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The impact of cellulose and PLA biopolymer nonwoven mulches on the soil health

Selüloz ve PLA biyopolimer nonwoven malçların toprak sağlığına etkisi

***Yazar(lar) (Author(s))**: Paula MARASOVIĆ[1], Dragana KOPITAR[2], Ružica BRUNŠEK[3], Ivana SCHWARZ[4]*

ORCID[1]: 0000-0002-9887-5651

ORCID[2]: 0000-0003-4895-2548

ORCID[3]: 0000-0003-4859-6088

ORCID[4]: 0000-0001-6163-0557

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The Impact of Cellulose and PLA Biopolymer Nonwoven Mulches on the Soil Health

Highlights

- *Impact of Mulching on Microbial Populations*
- *Improvement in Soil Physio-Chemical Properties*
- *Temperature-Dependent Bacterial Population*
- *Recommendation for Short-Term Mulching*

Graphical Abstract

Viscose fiber mulches increased bacterial populations due to favorable anaerobic conditions. The nonwoven mulches also had a higher fungal population, with a 161% higher population under viscose fibers.

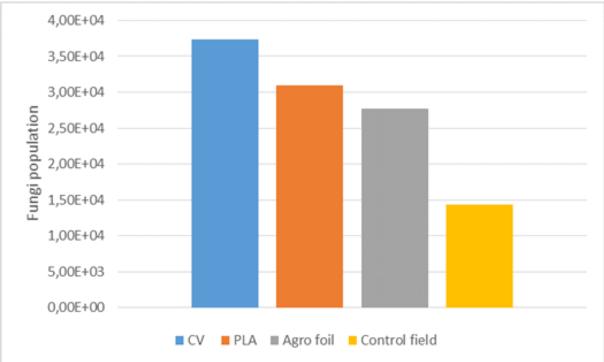

Figure. Fungi population on control field and beneath mulches

Aim

The aim of the presented work is to identify the impact of cellulose and PLA nonwoven mulches on a number of populations of bacteria nad funghi, soil nutrients, and soil temperature and moisture.

Design & Methodology

After 50 days, the soil samples beneath each mulch and on the control field were collected, where the bacteria and fungi population as well as the physio-chemical properties of the soil were measured.

Originality

Detailed analysis of the soil under the viscose and PLA mulches produced on the card, bonded by the needling process with the same production parameters, exposed to real external conditions.

Findings

The study's findings show that nonwoven mulches constructed of viscose fibers are suitable for short-term mulching applications because they successfully boost the microbial population and enhance the physio-chemical characteristics of soil.

Conclusion

The bacterial population of soil beneath the mulches made of viscose fibre significantly increased due to favourable anaerobic conditions, respectively soil temperature and moisture. Under all mulches, compared to the control field, a higher fungal population was observed.

Declaration of Ethical Standards

The author(s) of this article declare that the materials and methods used in this study do not require ethical committee permission and/or legal-special permission.

The Impact of Cellulose and PLA Biopolymer Nonwoven Mulches on the Soil Health

(This study was presented at ITFC 2023 conference. / Bu çalışma ITFC 2023 konferansında sunulmuştur.)

Araştırma Makalesi / Research Article

Paula MARASOVIĆ[1*], Dragana KOPITAR[1], Ružica BRUNŠEK[2], Ivana SCHWARZ[1]
[1]Department of Textile Design and Menagment, Faculty of Textile Technology, University of Zagreb, Croatia
[2] Department of Materials, Fibres and Textile Testing, Faculty of Textile Technology, University of Zagreb, Croatia

