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The Effects of Hedgerows Shading on Soil Temperature and Gravimetric Soil Water Content

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ABSTRACT

This study sets out to examine the effects of hedgerow shading on soil physical properties, specifically soil gravimetric water content and soil temperature. Analyses of both soil parameters were conducted at two locations with different shade proportion. The aim of the study was to address the links between hedgerow shading and basic physical soil properties which could be significant both for agricultural production and for ecological processes in agroecosystems. At both locations, soil samples and measurements were taken at different distances from hedgerow and in different time intervals. Diurnal shading variation at certain distances from the hedgerow on Location 1 and 2 was calculated with the software toll for Arboriculturists. At Location 1 shading is consistently high throughout the year, ranging from 76 to 100%. In contrast, shading at Location 2 varies from 1 to 25%. The results reveal that hedgerows at Location 1, do not have a statistically significant impact on gravimetric soil water content and soil temperature across the entire plot surface. Additionally, the percentage of shading is only marginally decreases with distance. Conversely, Location 2 exhibits an increase in soil temperature and a slight but (non-significant) decrease in soil gravimetric water content as the distance from the hedgerow increases., The total mean shading at Location 2 is considerably lower compared to Location 1, and the shading percentage declines more at the distance from the hedgerow increases. Overall, lower soil temperatures and higher gravimetric soil water content where observed at the more shaded Location 1. The research outcomes are helpful in agricultural production planning as well as in the evaluation of hedgerows for the needs of agricultural policy.

Keywords: soil water content, soil temperature, hedgerow, sunlight

INTRODUCTION

Hedgerows, or related structures such as rows of trees or shrubs are important landscape elements in the agroecosystems. Hedgerows are linear features composed of trees and/or shrubs of various species (Betbeder et al., 2014). According to Hannon and Sisk (2009) hedgerows play a crucial role in controlling physical, chemical and biological fluxes in landscapes and in conserving biodiversity (Baudry et al., 2000; Montgomery et al., 2020; Vanneste et al., 2020; Borec et al., 2021). Numerous research studies have been conducted on these topics. However, fewer studies have focused on interception loss and shading effect from linear vegetation structures.

Research on hedgerows and their effects on water balance (Plamboeck et al., 1999; Fleischbein et al., 2006; Sidle et al., 2007; Tromp-van Meerveldet et al., 2007; Ghazavi et al., 2008) provides some indications about the influence of linear vegetation structures, even more scientific evidences has been found about the impact of hedgerow on soil characteristics (Merot, 1999).

Studies in France (Carnet,1978; Caubel et al., 2003) and Australia (White et al., 2002) have reported about strong drying effect of hedgerows on soil in summer and the increase of their vertical drainage capacity with large reductions in nitrate concentration in the ground-water beneath a hedgerow. Another study has found that hedgerow can intercept up to 80% of precipitation from a rainfall event, however the impact of trees on rainfall interception differs for trees with and without leaves (David et al., 2006). Hedgerows therefore have a strong impact on soil properties, water availability and distribution.

Not only does the hedgerow vegetation itself impact soil parameters, but also their shade effect can result in significant changes to various soil parameters. For example, shade reduces air and soil temperatures (Montgomery et al., 2020), and preserves soil moisture next to the hedgerow (Raatz et al., 2019).

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On the other hand, hedgerow removal could affect a range of factors including water loss (Kinama et al., 2007), precipitation, and light interception (Herbst et al., 2006), ultimately impacting on local microclimate.

While numerous soil related studies have been conducted in Slovenia, there is a scarcity of scientific literature specifically focusing on hedgerow effect on soil quality parameters. For this reason, this study carries out a basic analysis of physical parameters assuming that gravimetric soil water content and soil temperature are primarily affected by the shade of hedgerows. Further, the different shade proportions play an important role in the soil physical properties and thus may affect the agricultural growth.

