Journal of Central European Green Innovation
Talajbiológia különszám, 26–38. (2022) DOI: 10.33038/jcegi.3560

HOW DIFFERENT MULCH MATERIALS REGULATE SOIL MOISTURE AND MICROBIOLOGICAL ACTIVITY?

ENIKŐ PAPDI – ANDREA VERES – FLÓRIÁN KOVÁCS – KATALIN JUHOS

Abstract

As a result of climate change, the frequency of droughts across Europe is showing an increasing trend. The solution to this problem can be various soil cover techniques, which help to preserve soil moisture and soil biological activity, thereby increasing crop yield. In our research, we examined how different mulch materials affect the regulation of soil moisture and the microbiological activity of the soil. The experiments were set up on two sites: a sandy soil with a low soil organic matter content (Királyhalom, Serbia) and an coarse loamy soil with a higher water capacity (Thessaloniki, Greece). The treatments were set up in 4 repetitions with pepper plants (Capsicum annuum L.). Daily intensive irrigation with wool mulch, agrotextile, straw mulch and control treatments was used on the Serbian site. The irrigation was carried out every 6 days at the Greek site, where the treatments were as follows: wool mulch with plants, wool mulch without plants, plants without mulch and the control without plants. The yield was measured, and the moisture content, β-glucosidase activity and active (permanganate oxidizable) carbon content of the soils at the time of sampling were examined every 2 weeks. In the Serbian area, wool mulch showed significantly lower β-glucosidase activity compared to the other treatments. This was presumably due to the good water absorption capacity of the wool mulch and the fact that the soil could not aerate in addition to the intensive irrigation, thus the enzyme activity decreased. All mulch treatments increased the active carbon content compared to the untreated control, with the straw mulch to the greatest extent. In the extensively irrigated Greek soil, β-glucosidase was significantly higher in pepper plots covered with wool mulch compared to the control area without plants, but also higher compared to pepper plots not covered with wool mulch. The higher yield results measured on the mulched plots indicate that, in addition to water retention, biological activity also plays a major role in the development of yields. The effect of each mulching method on soil biological activity depends on the degradability of the mulch material, the frequency of irrigation, and the soil's water-holding capacity.

Keywords: *living mulch, agro textile, wool mulch, β-glucosidase, soil active carbon*

HOGYAN SZABÁLYOZZÁK A KÜLÖNBÖZŐ MULCS ANYAGOK A TALAJNEDVESSÉGET ÉS A MIKROBIOLÓGIAI AKTIVITÁST?

Összefoglalás

A klímaváltozás következtében az aszály gyakorisága Európa szerte növekvő tendenciát mutat. Erre a problémára megoldást jelenthetnek a különböző talajtakaró technikák, amelyek segítenek a talajnedvesség és talajbiológiai aktivitás megőrzésében, ezáltal a terméshozam növelésében. Kutatásunk során arra kerestük a választ, hogy a különböző mulcs anyagok hogyan hatnak a talajnedvesség szabályozásán keresztük a talaj mikrobiológiai aktivitására. A kísérleteket két termőhelyen, egy gyenge humusz tartalmú homoktalajon (Királyhalom, Szerbia) *és egy nagyobb vízkapacitású vályog talajon (Thesszaloniki, Görögország) állítottuk be 4 ismétlésben paprika növénnyel (Capsicum annuum L.). A szerbiai termőhelyen napi gyakoriságú intenzív öntözést alkalmaztunk gyapjúmulcs, agroszövet, szalmamulcs és kontroll kezelésekkel. A görögországi termőhelyen 6 naponta történt az öntözés, ahol a kezelések a következők voltak: gyapjúmulcs növénnyel, gyapjúmulcs növény nélkül, növény mulcs nélkül és a növény nélküli kontroll. Mértük a terméshozamot, valamint 2 hetente vizsgáltuk a talajok mintavételkori nedvességtartalmát, β-glükozidáz aktivitását és aktív (permanganát oxidálható) széntartalmát. A szerbiai területen a gyapjúmulcs a többi kezeléshez képest szignifikánsan alacsonyabb β-glükozidáz aktivitást mutatott. Ennek feltehetően az lehetett az oka, hogy a gyapjúmulcs jó vízfelvevő képessége és az intenzív öntözés mellett a talaj nem tudott szellőzni, ezálatal az enzim aktivitás csökkent. Mindegyik mulcs kezelés növelte az aktív széntartalmat a takaratlan kontrollhoz képest, a legnagyobb mértékben a szalmamulcs esetében. Az extenzíven öntözött görögországi talajon a β-glükozidáz a gyapjúmulccsal takart paprika parcellák esetében szignifikánsan magasabb volt a növény nélküli kontroll területhez képest, de magasabb volt a gyapjúmulccsal nem takart paprika parcellákhoz képest is. A mulcsozott parcellákon mért magasabb terméseredmények rámutatnak arra, hogy a vízmegtartás mellett a biológiai aktivitásnak is nagy szerepe van a terméshozamok alakulására. Az egyes mulcsozási módok talajbiológiai aktivitásra gyakorolt hatása a mulcsanyag lebomló képességétől, az öntözés gyakoriságától és a talajok víztartó képességétől is függ.*

Kulcsszavak: *élő mulcs, agroszövet, gyapjúmulcs, β-glükozidáz, talaj aktív szén*

Introduction

Population growth, global warming, and climate change affect the water supply of the agriculture (KADER et al., 2017a). One of the biggest problems for agricultural sectors is drought. The drought causes significant economic, social and environmental damage, the severity of which has increased in recent times in the Carpatian Basin as well. Drought makes agricultural production impossible without irrigation, especially on sandy soils with low water capacity. Wind erosion is an other significant problem, especially in poorly structured sandy soils (KERTÉSZ et al., 2012a). The effect of wind erosion can be indirect or direct. Its direct effect means worse damage, for example, the crop area decreases, and the productivity of the soil decreases (JAKAB et al., 2010; MEZŐSI et al., 2017).