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ABSTRACT

The nonwoven mulches produced from regenerated viscose and polylactic acid (PLA) fibres as well as conventional agro foil were placed on the soil by randomly arranged blocks of four replication plots. After 50 days, the soil samples beneath each mulch and on the control field were collected, where the bacteria and fungi population as well as the physio-chemical properties of the soil were measured. The severe reduction in bacterial population in soil under the agro foil and mulches made of PLA fibres occurs due to the prevalence of high soil temperature. The bacterial population of soil beneath the mulches made of viscose fibre significantly increased due to favourable anaerobic conditions, respectively soil temperature and moisture. Under all mulches, compared to the control field, a higher fungal population was observed. The fungal population under the nonwoven mulch produced by viscose fibres was 161% higher in comparison to the control field. The available nutrient contents of soils under the nonwoven mulches were higher compared to the control field. The control field showed higher available nutrient contents of soil than the field covered by conventional agro foil. The results of the study reveal that usage of nonwoven mulches made of viscose fibres is most appropriate for short-term mulching application since successfully increases microbial population and improves the physio-chemical properties of soil

Keywords: Viscose, PLA, Nonwoven mulches, Bacterial and fungi population, Physio-chemical properties of soil.

Selüloz ve PLA Biyopolimer Nonwoven Malçların Toprak Sağlığına Etkisi

ÖZ

Rejenere viskoz ve PLA liflerinden ve ayrıca geleneksel tarımsal folyodan üretilen dokunmamış malçlar, rastgele düzenlenmiş dört tekrarlama parselinden oluşan bloklar halinde toprağa yerleştirildi. 50 gün sonra, her bir malç altında ve kontrol alanında toprak numuneleri toplandı ve burada bakteri ve mantar popülasyonunun yanı sıra toprağın fizyo-kimyasal özellikleri ölçüldü. Agro folyo ve PLA liflerinden yapılan malçların altındaki topraktaki bakteri popülasyonundaki ciddi azalma, yüksek toprak sıcaklığının yaygınlığından kaynaklanmaktadır. Viskoz elyaftan yapılan malçların altındaki topraktaki bakteri popülasyonu, sırasıyla toprak sıcaklığı ve nem olmak üzere uygun anaerobik koşullar nedeniyle önemli ölçüde artmıştır. Tüm malçların altında, kontrol alanına kıyasla daha yüksek bir mantar popülasyonu gözlendi. Viskon liflerinden üretilen dokunmamış malç altındaki mantar popülasyonu, kontrol alanına kıyasla %161 daha yüksekti. Dokumasız malçların altındaki toprakların mevcut besin içerikleri, kontrol alanına kıyasla daha yüksekti. Kontrol alanı, geleneksel tarımsal folyo ile kaplanan alana göre toprağın daha yüksek kullanılabilir besin içeriği gösterdi. Çalışmanın sonuçları, mikrobiyal popülasyonu başarılı bir şekilde artırması ve toprağın fiziko-kimyasal özelliklerini iyileştirmesi nedeniyle kısa süreli malçlama uygulamaları için en uygununun viskon liflerinden yapılan dokunmamış malç kullanımının olduğunu ortaya koymaktadır.

Anahtar Kelimeler: Viskon, PLA, Nonwoven malçlar, Bakteri ve mantar popülasyonu, Toprağın fiziko-kimyasal özellikleri.

1. INTRODUCTION

Mulching is a widely recognized practice in agriculture and horticulture that involves covering the soil with a layer of material that can improve crop production and increase yields, extend the growing season, reduce weed pressure without the use of pesticides, increase fertilizer efficiency, conserve soil moisture, and increase soil temperature [1-3].

Low-density polyethylene (LDPE) agro foil mulches have been used in agriculture for over half a century [3].

The use of plastic goods in agriculture has increased significantly over the years. In 2017, 22 million hectares of soil were covered by plastic agro foils, of which 84% was recorded in China. In Europe, LDPE mulches accounted for 25.3% of the plastic sold for crop production and 11.2% of the total plasticulture [4].

LDPE mulches can modify the soil microclimate, affecting microbial activity and populations. Studies have shown that LDPE mulch can increase or decrease microbial activity depending on temperature and soil

* *Corresponding Author*
e-posta : paula.marasovic@ttf.unizg.hr

moisture beneath the material. When ambient temperatures are cool, LDPE mulches increase soil temperature closer to microbial optima and increase microbial activity. Respectively, when the ambient temperature is warm, mulches increase the temperature above optima, limiting soil microbial activity [5].

