements of the agricultural forestry system (Ellis et al., 2005; Bergmeier et al., 2010; Keesman et al., 2011; Nair and Garrity, 2012), which it is necessary to provide the habitat conservation of Directive 92/43 EEC through an appropriate grazing plan (Perrino et al., 2021). Concerning in Hungary country, especially the vast majority of the grasslands of the Great Hungarian Plain (Dorner, 1928; Gyárfás, 1989). As of today, this condition is still unchanged (Saláta, 2007, 2009). Due to the increasing effects of climate change in the recent years, the grazing livestock were acutely exposed to the extreme weather conditions in the absence of trees that could provide soothing shades. Due to their inherent sensitivity for windy conditions and their low heat resilience that stems from their warm wool cover, sheep require special attention (Haraszti, 1977). During the midday resting and rumination period, according to which the temperature, humidity and also the wind speed on the open pasture are higher during the day, Lakatos and Bihari (2011) report that from 1861 until the writing of their manuscript in 2010, a significant mean temperature increase has been measured in Hungary. The magnitude of the change is the largest in the eastern part of the country (where our experiment is located), with an increase of 1.75 degrees Celsius in the mean annual temperature between 1980 and 2010. Padányi and Halász (2012), examining climate change in Hungary over a 104-year time horizon, found that since 1991, all heat indices have shown an increase. The national average mean temperature follows global changes, but shows a higher warming than global mean temperature, with a point estimate of 0.77 degrees Celsius.

As mostly saline soil pastures were available for afforestation, in his study, Hóman (1880) suggested a furrow planting system with samplings that were grown in saline soil, in order to increase the amount of productive layer. Bedő (1896) and Berendy (1902) suggested the plantation of grove-like resting forests at the shallower, watery parts of the grass pastures in order to protect the livestock. Contrary to them, Márton (1897) asserted that a possible way to create grazing forests is to thin out forests that are planted in forest soil that is unsuitable for cultivation, in the areas where trees are not subject to forestry anymore. Károly (1905) specified three types of tree and grass combinations: woody grass pastures, grazing forests, and grove-laced pastures. Bíró (2010) further developed the form defined as grove-laced pasture, at which he would have located forest patches within the pastures in a mosaic-shaped layout, with complete forest-like closure characteristics while the rest of the area could only have been utilised as grassy pasture. Gyárfás (1989) described the importance of witness trees and groves on the dry-farming pastures of Transdanubia, concerning grass production and the well-being of the livestock. Béky (2010) urged the afforestation of the pastures of the Great Plains, in a so called thick format, within the maximum area of 1 cadastral moon (0.575 ha), in order to create cool resting forests. Gruber (1962) and Haraszti (1977) emphasize the role of resting forests at the days of heat.

Stott and Williams (1962), as well as Roman-Ponce et al. (1977) examined the role of shel-terbelts in the heat of summer in the course of their experiments with cattle, and came to the conclusion that windy shades have a positive effect on milk production on hot days, and are also quite beneficial concerning the weight gain of store cattle. During their Queensland experiments conducted with milk cows, Davison et al. (1988) found that the cows that could rest in shady shelters in the grazing period had increased milk yield with lower body temperatures while the number of somatic cells in their milk also decreased. Holmes and Sykes (1984) compared the weight gain of sheep and cattle, and determined that in case of sheep, resting forests had an increased measure of protective effects. Also, regarding sheep, paradoxically, the tree groups planted on the pasture could have a positive effect even in cold weather conditions. During their research, Doney et al. (1973), Lynch and Donelly (1980) as well as Jávor et al. (1999) came to the conclusion that in case of freely-kept sheep that stayed in resting groves, the number of miscarriages caused by catching a cold as well as the rate of lamb mortality in lambing season decreased.