Different soil covers can be a solution to this problem. The soil covers used in agriculture can be classified into three groups: natural, artificial (e.g. agro textile), and special (e.g.sand) (KADER et al., 2017a). Natural mulches can be living and non-living (e.g. straw) mulch. Waste fibres such as wool can be the basis of innovative soil water storage technologies (MARCZAK et al., 2022). Soil covers help conserve soil moisture (KERTÉSZ et al., 2012; FEKETE et al., 2021), increase yield (GHOSH et al., 2016; KOVÁCS et al., 2020), and prevent weeding (PARMAR et al., 2013; SHARMA et al., 2022) and soil erosion (SZARKA et al., 2015; MADARÁSZ et al., 2021). Plants and living organisms need soil moisture for nutrition uptake. Water is not only a necessary essential transport medium for substrates but also plays an important role in hydrolysis. Therefore, microbial activity is regulated by soil water content (YAN et al., 2015; KOCSIS et al., 2015; KOTROCZÓ et al., 2020). CHAKRABORTY et al., (2008) described in their article that the combination of irrigation and soil cover ensures better water absorption in the case of winter wheat, and the number of irrigations is reduced due to the surface cover effect. Soil covers also help maintain soil health (NGOSONG et al., 2019).

Most mulches can be said to increase the soil microbe population (MANNA et al., 2018), and their activity (LI et al., 2018; BUTCARU et al., 2020). The microbiological properties of the soil are closely related to most of the soil's organic matter content (DEMETER et al., 2013;

BÉNI et al., 2017; KOTROCZÓ and FEKETE, 2020) and water content (BOROWIK et al., 2016; KOCSIS et al., 2022). Organic materials protect the moisture and structure of soils, reducing climatic stress effects, and soil life ensure the cycle of nutrients and the availability of reserve nutrients and bound water for plants (BIRÓ, 2002). The water content in the soil affects the physiological state of microorganisms. Therefore, properly moist soil supports more diverse microbial communities (BOROWIK et al., 2016). Fungi and bacteria release extracellular enzymes such as phosphatase and β-glucosidase. These enzymes have an important function in the mineralization of soil organic matter (KOTROCZÓ et al., 2014). So, mulching has an important function in increasing the water-holding capacity and biological activity of soils, and in increasing their ability to supply nutrients. However, very little scientific data can be found on the soil biological effects of different mulch materials (KADER et al., 2017a; LAL et al., 2020). Most of the research focuses primarily on soil moisture, soil temperature and the effects on the crop yield (KADER et al., 2017b; ADEKALDU et al., 2021; MARCZAK et al., 2022).

Therefore, the aim of our research was to investigate how different mulch materials (wool mulch, agro textile, straw) affect the activity of microbes in the soil and the crop yield under irrigated field conditions.

Material and methods

Material

The experiment was carried out in two areas with different climates and soil types (in Serbia and Greece). The Serbian site is characterized by carbonate sandy soil with low water capacity and organic matter content (Table 1). The Greek site has coarse-loamy neutral soil with a low organic matter content (Table 1). The average daily mean temperature during the growing season was 26.4 °C at the Greek site and 24.5 °C at the Serbian site.

Table 1. Soil physical and chemical properties of the experimental sites.

Site location	**Texture**	**pH ($CaCl_2$)**	**$CaCO_3$ (m/m %)**	**Soil Organic Matter (m/m %)**
Serbian site (Királyhalom)	sandy	7.44	3.57	0.30
Greek site (Thessaloniki)	coarse-loamy	6.9	0.00	1.57

The experimental plant in both places was pepper (*Capsicum annuum L.*). At the Serbian site, we used pepper of the Amy type, which does not require a support system and has good yields (https://zoldseg-palanta.hu). In the Greek site, we used the Flavorburst F1 variety, which has a high yield, requires a support system and a lot of light (https://www.burpeehomegardens.com). The Serbian site was covered with wool mulch, agro textile, and straw, and there was an uncovered control. There were the following four treatments at the Greek site: a plant with mulch, a plant without mulch, mulch without plant, and uncovered control.

Methods

4 plots (replications) were planted per treatment. We planted 10-10 plants on the Serbian plots and 8-8 plants on the Greek plots (approx. 2 m^{-2} plots). The pepper were planted at the end of June. To reduce the impact of environmental factors, the experiment was surrounded by a protective strip. Nutrient supplementation was based on the nutrient requirements of the plants. Daily intensive irrigation was used at the Serbian site, while surface irrigation was used every 6 days at the Greek site. The soil sampling was carried out every two weeks (4 times during the growing season) before the actual watering from the upper 0-10 cm soil layer. Also, soil temperature was measured a few times at the Greek site.

In measuring the β-glucosidase activity, we used SINSABAUGH et al., (1999) method with a minor modification, according to KOTROCZÓ et al., (2014) study, increasing the concentration of the buffer and terminal solutions. Active Carbon was measured according to WEIL et al., (2003) with the change in concentration of $KMnO_4$ used to estimate the amount of carbon oxidized. The method was modified by shaking of 1 g of air-dry soil in 10 mL 0.02 M $KMnO_4$ solution for 5 minutes and the absorbance measured at 565 nm wavelength using Biochrom Libra S22 spectrophotometer. Soil moisture was determined from the soil sample using a gravimetric method. The yields were characterized by the pepper mass harvested during the entire vegetation period per plant.