MATERIALS AND METHODS

Study area

The study area is situated in the northern part of the municipality of Hajdina (46°45'29'' N, 15°81'18'' E), on the alluvial plain of the river Drava (Atlas okolja, 2023). The altitude is 232 m above sea level and the prevailing wind direction is South-Southwest. The area is intended for intensive agricultural production due to the favorable climate, flat relief, agricultural holding's structure, and the size of farmlands. The soil type is characterized by Alluvial soils, Eutric, Calcaric (Vidic et al., 2015; FAO, 2014; KIS/eTLA). The specific soil characteristics are the result of the deposition of Drava river sediments and are usually light and airy, which is favorable for most agricultural crops. The soils developed on alluvial sediments, larger gravel and sand predominate, soils are shallow (Glavan et al., 2015).

The area is characterized by a continental to sub-continental climate, with lower precipitation and evapotranspiration in winter-spring (January–April) and the highest in the summer (June–September) with significant storm rainfall and temperatures, respectively. At the nearest meteo data station Ptuj the average annual rainfall measured in the 2022 was 841 mm. In general, the Ptuj station is characterized by a continental rainfall regime with an average annual rainfall up to 1300 mm (ARSO, 2023). Yearly mean temperatures during vegetation period range from 17.0 in May to 22.6 °C in July and mean highest monthly temperature varies from 20.8 (September) to 29.2 °C (July).

Side Selection

The selected study sites are two neighboring field plots bordered by hedgerows (Figure 3). The study of hedgerows shading on the soil characteristics (gravimetric soil water content and soil temperature) was carried out on Location 1 (Figure 1) and Location 2 (Figure 2). Location 1 lies between two parallel hedgerows (in Figure 3 marked as H1 and H2) cultivated with Common wheat (*T. aestivum*) and has a size of 0.39 ha. Location 2 borders on the hedgerow (H2) only on one side, cultivated with Maize (*Zea mays*) and has a size of 2.4 ha (Figure 3). Both hedgerows in the study area are 300 meters long and are running in north–south direction, with precise coordinates for H1 46°26'30" N 15°49'16" E and for H2 46°26'33" N 15°49'15" E.

Figure 1: Photo of Location 1

Figure 2: Photo of Location 2

Both hedgerows are well structured, preserved and in good condition. As the hedgerows H1 and H2 are only 18-20 m apart, their vegetation composition is almost identical. The average size of hedgerows trees is between 15 to 20 meters. The most frequent tree and shrub species are presented in Table 1. Species are listed in the approximate order of abundance. Vegetation is autochthonous, adapted to environmental factors such as geological base, soil type, climatic conditions, relief and altitude. The hedgerows species are comparable to vegetation of the surrounding forest edges (Lešnik, 2018). *Ulmus carpinifolia* is the most frequent tree species followed by *Alnus glutinosa*, *Euonymus europaeus*, *Prunus padus* and *Prunus avium*. The hedgerow management includes pruning for firewood, as well as the harvesting of fruits and flowers.

Table 1: Most frequent hedgerows vegetation

Tree species	Shrub /invasive species and climbers
Ulmus carpinifolia	*Phytolacca americana*
Alnus glutinosa	*Humulus lupulus*
Euonymus europaeus	*Clematis vitalba*
Prunus padus	*Prunus spinosa*
Prunus avium	*Solidago virgaurea L.*
	Sambucus nigra

Soil sampling and measuring

Soil samples were taken in the vegetation period between May and September 2022 and during the day between 7 a.m. and 12 p.m. (Table 2).

Soil sampling was performed at six distances along three transects, with each transect consisting of six sampling positions at distances 0, 2, 5, 10, 15, and 17 m at Location 1 in the direction from H2 to H1 and at distances 0, 2, 5, 10, 20 and 30 m at Location 2 in the opposite direction from H2 (Figure 3). At each position, average soil sample as a mixture of ten subsamples were taken at a depth of 20 cm with a sing 2.5 cm internal diameter gouge auger. All soil samples were oven-dried at 105 °C for a minimum 24 h. In total, 216 mixed soil samples were collected (2 locations, 6 distances/sampling points, 3 blocks, 6 dates).

Table 2: Soil sampling dates in the vegetation period between May and September 2022

Location	Date					
	May	June	July	Aug	Aug	Sept
1	21.5.	12.6.	8.7.	6.8.	30.8.	19.9.
2	21.5.	12.6.	7.7.	6.8.	30.8.	20.9.