The LDPE mulches offer certain advantages, but concerns regarding their long-term impact on soil health and the environment have arisen. The plastic LDPE mulches disposal at the end of the growing season is a significant challenge. They often end up in landfills, incinerators, or litter in the environment. It can take several hundred years to completely decompose plastic LDPE mulches, leading to long-term accumulation of plastic waste. The significant limitations of LDPE agro foil mulches, besides their disposal after usage and remaining plastic residues in agricultural soil, are reduced soil capacity and changes in the soil habitat. Microplastics are thought to be the possible cause of soil microorganisms' change [6,7]. The continuous application of LDPE mulches led to persistent plastic fragments and chemicals (mainly pesticides on the mulches) accumulation in agricultural soils, jeopardizing soil health, food security, and environmental sustainability [8]. Furthermore, LDPE mulch production implies polymer extraction from non-renewable resources where greenhouse gases during manufacturing are released, further exacerbating environmental pollution.

Alternative mulching materials, such as nonwoven mulches produced by natural fibres, have emerged as a more sustainable option. Research has shown that nonwoven mulches produced by polymers from natural sources and biopolymers are superior compared to plastic mulches regarding increasing yield, microbial activity and soil quality [9-13].

The studies revealed that using nonwoven mulches made of jute fibres increased yield, suppressed weeds, increased soil moisture and available N, P and K contents, the organic carbon, available N, P2O5 and K2O to the plant and microbial population of the soil in comparison to the conventional LDPE agro foil [9,10].

Likewise, mulching with biodegradable spunbonded PLA nonwoven (61 g m-2), in a two-year study on the yield and quality of tomato, resulted in fruits with a higher content of soluble sugars and dry matter as well as a lower concentration of nitrate ions than in the control field [11]. An 18-month study examined the effects on soil quality of four potentially biodegradable mulches (commercial biodegradable starch films, cellulose-based films and nonwoven spunbonded PLA mulch) and control field (uncovered field) in the high tunnel and open field tomato production systems in three geographically distinct locations. After 18 months, values of soil microbial biomass carbon (C, g kg-1) were higher on the control field on all three locations, while values of total organic carbon (C, %) at two locations indicated higher values with spun-bonded PLA mulch treatment. No correlation between soil quality indicator values and degradation levels was found [12]. Another study, conducted in a greenhouse environment, found that spun-melt nonwoven PLA mulch did not significantly decrease total nitrogen and total carbon in the soil throughout the experiment, suggesting that nitrogen and carbon are not being added to the soil due to mulch degradation. The study showed significant increases in soil pH during the 29-week study period compared to the control soil [13].

Among cellulose-based materials, viscose is becoming popular for mulching and production of plant seedlings, due to its good sorption properties and fast biodegradation. One of the main benefits of viscose nonwoven mulch is that they improve soil moisture retention due to its water absorption properties and porose structure. This can be especially beneficial in dry or arid regions, where water conservation is critical for crop growth and productivity [14].

The research on mulch effects on soil temperature and moisture confirms its influence during the whole year. Compared with the no-mulching treatment, using plastic film mulch has been shown to increase soil temperature and improve yield [15]. The mulched treated plots showed higher soil moisture content, especially nonwoven jute mulch, compared to the control field because of their increased water retention, reduced evaporation, and reduced weed population density [9]. The recycled natural fibre-based mulch showed inferior soil moisture retention capacity compared with the biodegradable plastic film mulch [16]. In a comparison of nonwoven bio fabrics to two commercially available bioplastic films and bare soil control, bio-fabric mulches did not alter soil temperature relative to bare soil, whereas bioplastic films increased soil temperatures by as much as 1.7 ◦C in northern Illinois [17]. In research that estimated differences in temperature, weed suppression, and yield of different groups of mulches, biodegradable mulch films reduced soil temperature up to 8% ± 1.7% compared to polyethylene mulch film. They also conclude that some agronomic benefits of polyethylene mulch film are either redundant or counterproductive and that the choice of mulch certainly depends on the climate in order to make the most of the properties of each mulch [18].