All statistical analyses were performed using R version 4.2.1 (R Core Team, 2018) and dplyr version 1.0.10 (WICKHAM and FRANCOIS, 2015) as well as ggplot2 packages. We tested the differences in the effect of treatments towards glucosidase activity among the mulching groups using the Kruskal-Wallis test with subsequent non-parametric Dunn's test comparisons. The assumption of normality of the residuals was checked using the Shapiro-Wilk test. Differences in labile carbon activity among the mulch treatments were tested with an one-way ANOVA followed by posthoc comparisons using Tukey’s HSD method. The homogeneity of variances was checked using Levene's test. We report partial eta squared (η2) values as the effect size indicator for ANOVA, which is essentially the same as the fitted R-squared indicator used in regression analysis). The η2 measures the proportion of the variability in the outcome variable that can be explained in terms of the predictor. The value of this indicator can range from 0 to 1.00. Zero indicates independence and 1.00 indicates a deterministic relationship.

Results and Discussion

At the Serbian site, β-glucosidase activity differed significantly among the mulch types ($H=18.21$, $p<0.001$, $\eta^2=0.34$). Follow-up tests demonstrated a significant difference between the straw and wool mulch ($p<0.001$), between the control and the wool mulch ($p<0.01$) and between the agro textile and wool mulch ($p<0.05$) (Fig. 1). The order of the average β-glucosidase activity for each treatment was as follows: straw (1.69 $\mu mol\ g^{-1}\ h^{-1}$), agro textile (1.322 $\mu mol\ g^{-1}\ h^{-1}$), control (1.45 $\mu mol\ g^{-1}\ h^{-1}$) and wool mulch (0.82 $\mu mol\ g^{-1}\ h^{-1}$). The highest β-glucosidase activity was therefore measured in the case of organic mulch (SM) that decomposes more easily. While, on average, the lowest activity was experienced in the case of wool mulch.

In contrast to our results, LI et al., (2016) found that, on strawberry plots, β-glucosidase activity of wool much treatment was higher compared to the control, whereas in our case there was no significant difference. Furthermore, when agrotextile was applied, WANG et al., (2020) found that beta-glucosidase activity was decreased compared to the control, while there was no negative effect in our case.

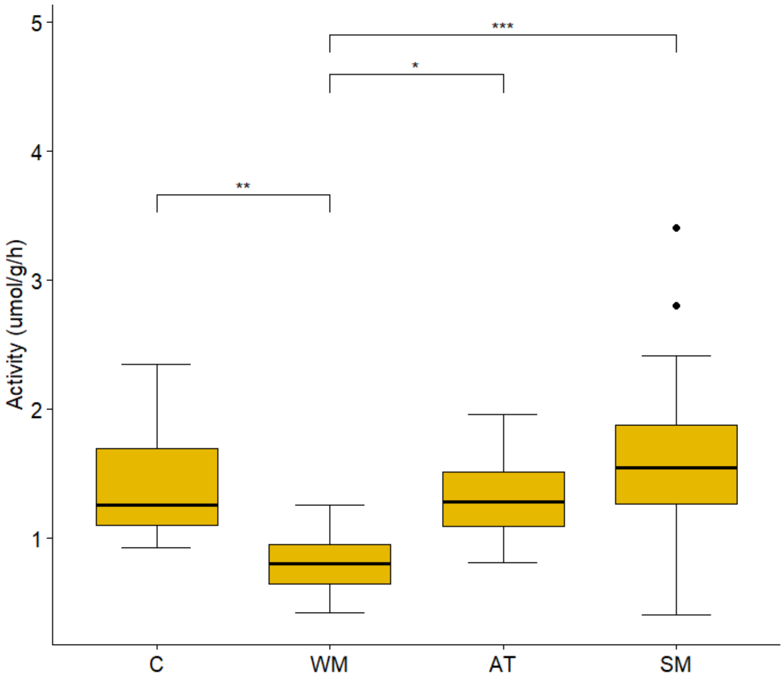

Figure 1. Data summary of β-glucosidase activity at the Serbian site with a box-and-whisker-plot indicating the outliers and variability outside the upper and lower quartiles, classified by the effect of treatments: C: control, WM: wool mulch, AT: agro textile, SM: straw mulch. The results of the multiple comparisons for a one-way ANOVA model are indicated by the lines above the graph. Statistical significance was determined via *post-hoc* test, where '*'p<0.05 ''p<0.01 '***'p<0.001.**

At the Serbian site, the level of active carbon differed significantly among the mulch types ($F_{3,20}$=13.18, p<0.001, η^2=0.66) (Fig. 2). Follow-up tests demonstrated a significant difference between the agro textile (mean: 361.19 mg kg^{-1}) and control (p<0.001) (mean: 249.80 mg kg^{-1}). The straw (mean: 387.26 mg kg^{-1}) was also significantly different from the control and the wool mulch (mean: 299.57 mg kg^{-1}). So we found that all mulches increased the amount of active carbon in the soil compared to the control.

Similar to our results, YU et al., (2007) found that straw mulch can increase soil labile carbon content compared to other treatments. In a study of bacterial and fungal species and soil respiration, BUTCARU et al., (2017) found higher biological activity in areas covered with wood mulch and combined with cover crops than in areas covered with cotton mulch and cover crops.

At the Serbian site, because of the intensive irrigation, there was no major difference in soil moisture among the treatments. The average soil moisture content at the time of soil sampling was 10.54%, 8.72%, 8.33% and 7.89% for agro textile, straw, wool mulch and control plots. HOOVER (2000) also found no difference in soil moisture between different mulch types under intensive irrigation. Soil moisture contents are therefore not always related to soil biological parameters.