On all the sampling points, soil temperature was measured by using a thermometer at a depth of 5 cm. The depth of 5 cm was specified according to Mungai (2000) who stated the shadow impact on soil temperature is recognized only above 7.5 cm depth.

Shade determination

ArborShadow R4 programme was used to determine the shade of hedgerows. The shading graphs were carried out separately for Location 1 and 2 (Figure 4 and 5). The programme input data were latitude and longitude, hedgerow orientation, field and hedgerow surface, specific date, and tree sizes, which were also the basic parameters to plot the shade proportion for each field side. The shading graphs were calculated daily between 2 a.m. and 10 p.m. with scan rate of 5 minutes and throughout the year, although it was necessary to consider particularly the vegetation period. The red colour represents shading between 76 and 100%, the blue colour a percentage of shading between 51 and 75%, the green colour a percentage of shading between 26 and 50%, and the orange colour between 1 and 25%. The different shade proportions where expressed in

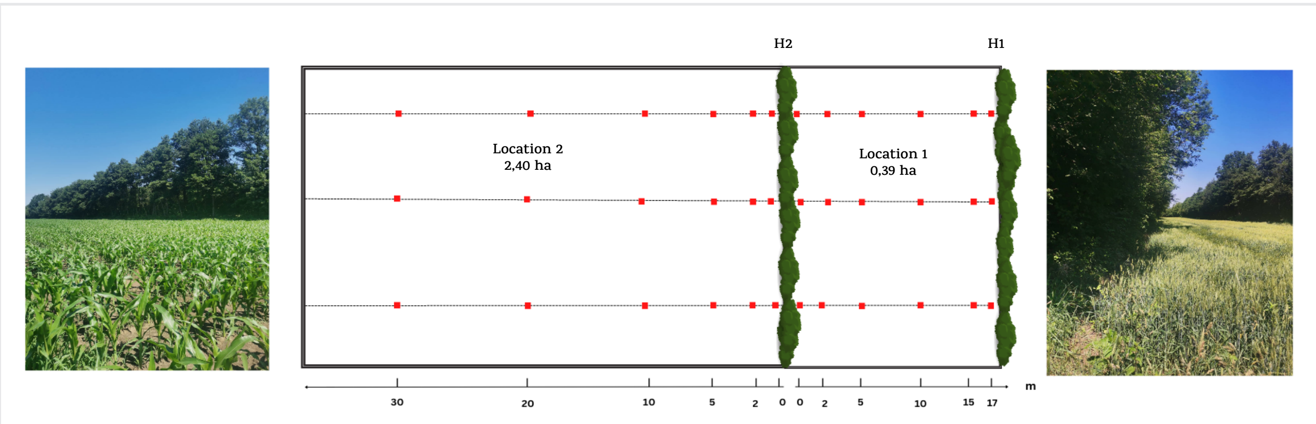

Figure 3: Location of soil sampling points in the study area

different percentage of shading on filed plots. It should not be overlooked that for the Location 1 the shading was calculated for H1 and H2.

Statistical Analysis

Statistical analysis was performed using the software package R (version 4.2.2) and IBM SPSS Statistics 28. Group means, minimum (maximum) values, and standard deviations were calculated for the parameters of temperature, gravimetric soil water content and shade. A linear mixed effects model using the lmer function of the lme4 package (Bates et al., 2022) was applied to test the null hypothesis that the mean of the measured parameters did not change depending on the different distances from the hedgerow. "Distance" was defined as a fixed factor, "date" and "block" and their interaction as random factors. Figure 5 shows that the design was divided into 3 blocks. Multiple comparisons were tested using the Tukey test in the emmeans package (Lenth et al., 2023). Correlations between observed variables were estimated using Pearson's correlation coefficient.

RESULTS

Hedgerow shading

Hedgerow shading graphs are separately represented for Location 1 and 2. Figure 4 shows the percentage of shading for Location 1, for which must be emphasized that the shading graph covers shade effect for both hedgerows in the study area. Only for a short time in the morning, namely between 8 a.m. to 10 a.m. shading for Location 1 varies from 1 to 75%. For most of the observed period, the shading percentage is between 76 to 100%.