On sloping productive areas, forest groves can reduce erosion, preserving the shal-low mould for the grassy vegetation (Vanderberghe et al., 2007). As it also stands out from the typological survey conducted by Saláta (2007) in the Northern Middle Mountains, in several areas that are uti-lised in so-called foothill grass cultivation, trees are present in the form of woody pastures, thus protecting the soil, the vegetation and the grazing livestock. According to Haraszthy et al. (1997), Vanderberghe et al. (2007) as well as Varga et al. (2014), the woody pasture associations have the greatest of diversity. Abandonment and reafforestation reduce the diversity of vegetation. Öllerer (2012) studied the 133 hectare-large woody pasture of Breit for six years, and identified 470 plant taxa. The above statements are also confirmed by the MÉTA charts constructed by Bölöni et al. (2011). Plieninger et al. (2015) consider woody pastures as the archetype of the areas with High Natural Value. According to the use of the LUCAS database, the total area of woody pastures in Hungary is estimated to be 2166 squared kilometres. Due to government support, the concept of agro-forest is one of the most determinative research and development subjects (Nyári, 2006; Nair and Garrity, 2012). Some of the most representative saline afforestation experiments are located at Püspökladány (Farkassziget) (Führer, 1995). Führer (1995) published observations concerning the afforestation of saline areas with woody plants. The establishment of a grazing forest consisting of Black Locust (Robinia pseudoacacia) species is also worth mentioning (Hortobágy 5 A, B). Csízi (1998, 2001), and Monori and Csízi (2002) published their practical observations in 1990, concerning the establishment of protective woodland fringes with furrow planting technology on medium meadow solonetz soil, in order to separate pastures, at the University of Debrecen, IAREF, Research Institute of

Karcag.

In each of the Forestry Acts (1879, 1961 and 2009), the actual government expressed the raison d'être regarding clumps of trees planted on the pastures (Saláta, 2007; Saláta et al., 2013). According to the definition of Saláta (2007): ”Woody pastures bear witness of the traditional grazing livestock farming of the Carpathian Basin”.

In our area, russian willow (*Eleaganus angustifolia*) shelterbelts are used to protect the sheep flock from the heat. The russian willow is invasive, germinates from seed in saline, narrow-growing areas, spreads naturally, provides little shade, and is prickly. We have planted poplar (Populus alba) for animal welfare reasons as it provides more shade and is prickly. A poplar shelterbelts can only be implemented in deeper areas with better water supply. Based on empirical experience of tree plantations in the area, a species of poplar (*Populus alba*) was selected that meets 4 criteria: fast growth, high shade, thorn-free, tolerance of intermittent water cover. The choice of the tree species took into account the recommendations of Magyar (1960) and Gyárfás (1989) on lowland grazing.

In the grazing system associated with the shelterbelts, in addition to sheep, animals are kept that are not food competitors, and therefore, mainly insectivorous species such as hens (*Gallus gallus domesticus*), guinea fowl (*Numida meleagris f. domestica*), turkeys (*Meleagris gallopavo gallopavo*) (Vinczeffy, 1993).

The Hungarian national parks report that the grazing habits and ethological behaviour of the species of farm animals on the grasslands they use also vary. According to Vinczeffy (1993), sheep breeds indigenous to the Carpathian Basin and so-called endangered (like the Hungarian Merino), behave from the herding instinct, following the movements of the lead mother. The sheep breeds imported from Western Europe graze in a dispersed, spaced-out way in the optimal enclosed pasture.

In the Hungarian lowland grasslands, it is an ancient pastoral tradition to graze sheep on the undergrazed grassland after cattle grazing (Vinczeffy, 1993). In the Bükk National Park, the richest grasslands on the plateaus grazed by horses were recorded when cattle grazed them after the horses as the latter species consumed the biplanar plants left by the horses. It reports that the sheep-cattle-horse grazing community is favourable to the plant community structure of a given grassland community because they graze at different depths. They even suggest grazing goats as a pre-group if there are many shrubs in the pasture.

The main sources of income for sheep farmers are dairy lambs sold at 20-25 kg live weight and environmental grass subsidies (e.g. Natura 2006, land-based subsidies). These subsidies account for about 70% of sheep farmers' income, the remainder coming from arable crops.

Scattered trees, groups of trees, or forest edges have always played an important role in grazing as they provided shade and rest for all animals; in the case of grazing animals and wild fruit trees, their crops were also consumed by humans; animals have also been used as rubbing trees (Bellon, 2003).