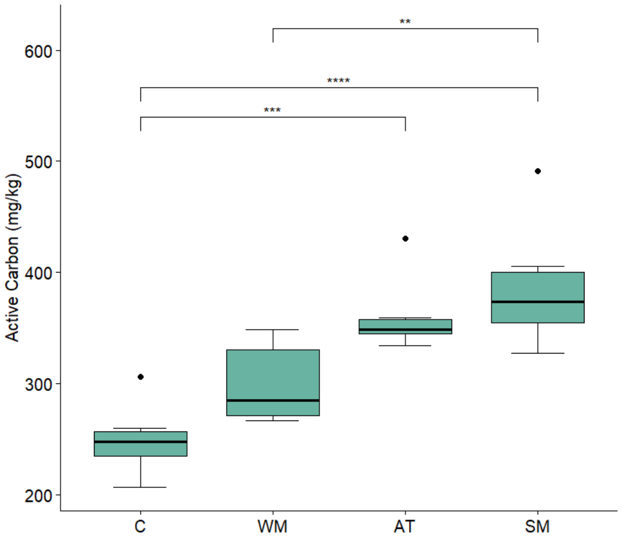

Figure 2. Data summary of active carbon at the Greek site with a box-and-whisker-plot indicating the outliers and variability outside the upper and lower quartiles, classified by treatments: C: control, WM: wool mulch, AT: agro textile, SM: straw mulch.The results of the multiple comparisons for a one-way ANOVA model are indicated by the lines above the graph. Statistical significance was determined via *post-hoc* test, where '*'p<0.05 ''p<0.01 '***'p<0.001**

In the case of Greek site, the β-glucosidase activity of control plots (mean: 0.152 μmol g^{-1} h^{-1}) were significantly lower compared to the plant with wool mulch plots (p<0.001) (mean: 0.956 μmol g^{-1} h^{-1}) (Fig. 3). In the case of wool mulch without plants, the β-glucosidase activity was also higher (mean: 0.745 μmol g^{-1} h^{-1}) compared to the control, although the difference was not significant due to the high standard deviation of the data. In contrast to the Serbian site, the β-glucosidase activity in the soil increases as a result of the wool mulch on the Greek site.

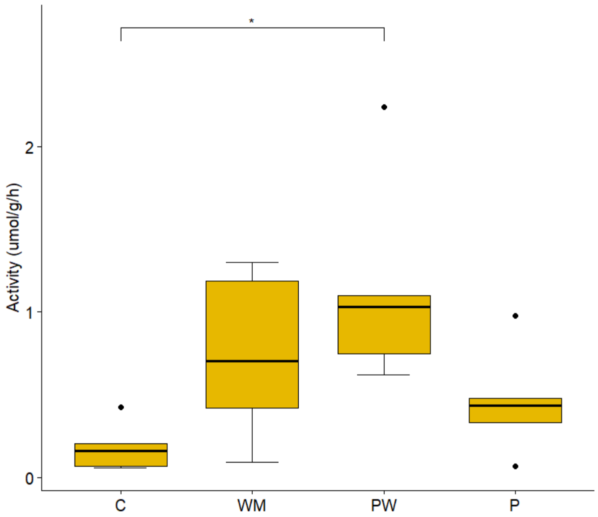

Figure 3. Data summary of β-glucosidase activity at the Greek site with a box-and-whisker-plot indicating the outliers and variability outside the upper and lower quartiles, classified by the effect of treatments: C: control, WM: wool mulch without plant, PW: a plant with wool mulch, P: plant without mulch. The results of the multiple comparisons for a one-way ANOVA model are indicated by the lines above the graph. Statistical significance was determined via *post-hoc* test, where '*'p<0.05 ''p<0.01 '***'p<0.001.**

Active carbon levels on the Greek plots also differed significantly among the treatments and follow-up tests ($F_{3,8}$=5.57, $p<0.05$, η^2 =0.69) demonstrated a significant difference between wool mulch without plant (WM) (mean:1226.83 mg kg^{-1}) and control ($p<0.05$) (mean: 948.36 mg kg^{-1}) (Fig. 4). However, the plant with wool mulch and plant without wool mulch treatments did not differ significantly from each other, although their active carbon concentrations (1032.495 and 1039.605mg kg^{-1}) were on average higher compared to the control.

At the Greek site, the average soil moisture content at the time of soil sampling was 21.35%, 15.78%, 15.48% and 10.68% for mulch without plant, plant without mulch, plant with mulch and control. So, soil moisture contents are usually related to soil biological parameters. Soil moisture is therefore a limiting factor for soil biological activity, as confirmed by many authors (YU et al., 2007; LI et al., 2016; BUTCARU et al., 2017).