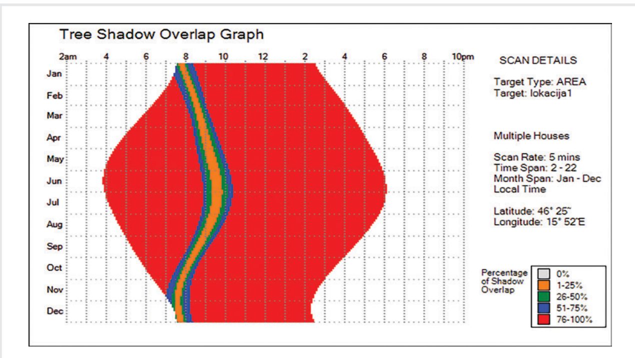

Figure 4: Hedgerow shading Graph for Location 1

Figure 5 shows the percentage of shading for Location 2. The field plot is the most shaded in the morning time, where shading is between 76 and 100%. After 9 am in summer percentage of shading for Location 2 decreases to a max. 25%.

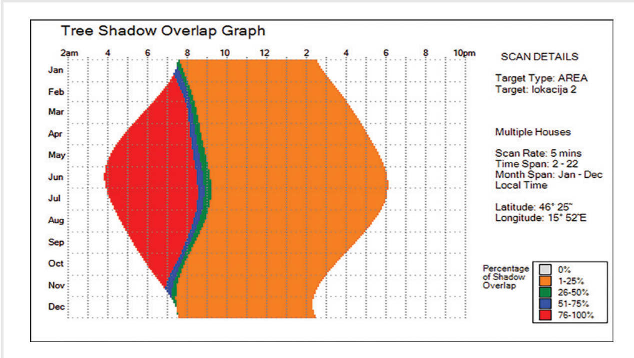

Figure 5: Hedgerow shading Graph for Location 2

Measurement data and basic statistics

The basic statistical analysis with three parameters (soil temperature, gravimetric water content and shade overlap) is presented in the Table 3 and 4 separately for each field plot (Location 1 and Location 2) according to different distances from the H2.

Findings for Location 1

According to Table 3 distance from the hedgerow did not significantly affect soil temperature during the growing season (P=0.272). The total T (°C) mean is 20.1 °C with mean standard deviation 2.5 °C. The highest mean soil temperature (21.5 °C) is noticed at 17 m distance, and the lower mean soil temperatures at 0 and 10 m (19.6 °C) and 5 m (19.5 °C) distances. According to the Table 3, there is a large variability of T (°C) data, where min. measured soil temperature is 13.9 °C, and max. 23.8 °C).

Soil gravimetric water content did not significantly differ among different distances from the hedgerow (P=0.3311). Focusing on the mean values, the lowest soil water content is noticed at 17 m distance (31.8%), while the highest at 15 m distance (34.7%). The total mean value is 32.7% with standard deviation 5.3%. The wide range between the min. (18.6%) and the max. (43.0%) values of gravimetric soil water content is detected.

For the shade it was found out, that the hedgerows significantly impact shading (P=0.004). The total mean shade value at Location 1 is 78.6% with standard deviation 10.1%. According to mean values shading (%) only slightly decreases with distance from the hedgerow, from 80.9% at 0 m distance to 76.6% at 17 m distance (Table 3). The maximum percentage of calculated shading is noticed at the distance of 15 m from the hedgerow, where the area is shaded for 96.2% of the day, while the minimum calculated shading percentage is noticed at the distance of 10 m from the hedgerow with 50.8% of shading.

Different individual distances for Location 1 and 2 are considered since the total width for Location 1 is only 17 m and for Location 2 the plot is more than 30 m width.

Findings for Location 2

With the distance from the hedgerow, mean soil temperature increases from 19.5 °C (at 0 m) to 22.7 °C (30 m). The soil temperature values vary between 16.0 °C (min. total) at 0 meters and 25.8 °C (max. total) at 30 m from the hedgerow. The study found significant differences in soil temperatures depending on the distance from the hedgerow ($P<0.001$). However, no statistical differences were found between the lower means at distances of 0, 5, 2, and 10 m, and the higher mean values at 10, 20, and 30 m did not differ significantly (Tukey, $P \leq 0.05$).