Research of soil microbial communities showed that the main affecting parameters are soil type, climate, plant species and management, where interaction with each other directly and indirectly affects the soil microbial community [19]. Most of the studies are focused on agro foil mulches influence on soil microbial population. The application of agro foil mulches modifies soil moisture and temperature providing a more stable soil microenvironment that enhances a number of bacteria that are able to produce degradative enzymes for mulches biodegradation [20, 21]. Nonwoven jute mulches increase bacterial and fungi populations in soil due to favourable conditions [9], and organic mulch improved the physicochemical conditions of tea garden soils and induced great changes in soil bacterial and fungal communities [22]. Hamp fabric mulch showed fungal diversity while plastic cover had lower enzymatic activities and different soil microbial community structures [23]. Previous studies confirm that mulching generally causes a significant increase in bacterial and fungal richness and diversity, thus research on the effect of newly designed mulches on soil microbial communities has become a fundamental aspect of sustainable agriculture.

This study investigates the possible replacement of conventional LDPE agro foil with nonwoven mulches made of recycled viscose and PLA fibres. The nonwoven mulches are made with the same technological process and production parameters on the card and bonded by needle punching. The influence of the nonwoven mulches' raw material (viscose and PLA biopolymer) and structure on the soil temperature and humidity, microbial population, as well as physio-chemical properties, were investigated.

2. MATERIAL AND METHOD

The nonwoven fabrics are produced from regenerated viscose fibres and PLA biopolymer on the card and bonded by the needle punching process with the same production parameters. The mass per unit area of nonwoven mulch made from regenerated viscose fibres was 410 gm-2, while the mass per unit area of PLA biopolymer fibres mulch was 360 gm-2. To compare results with conventionally used material for mulching and un-mulched soil, commercial agro foil of 28.17 gm-2 mass per unit area and control field (uncovered field) were used.

The nonwoven mulches and agro foil of 1.65 m2 (1.5 x 1.1 m) were placed on the soil by randomly arranged blocks of four replication plots (Figure 1). The four replication plots included the control fields as well. During 50 days of trial, soil temperature and moisture were recorded once per week.

The soil moisture was measured at a 15 cm depth with a PMS-714 soil moisture meter. Soil temperature at 15 cm depth measured with waterproof unstained steel, Fisher brand bi-metal dial thermometer with a long probe. Air temperature and humidity values during exposure of mulches to environmental conditions were obtained from the nearest hydro-meteorological station.

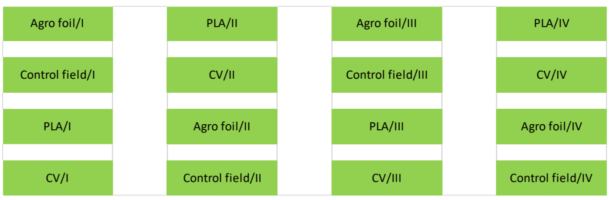

Figure 1. A field experiment with four replication plots

The samples were placed on the soil in late April, and after 50 days the soil samples beneath each mulch and control field of four replication plots are collected. Soil samples from each experimental field (under viscose mulch, PLA, agro foil and in the control field) were taken with the help of a cylindrical agrochemical probe for soil sampling, at a depth of 0-30 cm, and 1 kg was taken from each sample, i.e. from each experimental field. Physio-chemical properties were measured according to the standards on the initial soil (soil before the experiment starts), the soil beneath nonwoven mulches and on the control field.

After 50 days of mulches exposure to the environmental condition, using classic microbiological methods, the total number of bacteria and fungi in the soil beneath mulches was analysed. All soil samples were homogenized in a sterile physiological solution for five minutes. Nutrient agar (NA) was used to determine the total number of bacteria, while Czapek agar was used to determine the total number of fungi. All samples were analyzed in triplicate. After the cultures had grown on nutrient media, the colonies were counted and the CFU values of individual groups of microorganisms per gram of soil were determined.