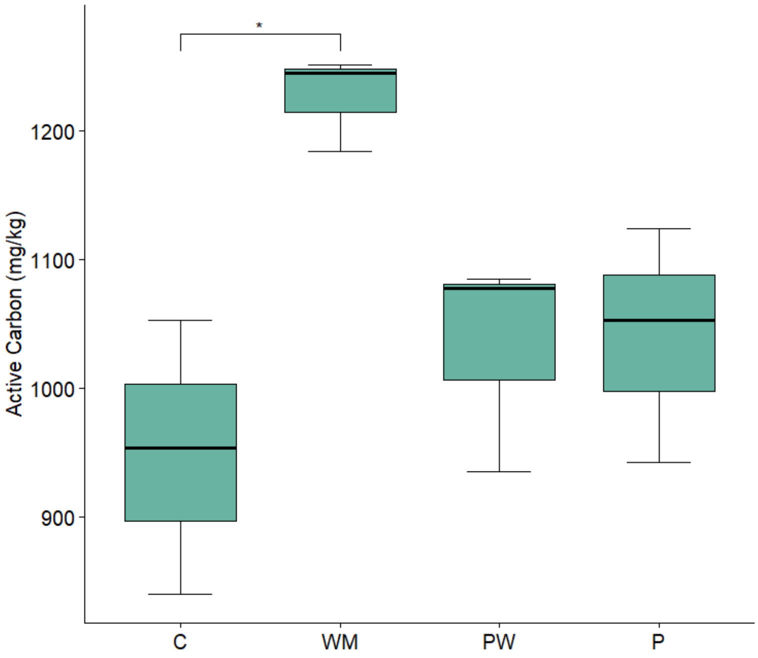

Figure 4. Data summary of active carbon at the Greek site with a box-and-whisker-plot indicating the outliers and variability outside the upper and lower quartiles, classified by treatments: C: control, WM: wool mulch without plant, PW: a plant with wool mulch, P: plant without mulch. The results of the multiple comparisons for a one-way ANOVA model are indicated by the lines above the graph. Statistical significance was determined via *post-hoc* test, where '*'p<0.05 ''p<0.01 '***'p<0.001.**

As shown in Fig 5, at the Greek site, the highest average soil temperature in all cases was in the control treatment (11 August: mean: 35.84 °C, 17 August: 30 °C, 18 August: 33 °C. 3°C, Aug. 20:33°C), while the lowest soil temperature was in the plant with mulch treatment (PW) (Aug. 11: mean: 29.6°C, Aug. 17: 29.5°C, Aug. 18: 28°C, Aug. 20: 28.3°C). This interaction can be explained by the fact that the presence of wool mulch has some insulating effect (HOOVER, 2000), which helps to regulate soil temperature, and the presence of plants also helps to reduce soil temperature.

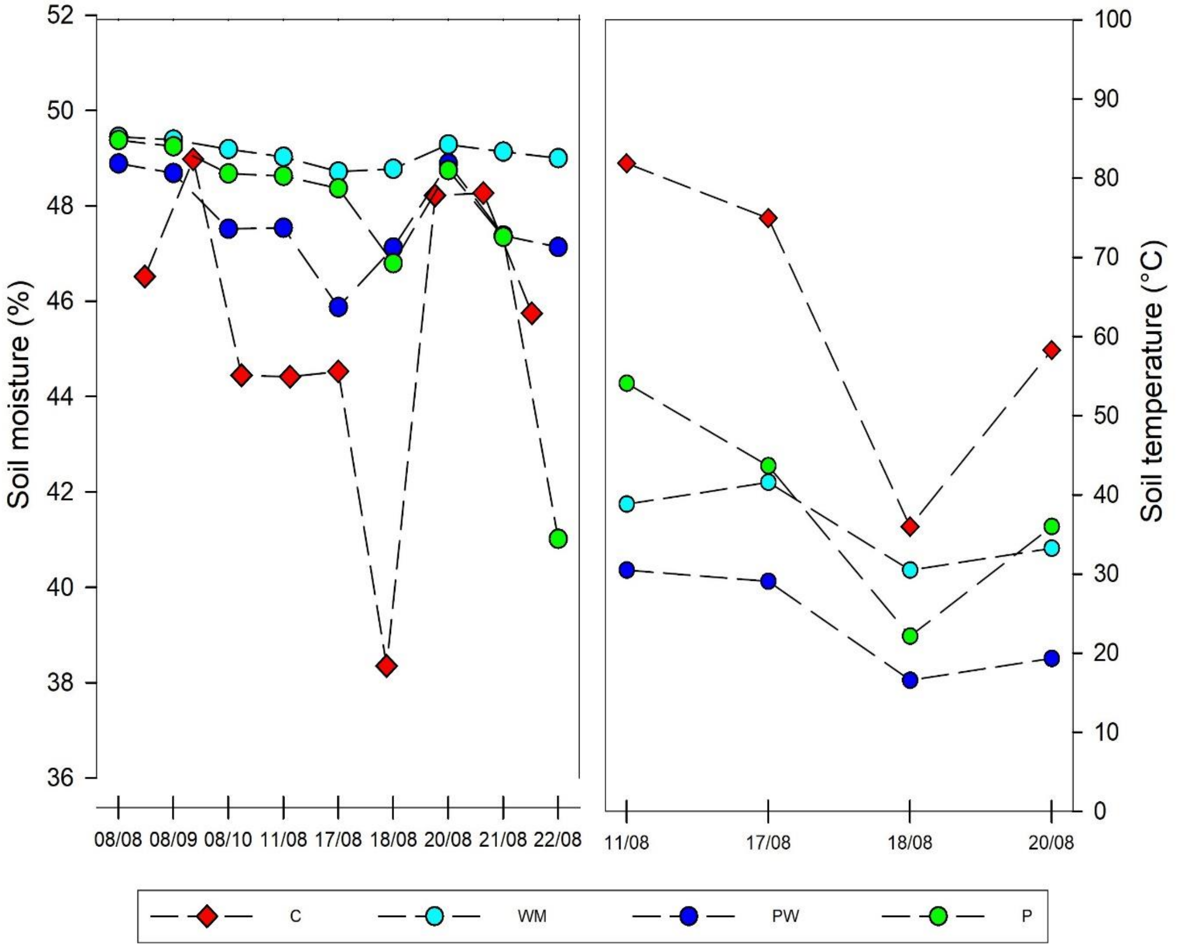

Figure 5. Soil temperature (°C) on the left and soil moisture (%) on the right are plotted as a function of treatments at different times at the Greek site.

Table 2. Average pepper yield per plant measured in different treatments on the research sites.