The aim of our research is to compare meteorological data recorded in the open pasture and the shelterbelt, the two main habitats of our sheep flocks, and to clarify the role of the shelterbelt in extensive grazing-based sheep management.

## Materials and methods

This study was conducted to examinations (Figures 1 and 2) the pasture-garden system (lot number 01712/1) utilised by 550 sheep in the IAREF Research Institute of Debrecen University at Karcag (47.289007, 20.925997).

One of the test sites was a "Blanche du Poitou" poplar resting forest, planted in 2 by 2 m squares; planted at 1 hectare at the deeper end of the pasture, in 1990. Elevation is between 120-150 metres. The delta forest was planted in the lower-lying area. This area covers 74 hectares. The shelterbelt has 6 grazing gardens, the fences of which are fixed, and each is equipped with a gate. The 6 pasture gardens have been designed to vary in size to suit grassland soil

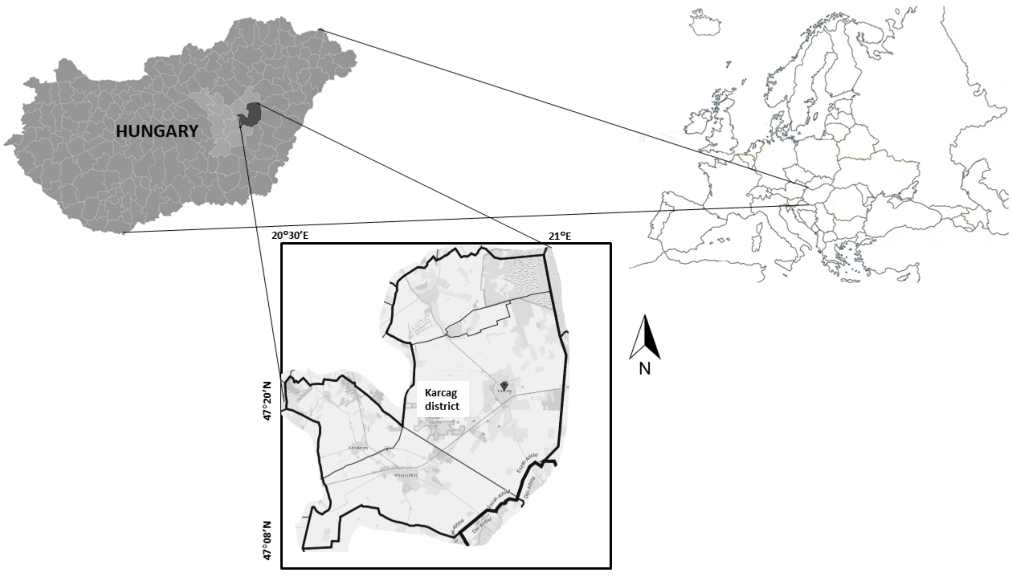


**Figure 1.** The location of the study area, Hungary, Karcag.

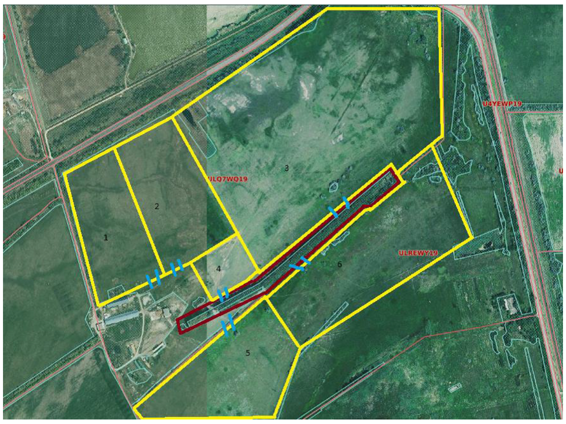

**Figure 2.** Map showing the relationship between the shelterbelt and the pasture gardens (Source: www.mepar.hu). The red line indicates the shelterbelt; the yellow line indicates the pasture gardens; the blue line indicates the pasture garden gates. The numbers indicate the pasture gardens. There is no distance between the red and yellow lines around the delta forest.