Table 3: Mean, standard deviation (sd), minimum (min), and maximum (max) values of soil temperature, gravimetric soil water content and shading at individual distances (0, 2, 5, 10, 15, 17 m) with Tukey post hoc test for Location 1 in the vegetation period (May to September)

Distance (m)		Soil temperature (°C)	Gravimetric soil water (%)	Shading (%)
0	mean	19.6[a]	32.3[a]	80.9[b]
	sd	2.3	5.7	10.6
	min	14.6	19.0	59.6
	max	22.8	42.3	92.9
2	mean	20.0[a]	32.5[a]	79.7[b]
	sd	2.6	5.9	11.2
	min	14.7	19.0	53.3
	max	23.6	39.2	92.5
5	mean	19.5[a]	32.4[a]	78.9[b]
	sd	2.6	5.9	10.5
	min	14.1	18.6	51.7
	max	23.6	40.2	92.1
10	mean	19.6[a]	32.4[a]	78.1[ab]
	sd	2.8	4.6	9.7
	min	14.1	25.7	50.8
	max	23.5	41.7	87.1
15	mean	20.4[a]	34.7[a]	77.5[ab]
	sd	2.4	4.2	10.4
	min	13.9	27.3	51.7
	max	23.1	43.0	96.2
17	mean	21.5[a]	31.8[a]	76.6[a]
	sd	1.8	5.5	8.6
	min	17.1	22.9	53.3
	max	23.8	40.9	85.4
Total	mean	20.1	32.7	78.6
	sd	2.5	5.3	10.1
	min	13.9	18.6	50.8
	max	23.8	43.0	96.2

a, b Differences between means that share a letter in the same column are not statistically significant (Tukey, $P \leq 0.05$)

Table 4: Table 4: Mean, standard deviation (sd), minimum (min), and maximum (max) values of soil temperature, gravimetric soil water content and shading at individual distances (0, 2, 5, 10, 20, 30 m) with Tukey post hoc test for Location 2 in the vegetation period (May to September)

Distance (m)		Soil temperature (°C)	Gravimetric soil water (%)	Shading (%)
0	mean	19.5[abcd]	29.5[a]	23.3[d]
	sd	2.6	6.5	5.6
	min	16.0	17.2	12.9
	max	24.0	40.7	27.9
2	mean	20.5[a]	28.4[a]	22.4[d]
	sd	2.2	4.5	5.1
	min	17.5	22.1	10.8
	max	24.9	36.0	27.1
5	mean	19.9[a]	28.7[a]	18.9[cd]
	sd	1.8	4.4	5.9
	min	16.9	18.6	3.8
	max	23.9	37.1	26.3
10	mean	21.0[ab]	26.7[a]	14.5[bc]
	sd	2.1	5.1	7.4
	min	17.4	17.6	0.0
	max	24.8	33.7	25.0
20	mean	21.9[b]	26.5[a]	11.0[b]
	sd	1.6	4.9	7.7
	min	19.7	18.9	0.0
	max	24.8	35.3	19.2
30	mean	22.7[b]	25.2[a]	8.1[a]
	sd	1.7	5.3	6.3
	min	19.8	18.0	0.0
	max	25.8	34.5	17.1
Total	mean	20.9	27.5	16.4
	sd	2.3	5.3	8.4
	min	16.0	17.2	0.0
	max	25.8	40.7	27.9

a, b, c, d Differences between means that share a letter in the same column are not statistically significant (Tukey, $P \leq 0.05$)

The gravimetric soil water content W (%) on Location 2 decreased slightly with distance, but the result is not statistically significant (P=0.285). The overall mean W (%) is 27.5%, and the standard deviation is 5.3%. Interestingly, both the highest and lowest values 40.7 and 17.2 of gravimetric soil water content, occurred at 0 m from the hedgerow.

Regarding shading on Location 2 the P<0.001 was used to test the null hypothesis that all group means are equal. The total mean shading value is 16.4% with a standard deviation of 8.4%. The individual shading measures ranged from a minimum shading level of 0.0% (at a distance of 15 m and 17 m, where there was no shading throughout the day) to a maximum shading level of 27.9% at a distance of 0 m. Mean values of shading decrease with distance from 23.3% at 0 m and 8.1% at 30 m distance from hedgerow.