Serbian site			Greek site		
	Treatment	Average yield (kg/plant)		Treatment	Average yield (kg/plant)
1.	Control (C)	0.504	1.	Plant with wool mulch (PW)	1.512
2.	Straw mulch (SM)	0.850			
3.	Agro textile (AT)	0.808	2.	Plant without wool mulch (P)	1.087
4.	Wool mulch (WM)	0.504			

Environmental factors influence the activity of microorganisms, and consequently the yield, because where conditions were more optimal for the microbes, the yield was higher. Table 2 shows the average yield per plant per treatment. On Serbian sandy soils, straw helped to increase the organic matter content, which also contributed to increased microbiological activity and yields. Similar to the experience of other authors, straw mulch increased yields of winter wheat (HUANG et al., 2005) and maize (SHEN et al., 2012). In contrast, DÖRING et al., (2005) did not observe a significant yield increase in potatoes when straw mulch was applied. In addition to the intensive irrigation, the wool mulch impeded soil aeration by absorbing moisture, which had a negative effect on microbial activity and consequently on yield. Under extensively irrigated conditions at the Greek site, however, wool mulch increased yields compared to non-covered control plots. CINCINNATI et al., (2012) reported that eggplants covered with wool mulch achieved higher yields. GARTON et al., (2013) also reported significantly higher yields in organic tomato production.

Conclusion

In this study, the effects of different mulches on soil biological activity and pepper yield under two different field conditions were investigated. We found that under intensively (daily) irrigated conditions on sandy soil, most mulches had no or negative effects on β-glucosidase activity but significantly positive effencts on active carbon. The significantly lower β-glycosidase activity in the case of wool mulch suggests that on intensively irrigated soils, wool mulch becomes saturated with water, which inhibits aeration and creates an inadequate habitat for microorganisms, which decreases their activity. We found that, because of organic matter input, active carbon and biological activity increased to the greatest extent in the case of using straw mulch. This is also reflected in the fact that, the yield using straw mulcs slightly exceeded the yield measured in the agrotextile treatment and was significantly higher compared to the control. However, under extensively irrigated situation on soil with higher water holding capacity, the wool mulch can be advantageous over unmulched areas, as its moisture retention capacity helps microorganisms survive and become active, thereby increasing yield. Mulching methods therefore affect crop yields not only through their water retention capacity, but also through their soil biological activity. The effect of each mulching method on soil biological activity and yields depends on the degradability of the mulch material, the frequency of irrigation, and the soil's water-holding capacity.

Acknowledgement

This work was supported by the Collegium Talentum Programme of Hungary.

References

ADEKALDU, E. – AMPONSAH, W. – TUFFOUR, H. O. – ADU, M. O. – AGYARE, W. A. (2021): Response of chilli pepper to different irrigation schedules and mulching technologies in semi-arid environments. *Journal of Agriculture and Food Research*, *6*, 100222. DOI: https://doi.org/10.1016/j.jafr.2021.100222

BÉNI, Á. – LAJTHA, K. – KOZMA, J. – FEKETE, I. (2017): Application of a Stir Bar Sorptive Extraction sample preparation method with HPLC for soil fungal biomass determination in soils from a detrital manipulation study. *Journal of Microbiological Methods* 136, 1–5. DOI: https://doi.org/10.1016/j.mimet.2017.02.009

BIRÓ B. (2002): Talaj és rhizobiológiai eszközökkel a fenntartható növénytermesztés és környezetminőség szolgálatában. Acta Agronom. Hung. 50:77–85.

BOROWIK, A., – WYSZKOWSKA, J. (2016): Soil moisture as a factor affecting the microbiological and biochemical activity of soil. *Plant, Soil and Environment*, *62*(6), 250–255. DOI: https://doi.org/10.17221/158/2016-PSE

BUTCARU, A. C. – F. STĂNICĂ – R. MADJAR (2017): Influence of ameliorative plants and mulch on some soil agrochemical characteristics in an organic edible rose crop. *Scientific Papers. Series B, Horticulture* 61: 101–106.

BUTCARU, A. C. – POMOHACI, C. – MADJAR, R. – MIHAI, C. A. – STĂNICĂ, F. (2020): Influences Between Soil Microbiological and Agrochemical Parameters in an Organic Edible Rose Plantation. *Bulletin of the University of Agricultural Sciences & Veterinary Medicine Cluj-Napoca. Horticulture*, *77*(1).

CHAKRABORTY, D. – NAGARAJAN, S. – AGGARWAL, P. – GUPTA, V. K. – TOMAR, R. K., GARG, R. N. – KALRA, N. (2008): Effect of mulching on soil and plant water status, and the growth and yield of wheat (Triticum aestivum L.) in a semi-arid environment. *Agricultural water management*, *95*(12), 1323–1334. DOI: https://doi.org/10.1016/j.agwat.2008.06.001

CINCINNATI, O.H. – O'BRIANT, M. – CHARLTON-PERKINS, K. (2012): Mulching with wool: opportunities to increase production and plant viability against pest damage. *Završno izvješće prokekta* FNC10-797.

CSERNI, I. – HÜVELY, A. – PETŐ, J. (2019): Gumós zeller (Apium graveolens convar. rapaceum) kálium trágyázási kísérlet= Potassium Fertilizer Experiment of Celery (Apium graveolens convar. rapaceum). *GRADUS*, *6*(2), 116–121.

DEMETER, I. – MAKÁDI, M. – ARANYOS, T. – FERENCZY, A. – POSTA, K. (2013): Az ökológiai és konvencionális művelés alá eső nyírségi talajok mikrobiológiai és talajkémiai vizsgálatai. *Tájökológiai Lapok*, *11*(2), 311–319.