conditions and relief conditions. The fences of the pasture garden are made of acacia poles cut every 5 metres and wildlife netting. In the pasture gardens, sectional grazing is used.
Another location was a so-called embanked yarrow-grass meadow association (control area), preferred by the sheep. A total of two weather stations were installed, one in the delta forest and one in the control area. In the representative centre of each locations, Conrad WH2080 weather stations were placed (see Figure 3 Shelterbelt: 47.288809, 20.925620; Control area: 47.286989, 20.925648). The Con-

**Figure 3.** The shelterbelt and the control area with the meteorological station and the pasture in the background (Source: Krisztina Varga, 2023).

rad WH-2080 is a variable atmospheric pressure weather forecaster that measures atmospheric pressure (hPa) with 0.1hPa display, air speed (m/s), humidity (%), and ground and air temperature (°C). The device records data every hour. Out of the large-scale examination dataset, for easier handling, we chose four hottest days of each month of the investigation (between June 1. 2019 and August 31. 2019) as well as three critical times (13:00, 15:00, 17:00) from the daily resting period, which were determinative concerning the stay of the flock in the resting forest. In the greatest warm weather, all sheep are in the shelterbelt and at 17:00 they begin to graze in the pasture again.
The needs of the sheep for delirium comfort zone were taken into account in the choice of the parameters tested. Sheep are about 1m tall in standing position (temperature °C) and lie on the ground in the delta forest at delta time (soil temperature °C). Crosswind is also important for the comfort zone needs of sheep as there is crosswind in the sheepfold (wind speed m/s, humidity %). The date was chosen because based on the average of the last 50 years in the region, the summer months have the highest number of heat days, which is important for continuous grazing.
The data collected in the experiments were recorded and summarised, and the results were processed and evaluated using Microsoft Office Excel. Analysis of variance at 5% significance level was used to evaluate the data.

## Results

The data recorded by the weather station can be found in the Appendix (Appendix Table). The weather station recorded data on ground surface temperature, air temperature, humidity and wind speed. A descriptive statistical analysis of each of the categories measured is also available. The average monthly temperature in the study area was 23.1 °C in June 2019, 21.8 °C in July 2019 and 23.8 °C in August 2019. The results were evaluated using one-step analysis of variance, with p-values shown in the following table (Table 1).

### Analysis of soil surface temperature data

In the control area (open grassland), soil surface temperatures ranged from 35.1-43.4°C at 13:00 while in the shelterbelt, they ranged from 32.5-35.2°C. The data measured at 15:00 showed that the control area measured between 36.3-42.8°C while the shelterbelt measured between 32.7-36.3°C. At 17:00, data ranged from 22.8-40.9°C in the control area and 25.4-35.9°C in the shelterbelt (Figure 4).
From the Figure 4, it can see that the control area had higher ground surface temperatures than the shelterbelt. In the control area, it measured higher values by an average of 16.03% at 13:00 while at 15:00, the average ground surface temperature was 13.00% higher and at 17:00 only 2.57% higher than that in the shelterbelt. Regarding the ground surface temperature values, we measured higher values in the shelterbelt 5 times at 17:00 (16/06; 26/06; 01/07; 21/07 and 26/07). It also observed that the herd ”woke up” and started to graze again at around 17:00. In the analysis of variance, there was no detectable correlation at 17:00 (p-value: 0.6286).

### Analysis of air temperature data

The measured temperature in the control area (open grassland) at 1h ranged from 32.2-35.0 °C while in the shelterbelt, it ranged from 30.1-33.8 °C. Data measured at the 15:00

**Table 1.** Analysis of variance for three treatment.

| Time/ p-value | at 13:00 | at 15:00 | at 17:00 |
|---|---|---|---|
| Soil surface temperature (°C) | $1.36E^{-08}$* | $7.81E^{-07}$* | 0.628647 |
| Temperature (°C) | 0.001229* | 0.000655* | 0.541492 |
| Humidity (%) | 0.062047 | 0.040369* | 0.439495 |
| Wind speed (m/s) | $2.48E^{-05}$* | $2.37E^{-05}$* | 0.000612* |

An asterisk means the result is significant.

hrs. time point show that the control area measured between 32.7-36.5 °C while the shelterbelt measured between 30.4-34.6 °C. At 17:00 hrs, data ranging from 22.4-36.6 °C in the control area and 28.5-34.1 °C in the shelterbelt were recorded (Figure 5.)