The pH value of the soil was tested according to the ISO 10390:2005 standard. The organic carbon value was calculated from the total humus value. The method of humus determination is the bichromate method based on the wet burning of soil organic matter using K-bichromate. Total nitrogen was obtained using the Kjeldahl method. The easily accessible (plant-available) P2O5 and K2O were obtained using the AL method, which is based on the extraction of phosphorus and potassium from the soil with an ammonium lactate solution with a pH of 3.75. Easily accessible (plant-available) potassium means its water-soluble and exchangeably sorbed form, while easily accessible phosphorus is considered to be the forms of phosphorus in the soil that pass into various solutions of weak acids, bases or salts.

3. RESULTS AND DISCUSSION

The results of soil temperature and humidity beneath the mulches, as well as average daily air temperature and humidity, are given in Tables 1 and 2. It is well known from previous research that the soil temperature beneath agro foil is greater than bare soil (control field) [15,16,18]. The same trend is obtained during the period of mulches exposure to the environmental conditions, respectively the temperature beneath agro foil is higher than the temperature of bare soil up to 1.5 °C, on average of 0.7 °C from 5th of May to 13th of June (Table 1, Figure 2).

Soil temperature beneath nonwoven mulch produced from PLA biopolymer is mostly the same as the temperature on the control field. Contrary to agro foil and PLA nonwoven mulch, the temperature beneath viscose nonwoven mulches is considerably lower, respectively up to 2.5 °C (1.4 °C on average). It is evident that the fibre type of nonwoven mulches significantly influences the soil temperature.

Table 1. Air and soil temperature on control field and beneath mulches from May to June 2022)

Period	May				June			Average, °C
	5	12	16	26	2	6	13	
Air, °C	15.8	23.0	21.0	19.6	20.2	21.6	22.1	20.5
CV, °C	13.8	15.3	16.9	18.6	17.1	20.7	18.9	17.3
PLA, °C	15.3	17.3	18.6	19.8	18.2	21.2	19.6	18.6
Agro foil, °C	16.1	17.9	19.4	21.1	19.1	22.0	20.3	19.4
Control field, °C	16.3	17.8	18.6	20.0	18.1	21.2	18.8	18.7

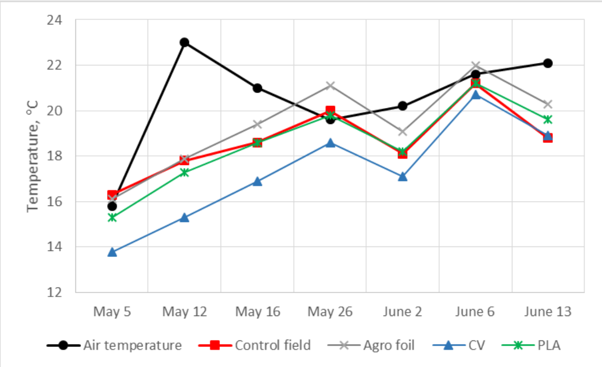

Figure 2. Average daily air temperature and soil temperature beneath the mulches measured from May 5 to June 13 in 2022

Contrary to the air and soil temperature beneath mulches, a clear trend for soil humidity is not visible (Table 2). It is observed that the days when the higher bare soil humidity is recorded, regarding the soil humidity beneath the mulches, are when higher rainfalls are recorded (from 16.3 mm to 21.0 mm). The influence of fibre absorption at certain temperatures as well as the dynamic of heat and water vapour exchange between the soil and the mulches should be further investigated.