FEKETE I. – BERKI I., LAJTHA K. – TRUMBORE S. – FRANCIOSO O. – GIOACCHINI P. – MONTECCHIO D. – VÁRBÍRÓ G. – BÉNI Á. – MAKÁDI M. – DEMETER I. – MADARÁSZ B. – JUHOS K. – KOTROCZÓ ZS. (2021): How will a drier climate change carbon sequestration in soils of the deciduous forests of Central Europe? *Biogeochemistry* 152: 13–32. DOI: https://doi.org/10.1007/s10533-020-00728-w

DÖRING, T. F. – BRANDT, M. – HEß, J. – FINCKH, M. R. – SAUCKE, H. (2005): Effects of straw mulch on soil nitrate dynamics, weeds, yield and soil erosion in organically grown potatoes. *Field crops research*, *94* (2-3), 238–249 DOI: https://doi.org/10.1016/j.fcr.2005.01.006

GARTON, W. – VERLINDEN, S. – CONNEWAY, R. (2013). Waste Wool, Cocoa Hulls, and Clover as Organic Mulch Alternatives in Tomato Production. In *Hortscience* (Vol. 48, No. 9, pp. S319-S320). 113 S West St, Ste 200, Alexandria, Va 22314–2851 Usa: Amer Soc Horticultural Science.

GHOSH, S. K. – BAIRAGI, S. – BHATTACHARYA, R. – MONDAL, M. M. (2016). An overview on test standards for evaluation of jute agrotextiles. *American Journal of Engineering Research*, *5*(2), 49–53.

HOOVER, E. E. (2000): Bio-based weed control in strawberries using sheep wool mulch, canola mulch, and canola green manure. Minnesota Department of Agriculture

HUANG, Y. – CHEN, L. – FU, B. – HUANG, Z. – GONG, J. (2005): The wheat yields and water-use efficiency in the Loess Plateau: straw mulch and irrigation effects. *Agricultural water management*, *72*(3), 209–222. DOI: https://doi.org/10.1016/j.agwat.2004.09.012

JAKAB G. – KERTÉSZ Á. – MADARÁSZ B. – RONCZYK L. – SZALAI Z. (2010): Az erózió és a domborzat kapcsolata szántóföldön, a tolerálható talajveszteség tükrében. *Tájökológiai Lapok / Journal of Landscape Ecology* 8, 35–45.

KADER, M. A. – SENGE, M. – MOJID, M. A. – ITO, K. (2017): Recent advances in mulching materials and methods for modifying soil environment. *Soil and Tillage Research, 168,* 155–166. DOI: https://doi.org/10.1016/j.still.2017.01.001

KADER, M. A. – SENGE, M. – MOJID, M. A. – NAKAMURA, K. (2017): Mulching type-induced soil moisture and temperature regimes and water use efficiency of soybean under rain-fed condition in central Japan. *International Soil and Water Conservation Research, 5*(4), 302–308. DOI: https://doi.org/10.1016/j.iswcr.2017.08.001

KERTÉSZ Á. – JAKAB G. – MADARÁSZ B. – TÓTH A., SZALAI Z. (2012): Geotextíliák alkalmazása a talajpusztulás megfékezésére Magyarországon. Természetföldrajzi kutatások Magyarországon a XXI. század elején, 67–80p.

KOCSIS T. – WASS-MATICS H. –KOTROCZÓ ZS. – BIRÓ B. (2015): A bioszén kedvező hatása a talaj pszikrofil- és mezofil csíraszámára. *A hulladékgazdálkodás legújabb fejlesztési lehetőségei* c. konferencia kötete 63–69.

KOCSIS, T. – RINGER, M. – BIRÓ, B. (2022): Characteristics and Applications of Biochar in Soil–Plant Systems: A Short Review of Benefits and Potential Drawbacks. *Applied Sciences*, 12(8), 4051. DOI: https://doi.org/10.3390/app12084051

KOTROCZÓ, Z. – VERES, Z. – FEKETE, I. – KRAKOMPERGER, Z. – TÓTH, J. A. – LAJTHA, K. – TÓTHMÉRÉSZ, B. (2014): Soil enzyme activity in response to long-term organic matter manipulation. *Soil Biology and Biochemistry*, 70, 237–243. DOI: https://doi.org/10.1016/j.soilbio.2013.12.028

KOTROCZÓ ZS., FEKETE I. (2020): Significance of soil respiration from biological activity in the degradation processes of different types of organic matter. DRC Sustainable Future: *Journal of Environment, Agriculture, and Energy* 1: 171–179. DOI: https://doi.org/10.37281/DRCSF/1.2.10

KOTROCZÓ ZS. – JUHOS K. – BIRÓ B. – KOCSIS T. – PABAR S.A. –VARGA CS. – FEKETE I. (2020): Effect of Detritus Manipulation on Different Organic Matter Decompositions in Temperate Deciduous Forest Soils. *Forests*, 11: 675. DOI: https://doi.org/10.3390/f11060675

KOVÁCS B. – KOTROCZÓ ZS. – KOCSIS L. – BIRÓ B. (2020): Potentials of indoor lettuce production in natural forest soil at limited watering. *Journal of Central European Agriculture*, 21(3): 531–536. DOI: https://doi.org/10.5513/JCEA01/21.3.2897

LAL, B. – SHARMA, S. C. – MEENA, R. L. – SARKAR, S. – SAHOO, A. – BALAI, R. C. – MEENA, B. P. (2020): Utilization of byproducts of sheep farming as organic fertilizer for improving soil health and productivity of barley forage. *Journal of Environmental Management*, 269, 110765. DOI: https://doi.org/10.1016/j.jenvman.2020.110765

LI, J. – LI, M. – GAO, X. – FANG, F. (2018): Corn straw mulching affects Parthenium hysterophorus and rhizosphere organisms. *Crop Protection*, *113,* 90–96. DOI: https://doi.org/10.1016/j.cropro.2018.08.002