Temperatures were higher in the shelterbelt on three occasions (16/06, 17/06 and 26/07) at 17:00 while at the other times, they were lower than in the open grassland. Temperatures in the shelterbelt were 4.94% lower on average at 13:00, 5.56% lower on average at 15:00 and 2.64% lower on average at 17:00 than the control area. In the analysis of variance, we found that at 13:00 hrs. and 15:00 hrs., temperatures at 1 m height were higher in the control area than those in the shelterbelt at all measurement times (13:00, p-value 0.0012; and 15:00, p-value: 0.0007).

### Analysis of humidity data

Measured humidity ranged from 31.0-51.0% at 13:00 hrs. in the control area (open grassland) and from 24.0-43.0% in the shelterbelt. Data measured at the 15:00 hrs. showed that

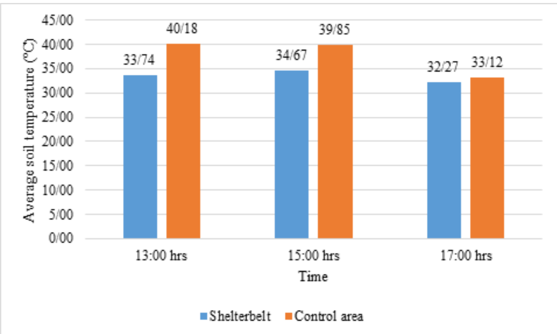


**Figure 4.** Plots of average soil temperature in the delta forest and the control area at the time points studied.

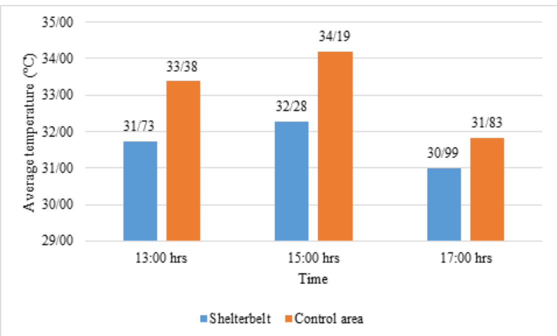


**Figure 5.** Plots of average temperatures in the delta forest and the control area at the time points studied.

the control area ranged from 27.0 to 53.0% while the shelterbelt ranged from 25.0 to 39.0%. At 17:00, data ranged from 28.0-77.0% in the control area and 24.0-70.0% in the shelterbelt (Figure 6).

The control area had one lower humidity (40.00% on 13 June at 17.00 hrs.) than the delta grove, and one identical humidity was measured in both study areas (70.00% on 27 June at 17.00 hrs.). Higher humidity values were measured in the control area than in the shelterbelt at 13:00 and 15:00 (13:00, p-value: 0.0620; 17:00, p-value: 0.0404). The humidity values were on average 12.20% higher than in the control area at 13:00, 15.36% higher at 15:00 and 11.57% higher at 17:00.

### Analysis of air speed data

In the control area (open grassland), the measured air velocity ranged from 1.4-5.2m/s at 13:00 while in the shelterbelt it ranged from 0-3.39m/s. The data measured at the 15:00 time point show that the control area measured between 1.4-5.2m/s while the shelterbelt measured between 0-3.11m/s. At 17:00, data ranging from 0.3-7.7m/s in the control area and 0-2.69m/s in the shelterbelt were recorded (Figure 7.)

In the shelterbelt, the measured air speed was higher than in the control area on a total of 3 occasions (at 13:00: 21.08.2019 and 17:00: 16.06.2019.; 21.08.2019). Furthermore, data from the weather station placed in the shelterbelt showed that there were 3 winds at 13:00 (3.39 m/s, 139 m/s, 2.00 m/s) 4 winds at 15:00 (1 m/s, 0.31 m/s, 3.11 m/s 1.71 m/s) and 4 winds at 17:00 (1.39 m/s, 0.69 m/s, 2.69 m/s, 1.39 m/s) while no air movement was observed at the other times.