Figure 6 illustrates how individual values in a data set deviate from the median based on the distance from the hedgerow, for both Location 1 and 2.

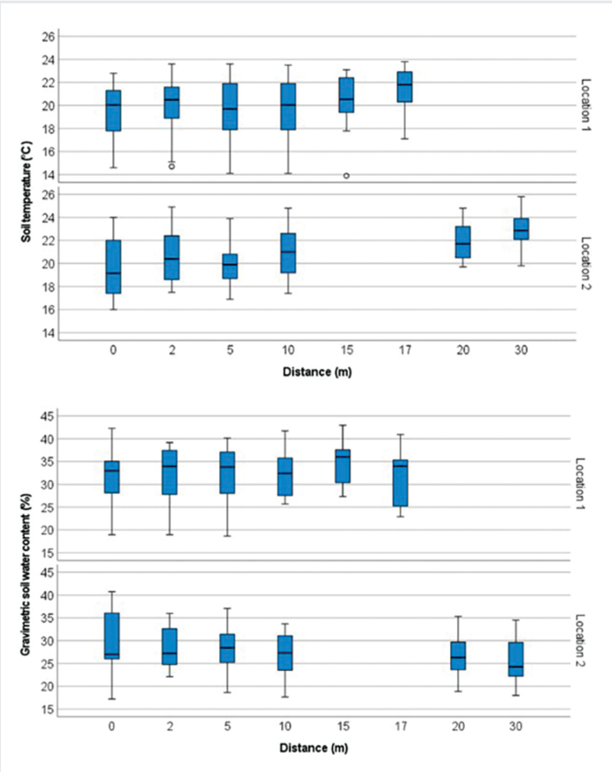

Figure 6: Distributions of soil temperature and gravimetric soil water content for Location 1 and Location 2 separately by distance

Table 5 shows the Pearson correlation coefficients between soil temperature, soil water content and shading for both locations separately. The results indicate that no significant correlations were found for Location 1. In contrast, for Location 2, a positive and significant correlations where found between soil water content and shading, while negative correlations was found between soil temperature and shading and between soil temperature and soil water content.

Table 5: The Pearson correlation coefficient of values of the parameters of soil temperature, gravimetric soil water and shading throughout the vegetation period for Location 1 (above the main diagonal) and Location 2 (below the main diagonal)

Pearson correlation coefficients			
	Gravimetric soil water (%)	Shading (%)	Soil Temperature (°C)
Gravimetric soil water (%)		0.141	−0.038
Shading (%)	0.263**		0.043
Soil temperature (°C)	−0.277**	−0.319**	

** Correlation is significant at the 0.01 level (2-tailed)

DISCUSSION

As expected, the study found that the shade of the hedgerow affects gravimetric soil water content and soil temperature. However, it is difficult to establish a direct comparison between Location 1 and 2 due to their different surroundings and field crops wheat and corn, respectively. It should also be noted that the soil samples were not taken at the same time of the day and as well over a period of few days. Additionally, the sampling period (May to September) also reflected different weather conditions such as air temperature, precipitation, and wind, which could affect (evaporative) transpiration, plant water uptake, and soil water distribution (ARSO, 2023).

Nevertheless, the study results are in general comparable to those of other studies, such as from Montgomery et al. (2020) and Raatz et al. (2019), which found that shade reduces soil temperatures and stabilize soil moisture next to the hedgerow. It was confirmed that Location 1, with high total percentage of shading and more uniform shading throughout the day and the vegetation period, exhibited more stable gravimetric water content and soil temperature, with no significant differences among different distances from hedgerow. In comparison to Location 2, the study found lower total average soil temperature and higher total soil gravimetric water content.

A study by Ghazavi et al. (2008) about hedgerow impacts on soil water transfer due to rainfall interception indicated that the average percentage of intercepted rainfall was much higher in vegetation period compared to leafless period. Similarly, a study by Caubel et al. (2003) about the influence of a hedge surrounding bottomland on seasonal soil-water movement indicated that the hedgerow induced a high rate of soil drying due to the high evaporative capacity of the trees. As the study for Location 1 and 2 was performed only during the vegetation period, the rainfall interception was not treated separately.