LI, S. – ZHANG, S. – PU, Y. – LI, T. – XU, X. – JIA, Y. – GONG, G. (2016): Dynamics of soil labile organic carbon fractions and C-cycle enzyme activities under straw mulch in Chengdu Plain. *Soil and Tillage research, 155*, 289–297. DOI:https://doi.org/10.1016/j.still.2015.07.019

MADARÁSZ B. – JAKAB G. – SZALAI Z. – JUHOS K. – KOTROCZÓ ZS. – TÓTH A. – LADÁNYI M. (2021): Long-term effects of conservation tillage on soil erosion in Central Europe: A random forest-based approach. *Soil & Tillage Research* 209, 104959. DOI: https://doi.org/10.1016/j.still.2021.104959

MARCZAK, D. – LEJCUŚ, K. – KULCZYCKI, G. – MISIEWICZ, J. (2022): Towards circular economy: Sustainable soil additives from natural waste fibres to improve water retention and soil fertility. *Science of the Total Environment*, *844,* 157169. DOI: https://doi.org/10.1016/j.scitotenv.2022.157169

MANNA, K. –KUNDU, M. C. – SAHA, B. – GHOSH, G. K. (2018): Effect of nonwoven jute agrotextile mulch on soil health and productivity of broccoli (Brassica oleracea L.) in lateritic soil. *Environmental monitoring and assessment*, *190*(2), 1–10. DOI: https://doi.org/10.1007/s10661-017-6452-y

MEZŐSI, G. – BATA, T. – BLANKA, V. – LADÁNYI, Z. (2017): A klímaváltozás hatása a környezeti veszélyekre az Alföldön. *Földrajzi Közlemények*, *141*(1), 60–70.

NGOSONG, C. – OKOLLE, J. N. – TENING, A. S. (2019). Mulching: A sustainable option to improve soil health. *Soil fertility management for sustainable development*, 231–249.

PARMAR, H. N. – POLARA, N. D. – VIRADIYA, R. R. (2013): Effect of mulching material on growth, yield and quality of watermelon (Citrullus lanatus Thunb) Cv. Kiran. *Universal Journal of Agricultural Research, 1*(2), 30–37. DOI: https://doi.org/10.13189/ujar.2013.010203

R CORE TEAM. 2018. R: A language and environment for statistical computing. Retrieved from http://www.R-project .org/

SINSABAUGH, R. L. – KLUG, M. J. – YEAGER, P. E. (1999): Characterizing Soil Microbial. *Standard soil methods for long-term ecological research,* 318.

SHARMA, N. – ALLARDYCE, B. – RAJKHOWA, R. – ADHOLEYA, A. – AGRAWAL, R. (2022): A Substantial Role of Agro-Textiles in Agricultural Applications. *Frontiers in Plant Science, 13*. DOI: https://doi.org/10.3389/fpls.2022.895740

SHEN, J. Y. – ZHAO, D. D. – HAN, H. F. – ZHOU, X. B. – LI, Q. Q. (2012): Effects of straw mulching on water consumption characteristics and yield of different types of summer maize plants. *Plant, Soil and Environment, 58*(4), 161–166.

SZARKA, G. É. – KOLLAR, J. – MOSNÁČEK, J. – IVÁN, B. (2015): Polimerek a talaj felett és alatt: korszerű környezetbarát polimerek. *Magyar Kémikusok Lapja*, *70,* 7–8.

WANG, Y. – HUANG, Q. – LIU, C. – DING, Y. – LIU, L. – TIAN, Y. – ZHAO, Z. (2020): Mulching practices alter soil microbial functional diversity and benefit to soil quality in orchards on the Loess Plateau. *Journal of Environmental Management, 271,* 110985. DOI: https://doi.org/10.1016/j.jenvman.2020.110985

WEIL, R. R. – ISLAM, K. R. – STINE, M. A. – GRUVER, J. B. – SAMSON-LIEBIG, S. E. (2003): Estimating active carbon for soil quality assessment: A simplified method for laboratory and field use. *American Journal of Alternative Agriculture*, *18*(1), 3–17. DOI: https://doi.org/10.1079/AJAA200228

WICKHAM, H. – FRANCOIS, R. (2015): dplyr: A grammar of data manipulation.

YAN, N. – MARSCHNER, P. – CAO, W. – ZUO, C. – QIN, W. (2015): Influence of salinity and water content on soil microorganisms. *International soil and water conservation Research*, *3*(4), 316–323. DOI: https://doi.org/10.1016/j.iswcr.2015.11.003

YU, J. G. – LI, H. X. – CHEN, X. Y. – HU, F. (2007): Effects of straw application and earthworm inoculation on soil labile organic carbon. *Ying Yong Sheng tai xue bao= The Journal of Applied Ecology*, *18*(4), 818–824.

Authors

Enikő Papdi
Ph.D. student
Department of Agro-Environmental Studies
Hungarian University of Agriculture and Life Sciences
Villányi str. 29-43, H-1118 Budapest, Hungary
papdi.eniko96@gmail.com

Andrea Veres, PhD
student of professional engineering
Department of Agro-Environmental Studies
Hungarian University of Agriculture and Life Sciences
Villányi str. 29-43, H-1118 Budapest, Hungary
mail.veresandrea@gmail.com

Flórián Kovács
Ph.D. student
Department of Agro-Environmental Studies
Hungarian University of Agriculture and Life Sciences
Villányi str. 29-43, H-1118 Budapest, Hungary
wdfort2@gmail.com

Katalin Juhos, PhD
senior lecturer
Department of Agro-Environmental Studies
Hungarian University of Agriculture and Life Sciences
Villányi str. 29-43, H-1118 Budapest, Hungary
Juhos.Katalin@uni-mate.hu