The measured air speeds were on average 81.08% higher in the control area at 13:00, 84.52% higher at 15:00 and 83.34% higher at 17:00.

Comparing the data from the control area and the shelterbelt, the analysis of variance concluded that the control area recorded higher values at all three measurement times (13:00, 15:00 and 17:00) from the weather station (13:00, p-value: 0.00002; 15:00, p-value: 0.00002; and 17:00, p-value: 0.0006).

Based on the metrological data recorded in the open pasture and the 30-year old poplar delta pasture, it was clearly established that the temperature and wind speed data measured at the critical times of 13:00 and 15:00 hrs for heat stress were demonstrably lower in the shelterbelt. Thus, grazing livestock may find shelter during the daytime ruminating period by a group of trees planted under similar growing conditions.

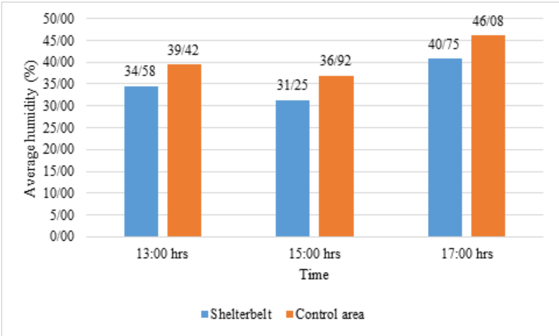


**Figure 6.** Plots of average humidity in the delta forest and the control area at the time points studied.

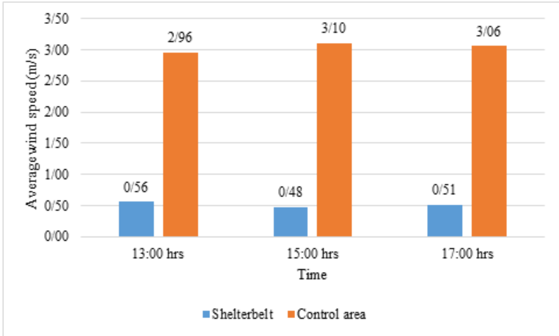


**Figure 7.** Plots of average wind speed in the delta forest and the control area at the time points studied.

## Discussion

Nowadays, extreme meteorological conditions generated by climate change, among others, make pasture-based sheep production more difficult (Komarek, 2007; Csízi and Fernandez, 2015) have verified the ageing potential of southern resting groves by non-stop recording of specific weather data, comparing the differences between the southern resting of sheep flocks on pasture and the southern resting of flocks in resting forests.

The importance of agroforestry systems as filter areas alongside intensively farmed agricultural land was also highlighted by Mize et al. (2008), confirming the findings of the Michigan NRCS (2006) on linear forest strips in grasslands that protect grazing livestock and provide habitat for wildlife. A longer-term solution to wind-induced erosion on Australian savannas is the establishment of forest strips with shrub and tree combinations by Cremer (1990) and Burke (2001). Marais et al. (2022) consider the structure of the planted forest structure important for balancing the ecological and economical benefits of forest strips.

The negative impacts of climate change could also cause dramatic changes in the grazing ruminant livestock sector. Favourable grazing conditions can be maintained longer in the hilly and mountainous areas of Hungary than in the extremely dry and saline pastures of the Great Plain, where sheep farming can remain the primary grassland sector. The daily grazing period of the flocks living here is often shortened due to the increasing frequency of hot days. In addition, grass pastures are not an optimal place for sheep flocks to graze in the early afternoon due to excessive sunlight and temperatures. In addition, an important labour efficiency aspect for the practice is to avoid the need to move the animals between the pasture and the livestock building during the day, and to allow them to rest in the woodland strip in the pasture. From the resting area, where the mobile watering troughs will also be located, the animals can go to graze or return to the resting area to graze as they wish.