According to previous studies, the microbial population beneath mulches should increase [9,12,24]. Regulated temperature, soil moisture retention, nonwoven decomposition through the accumulation of organic matter on the soil surface, and better aeration tend to increase microbial biomass in soil. The bacterial population increase is recorded only beneath viscose nonwoven mulches. The average bacterial population in soil was lowest beneath mulches made of PLA fibres (6.4 × 106 CFU per ml) and highest beneath mulches made of viscose fibres (1.15 × 107 CFU per ml) (Figure 3). The bacterial population in the control field soil were higher than under the agro foil. Only under the mulches made of viscose fibre, due to favourable anaerobic conditions, soil temperature and moisture bacterial population in soil significantly increased. During the seven weeks of the experiment, the temperature under mulch made of viscose fibres was the lowest (Table 1, Figure 2). The severe reduction in bacterial population in soil under the mulches made of PLA fibres and especially under the agro foil occurs due to the prevalence of high soil temperature.

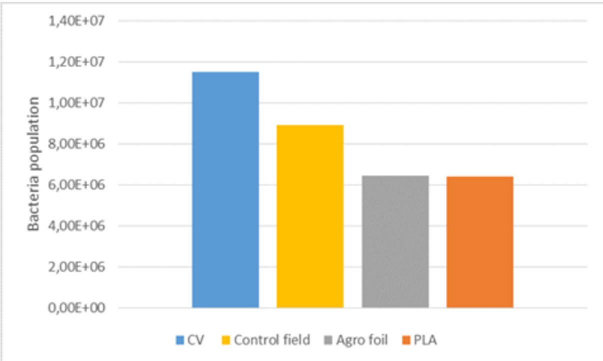

Figure 3. Bacteria population on control field and beneath mulches

Table 2. Air and soil humidity on control field and beneath mulches from May to June 2022

Period	May				June			Average, °C
	5	12	16	26	2	6	13	
Air, °C	90.0	95.0	86.0	98.0	92.0	87.0	88.0	90.9
CV, °C	31.2	39.4	45.5	46.1	43.2	46.4	46.1	42.6
PLA, °C	34.2	39.2	45.1	45.2	45.9	45.3	43.3	42.6
Agro foil, °C	26.6	40.0	45.8	45.8	44.4	46.4	43.9	41.8
Control field, °C	42.9	37.1	43.0	43.0	43.1	47.3	45.5	43.1

The higher fungal population under all mulches, including agro foil, compared to the control field were observed. The highest fungal population (3.73 ×104 CFU per ml) under nonwoven mulch produced by viscose fibres was recorded, where the fungal population was 161% higher compared to the control field.

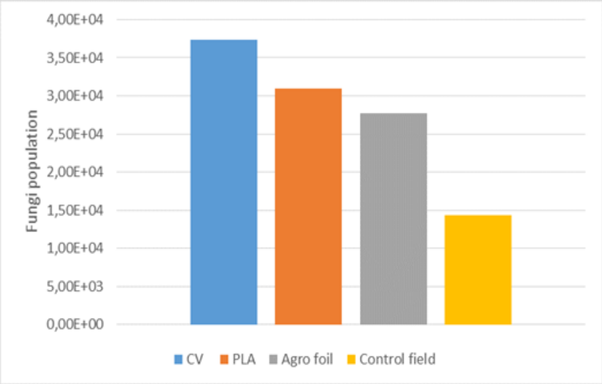

Figure 4. Fungi population on control field and beneath mulches

The number of bacteria and fungi colonies in the soil beneath mulches made of viscose fibres showed the highest number due to optimal conditions for bacteria and fungi development. The mulches made of viscose fibres had lower average temperatures during the field experiment compared to PLA (for 1.25°C), the control field (for 1.34°C) and agro foil (for 2.08°C).

Microorganisms consume organic matter and nutrients in the soil for energy and growth, so a soil with higher levels of organic matter and essential nutrients will support more diverse and abundant microbial communities. Additionally, competition for limited resources can also impact the number and diversity of microorganisms in the soil. The trend of the greater abundance of nutrients in the soil, especially C and N, was shown in the soil under the viscose nonwoven mulch, which has the highest number of bacteria and fungi (Table 3).