Nevertheless, results for Location 2 indicate the lowest (17.2%) and the highest (40.7%) value for gravimetric soil water content at 0 m distance from hedgerow, which could be explained by heavy rainfall between August and September high rainfall interception due to corn in the plot and slight leaf fall noticed since the end of September.

Although the study was influenced by external factors like different yields on the plots, different weather conditions during the soil sampling period and the fact that it was a local scale study, the study results as: more stable shading conditions on a plot surrounded by two parallel hedgerows also result in more stable soil gravimetric water content and soil temperature (Location 1); shading impact on both soil parameters varies more when the shading conditions change more daily and annually and the hedgerow impact is perceived only from one side (Location 2), are still in accordance with study results from Carnet (1978), Caubel et al. (2003) and White et al. (2002) who reported of hedgerow effects on soil vertical drainage capacity.

Only for soil temperature at Location 2, a statistically significant increase with distance from hedgerow was noticed, which could be explained with the fact, that soil temperature (measured at a depth of 5 cm) is changing rapidly with different shade proportion of hedgerow.

CONCLUSION

The study highlights the effect of hedgerow shading on gravimetric soil water content and soil temperature at different distances from hedgerow during the vegetation period and at different locations. Despite variability due to different yields at the examined locations, different weather conditions during the soil sampling period and the fact that it was a local scale study, it can be concluded that more stable shading conditions on a plot (Location 1 surrounded by two parallel hedgerows) also result in more stable soil gravimetric water content and soil temperature. The hedgerow shading impact on both soil parameters and varies more when the hedgerow is present only on one side of the plot. The study revealed no significant correlations between soil temperature, soil water content and shading for Location 1, while a positive significant correlation between soil water content and shading was found, and negative correlations where found between soil temperature and shading, as well between soil temperature and soil water content for Location 2. For a better understanding of the impact of hedgerow shading on soil quality, further studies are needed, including chemical and biological soil parameters such as stock of soil organic matter and some basic microbiological parameters. Further, for more detailed and precise results in the future, the shading overlap classes should be more narrow. Study results strengthened by additional studies on local and regional level will reinforced valuation of hedgerows and similar semi natural landscape elements and will better recognize their role for agroecosystems and food production.

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Učinki senčenja mejic na temperaturo tal in gravimetrično vsebnost vode v tleh

IZVLEČEK

Študija obravnava učinek zasenčenosti zaradi mejic na fizikalne lastnosti tal: gravimetrično vsebnost vode v tleh in temperaturo tal. Analiza obeh parametrov je bila izvedena na dveh lokacijah, pri čemer je bila lokacija 1 iz dveh strani obdana z mejico, lokacija 2 pa z mejico le na eni strani. Vzorci tal in meritve temperature tal so bili odvzeti na različnih razdaljah od mejice in v različnih časovnih intervalih na obeh lokacijah. Dnevno zasenčenost na različnih razdaljah od mejice na lokaciji 1 in 2 smo izračunali s programom ArborShadow R4. Na lokaciji 1 je zasenčenost zelo visoka in se giblje od 76 do 100% skozi vse leto, na lokaciji 2 pa nižja in se giblje med 1 do 25%. Na lokaciji 1 je bilo ugotovljeno, da mejice nimajo statistično pomembnega vpliva na gravimetrično vsebnost vode v tleh ter temperaturo tal po celotni površini parcele, medtem ko se odstotek senčenja z razdaljo le rahlo zmanjšuje. Na lokaciji 2 je bilo ugotovljeno povišanje temperature tal in rahlo zmanjšanje (statistično neznačilno) gravimetrične vsebnosti vode v tleh z naraščajočo oddaljenostjo od mejice, medtem ko je skupna povprečna zasenčenost glede na lokacijo 1 precej nižja. Poleg tega na lokaciji 2 odstotek zasenčnosti močneje upada z oddaljenostjo od mejice. Na splošno je mogoče opaziti nižje temperature tal in višjo gravimetrično vsebnost vode v tleh na bolj zasenčeni lokaciji 1.

Ključne besede: gravimetrični odstotek vode, temperatura tal, mejica, zasenčenost