Lampartová et al. (2015) findings have been confirmed regarding with protective role of the resting forest. It was found that temperatures were lower in the resting forest on heatwave days. Also, it was confirmed that the resting forest is protective in higher winds (Kenney, 1986).

## Conclusion

As it is clear from the literature review of the manuscript, in the Hungarian Great Plain, the persistently elevated summer air temperatures are an axiom in grazing sheep management. In hot days, the sheep flock can hardly graze on the heated open grasslands. All possibilities should be explored to ensure that sheep can continue to graze during the day in these conditions as long as possible to satisfy their biologically optimal feeding, digestive and behavioural habits. One realistic way of achieving this is to provide a shaded shelter with more favourable temperature conditions than open grassland. This research provided information on specific meteorological data from a poplar shelterbelt that is perspective to the lowland conditions and fits into the agroforestry concept. The research have been extended to analyse diurnal movements of sheep flocks equipped with GPS trackers. The ultimate goal is to refine a complex sheep-grassland-forest system for the survival of sheep herds based on environmentally friendly steppe grassland management.

**Appendix Table:** The soil surface temperature (°C), temperature (°C), humidity (%), wind speed (m/s) measured values (Karcag, 2019 June-August).

| Soil surface temperature (°C) | | | | | | |
|---|---|---|---|---|---|---|
| Time | at 13:00 | | at 15:00 | | at 17:00 | |
| Date/Area | Shelterbelt | Control area | Shelterbelt | Control area | Shelterbelt | Control area |
| 13 June 2019 | 32.50 | 40.00 | 32.70 | 39.00 | 32.00 | 35.00 |
| 16 June 2019 | 33.80 | 38.40 | 33.70 | 40.70 | 30.20 | 28.20 |
| 26 June 2019 | 33.80 | 39.40 | 34.90 | 36.80 | 33.80 | 32.60 |
| 27 June 2019 | 34.90 | 39.00 | 36.10 | 37.00 | 26.30 | 28.50 |
| 01 July 2019 | 33.20 | 37.80 | 35.00 | 36.30 | 34.20 | 32.60 |
| 02 July 2019 | 34.00 | 35.10 | 35.30 | 38.70 | 33.70 | 35.50 |
| 21 July 2019 | 32.60 | 42.60 | 33.60 | 40.90 | 32.00 | 30.80 |
| 26 July 2019 | 32.70 | 41.10 | 34.10 | 42.40 | 25.40 | 22.80 |
| 12 August 2019 | 35.20 | 41.90 | 36.30 | 42.80 | 35.90 | 38.00 |
| 13 August 2019 | 34.50 | 43.40 | 35.10 | 42.80 | 34.80 | 40.90 |
| 20 August 2019 | 34.60 | 42.40 | 34.50 | 42.20 | 34.80 | 36.80 |
| 21 August 2019 | 33.10 | 41.10 | 34.70 | 38.60 | 34.10 | 35.70 |

| Temperature (°C) | | | | | | |
|---|---|---|---|---|---|---|
| Time | at 13:00 | | at 15:00 | | at 17:00 | |
| Date/Area | Shelterbelt | Control area | Shelterbelt | Date/Area | Shelterbelt | Control area |
| 13 June 2019 | 30.20 | 33.10 | 30.40 | 33.40 | 29.60 | 32.70 |
| 16 June 2019 | 31.60 | 32.60 | 31.70 | 34.60 | 28.90 | 27.70 |
| 26 June 2019 | 31.50 | 32.20 | 32.00 | 32.80 | 31.10 | 33.40 |
| 27 June 2019 | 32.30 | 33.10 | 32.90 | 34.20 | 28.80 | 25.60 |
| 01 July 2019 | 31.10 | 33.20 | 31.90 | 34.10 | 31.70 | 33.80 |
| 02 July 2019 | 31.60 | 33.70 | 32.20 | 34.40 | 31.50 | 33.50 |
| 21 July 2019 | 30.10 | 32.50 | 30.70 | 33.30 | 29.90 | 31.60 |
| 26 July 2019 | 30.40 | 32.40 | 31.00 | 32.70 | 28.50 | 22.40 |
| 12 August 2019 | 33.80 | 35.00 | 34.60 | 36.50 | 34.10 | 36.60 |
| 13 August 2019 | 33.50 | 34.70 | 34.00 | 35.40 | 33.00 | 35.20 |
| 20 August 2019 | 32.70 | 34.60 | 33.00 | 34.80 | 32.40 | 35.10 |
| 21 August 2019 | 32.00 | 33.40 | 32.90 | 34.10 | 32.40 | 34.40 |