There is no significant variation of soil pH under nonwoven mulches and agro foil regarding the control field (Table 3). Soil organic carbon content on the control field and under the nonwoven mulches increased compared to the initial soil, while beneath the agro foil remained the same. The highest organic carbon content beneath mulch made of viscose could be explained by the decomposition of material with high contents of organic matter that was incorporated in the soil, improving the soil properties (an increase of bacteria and fungi as well as organic carbon).

Total N content was significantly increased compared to the initial soil, and its value was highest under the mulches made of viscose fibres (0.60%). The increase in total nitrogen was probably due to optimum moisture availability and increased mineralization of soil organic N. The higher phytoavailable phosphorus (P2O5) content of soils on the control field and under mulching may be attributed to better hydrothermal regimes and reduced weeds.

Phytoavailable potassium did not show any significant increase under the nonwoven mulches, mainly due to less decomposition of mulching material during the short duration of the experiment. Under the agro foil, phytoavailable potassium significantly decreased regarding the control field.

Overall, the available nutrient contents of soils under the mulches were higher compared to the control field (bare soil) because of decomposition under appropriate water and temperature levels as well as the release of available nutrients in the soil. The available nutrition contents were lower under the conventional agro foil regarding to the initial soil. Even the control field, i.e. bare soil that wasn't mulched during the experiment, showed higher available nutrient contents of soil regarding the field covered by conventional agro foil.

4. CONCLUSION

The conducted research confirms the possibility of replacing conventional agro foil with nonwoven mulches produced by viscose and PLA fibres. Soil temperature beneath mulches made from PLA biopolymer is mostly the same as the temperature on the control field, mostly higher beneath agro foil and considerably lower beneath viscose nonwoven mulches (up to 2.5 °C, i.e. 1.4 °C on average). It is evident that the fibre type of nonwoven mulches significantly influences the soil temperature. A clear trend of soil humidity beneath mulches is not visible. Rainfalls during the experiment affect the soil humidity on the control field and soil covered with

Table 3. Physio-chemical properties of soil beneath nonwoven mulches.

Soil sample	pH	Organic C, %	Total N, %	P2O5, mg/100 g	K2O, mg/100 g
Initial soil	7.65	2.23	0.13	3.03	31.32
Control field	7.54	2.55	0.58	10.55	29.61
CV	7.58	2.71	0.60	9.15	27.00
PLA	7.68	2.68	0.56	5.71	30.00
Agro foil	7.66	2.23	0.54	5.47	20.67

mulches. The influence of fibre type on the dynamic of heat and water vapour exchange between the soil and the mulches should be further investigated.

The severe reduction in soil bacterial population under the agro foil and mulches made of PLA fibres are recorded, where the bacterial population of soil beneath the mulches made of viscose fibre significantly increased. Under all mulches, compared to the control field, a higher fungal population was observed. The fungal population under the nonwoven mulch produced by viscose fibres was 161% higher compared to the control field. The available nutrient contents of soils under the nonwoven mulches were higher compared to the control field, where the soil under the conventional agro foil showed a decrease in the soil available nutrients.

Increased available nutrient contents of soils as well as bacteria and fungi populations beneath nonwoven mulches made from viscose fibres showed the best performance regarding nonwoven mulches made from PLA biopolymer and conventional agro foil. The results indicate positive properties of nonwoven fabrics made from viscose fibres for mulching application, where further research should be done to confirm their overall performance.

ACKNOWLEDGEMENT

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DECLARATION OF ETHICAL STANDARDS

The authors of this article declare that the materials and methods used in this study do not require ethical committee permission and/or legal-special permission.

AUTHORS' CONTRIBUTIONS

Paula Marasović: Performed the experiments and analyzed the results as well as writing the manuscript.

Dragana KOPITAR: Performed the experiments, metodology, writing- review and editing, and supervision.

Ružica BRUNŠEK: Performed the experiments, visualization.

Ivana SCHWARZ: Writing–review and editing, supervision.

CONFLICT OF INTEREST

There is no conflict of interest in this study.

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