| Humidity (%) | | | | | | |
|---|---|---|---|---|---|---|
| Time | at 13:00 | | at 15:00 | | at 17:00 | |
| Date/Area | Shelterbelt | Control area | Shelterbelt | Date/Area | Shelterbelt | Control area |
| 13 June 2019 | 38.00 | 35.00 | 34.00 | 38.00 | 41.00 | 40.00 |
| 16 June 2019 | 43.00 | 47.00 | 37.00 | 36.00 | 60.00 | 77.00 |
| 26 June 2019 | 42.00 | 48.00 | 37.00 | 51.00 | 37.00 | 44.00 |
| 27 June 2019 | 43.00 | 51.00 | 39.00 | 53.00 | 70.00 | 70.00 |
| 01 July 2019 | 36.00 | 41.00 | 32.00 | 38.00 | 34.00 | 40.00 |
| 02 July 2019 | 32.00 | 38.00 | 25.00 | 33.00 | 33.00 | 40.00 |
| 21 July 2019 | 30.00 | 37.00 | 30.00 | 32.00 | 29.00 | 36.00 |
| 26 July 2019 | 32.00 | 38.00 | 30.00 | 34.00 | 66.00 | 76.00 |
| 12 August 2019 | 30.00 | 36.00 | 31.00 | 35.00 | 32.00 | 35.00 |
| 13 August 2019 | 32.00 | 36.00 | 28.00 | 31.00 | 32.00 | 33.00 |
| 20 August 2019 | 24.00 | 31.00 | 25.00 | 27.00 | 24.00 | 28.00 |
| 21 August 2019 | 33.00 | 35.00 | 27.00 | 35.00 | 31.00 | 34.00 |

Continue of appendix Table.

| | Wind speed (m/s) | | | | | |
|---|---|---|---|---|---|---|
| Time | at 13:00 | | at 15:00 | | at 17:00 | |
| Date/Area | Shelterbelt | Control area | Shelterbelt | Date/Area | Shelterbelt | Control area |
| 13 June 2019 | 0.00 | 2.60 | 0.00 | 1.90 | 0.00 | 2.00 |
| 16 June 2019 | 0.00 | 1.40 | 0.00 | 1.40 | 1.39 | 0.30 |
| 26 June 2019 | 0.00 | 2.40 | 0.00 | 2.70 | 0.00 | 1.50 |
| 27 June 2019 | 0.00 | 5.20 | 0.00 | 5.20 | 0.69 | 3.60 |
| 01 July 2019 | 3.39 | 4.10 | 0.00 | 4.70 | 2.69 | 4.10 |
| 02 July 2019 | 0.00 | 3.50 | 0.00 | 1.50 | 0.00 | 3.10 |
| 21 July 2019 | 0.00 | 3.60 | 1.00 | 4.00 | 0.00 | 2.30 |
| 26 July 2019 | 0.00 | 2.60 | 0.00 | 2.60 | 0.00 | 7.70 |
| 12 August 2019 | 0.00 | 3.40 | 0.31 | 3.90 | 0.00 | 4.20 |
| 13 August 2019 | 1.39 | 3.20 | 3.11 | 5.10 | 0.00 | 5.00 |
| 20 August 2019 | 0.00 | 1.80 | 0.00 | 2.40 | 0.00 | 1.80 |
| 21 August 2019 | 2.00 | 1.70 | 1.39 | 1.80 | 1.39 | 1.10 |

**Authors contributions**
All authors have contributed equally to prepare the paper.

**Availability of data and materials**
The data that support the findings of this study are available from the corresponding author upon reasonable request.

**Conflict of interests**
The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.



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