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EFFECT OF BIODEGRADABLE MULCHING ON SOIL QUALITY IN STENOTERMAL VEGETABLE CROP PRODUCTION

WPŁYW MULCZOWANIA Z WYKORZYSTANIEM WŁÓKNIN BIODEGRADOWALYCH NA JAKOŚĆ GLEBY W UPRAWIE WARZYW CIEPŁOLUBNYCH

Abstract: Mulching with plastic materials that cover the soil creates a physical barrier to soil water evaporation, preserves good soil structure, controls weeds and protects plants from soil contamination. The removal and disposal of non-recyclable and non-degradable plastic wastes after harvest is difficult and expensive. Using alternative biodegradable polymers as covers has been of increasing concern in recent years. This paper provides a presentation of results concerning the physical and chemical properties of soil under biodegradable nonwoven covers. Biodegradable PLA (polylactide) and Bionolle (an aliphatic polyester of butylene glycol and succinic and adipic acid) films covering the soil on tomato and cucumber fields were evaluated to estimate the changes in several physical soil properties including bulk density, water field capacity, wet soil aggregate stability and chemical soil properties including soil acidity, EC, organic matter and soil mineral status. Favourable changes in the physical structure of soil can be achieved by mulching the soil surface of biodegradable polymers. The obtained results show that using covers with PLA and Bionolle biofilm significantly increased the amount of large aggregates and decreased the percentage of the smallest size aggregates in soils; however, the observed effects were strongly affected by weather conditions. Under wet conditions, mulching increased the soil bulk density and decreased soil water capacity. The results of soil chemical analyses demonstrated the low impact of treatments on macro- and microelement concentration measured after tomato and cucumber harvesting. Soils under PLA and Bionolle covers had smaller low ion concentrations in relation to bare soils.

Keywords: biofilm, bulk density, water-stable aggregates, soil organic matter, tomato, cucumber

Introduction

Plastic soil film covering has been used as mulch since the 1960s, mainly in vegetable production [1, 2]. It is well known that plastic mulch film increases the yield of many vegetables, in particularly early in the season, most likely by increasing soil temperatures and moisture and inhibiting weed growth [3-8]. However, the removal and disposal of non-degradable plastic mulch (polyethylene and polypropylene) after harvest is difficult and expensive. Disposal concerns and environmental legislation are forcing plastics manufactures to consider biodegradable polymers as an alternative material. A large amount of research is in progress to find the most suitable alternative to plastic mulch in vegetable production [9, 10]. Degradable plastics were introduced in the 1980s, though there remain many questions regarding their efficacy, degradability and potential residues [11]. After being used, photodegradable or biodegradable synthetic mulch does not need to be recollected, transported to a collection centre or landfill, or disposed through

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incineration [12]. Degradable films' breakdown is primarily affected by temperature, sunlight, moisture and microbial activity [13, 14].

An example of a successfully commercialised biodegradable polymer is poly(lactic acid), or PLA - a synthetic polymer made from lactic acid, a monomer found in nature. PLA is biodegradable and compostable [15]. Sustainability and eco-friendly characteristics make PLA an attractive polymer. PLA degrades mainly by hydrolysis, even in the absence of microorganisms. The rate of biodegradability in the composting environment depends on the size and shape of the article [16]. Another example of a completely mineralised synthetic polymer is trademarked Bionolle™, produced through the polycondensation reactions of glycols with aliphatic dicarboxylic acids such as succinic and adipic acids used as the principal raw material [17]. Aliphatic polyesters can be degraded with enzymes and microorganisms in soils [2].

The benefits of mulching on the growth and yield of vegetables have long been recognised. Mulching with organic or inorganic materials covers soils and creates a physical barrier to soil water evaporation, preserves good soil structure, control weeds and protect plants from soil contamination. Soil surface covering decreases erosion, protects against raindrop impact and increases aggregate stability [18]. In addition, mulches improve soil structure by creating favourable conditions for soil aggregation, *eg* through higher soil water content and temperature and the efficient mineralisation of soil organic matter [3]. Soil aggregates formed by the arrangement of soil particles are the fundamental components of soil structure. The linkage between soil particles depends on the interactions between primary particles and organic constituents to form stable aggregates [19]. The stability of soil structure affects soil fertility, quality and sustainability. Thus, the recognition of soil aggregate size distribution and soil aggregate stability is important to properly interpret soil structure [20]. In agricultural soils bulk density, various air and water capacity relationships and soil aggregate parameters are commonly used to indicate the physical quality of the soil. In general, soil physical quality is a central concept for developing "best management" land use practices. Mulching is known to attribute enhanced mineral nutrient availability to enhance nitrification. Mulching also improves soil aeration, creates better biological activates and thus has a consequent beneficial effect on soil fertility [11]. One of the advantages of using plastic mulches is also a reduction in fertilizer leaching. Plastic mulch covering prevents rainfall from percolating through the soil and moving nutrients. Preventing leaching improves the efficiency of plant nutrition and production. Li et al [21] demonstrated the CO_2 enrichment of the soil surface under plastic mulch. The metabolism, biomass, activity and diversity of the microbial community in soils can be significantly altered by CO_2 enrichment. It can also increase carbonate weathering, differ the rhizospheric exudation and enhance the amount of available C in the soil. CO_2 improvement can influence the transformation and bioavailability of metals in soils. Li et al [22] showed lower pH values and higher concentration of Cu, Pb, Zn and Cd in soil under plastic mulching. The authors also suggested that plastic mulching most likely causes the accumulation of heavy metals in surface soils by reducing metal leaching from surface runoff.

Many tomato or/and cucumber growers in Poland are using polyethylene mulch to warm the soil to advance harvest maturity under cool soil conditions. Warm season vegetables, including tomato and cucumber have produced better quality fruit and a greater yield when grown on plastics [6, 7, 23]. Black plastic film was used for many years for its ability to absorb light and raise soil temperature, which extended the production season in a colder climate [24]. Ngouajio et al [25] and Minuto et al [26] showed that tomato growth, yield and fruit quality from black biodegradable mulch was equivalent to that in low-density polyethylene mulch. Martin-Closas [27] found similar results for organically grown tomato. In addition, Anzalone et al [8] indicated that paper, biodegradable plastic and rice straw are potential substitutes for polyethylene and herbicides. There is an increasing interest in the use of degradable mulching for protected cultivation. Unfortunately, there are few published reports on how physical and chemical soil properties change after modifications in land use. Additional information on the biochemistry and decomposition of biodegradable films and their interaction with soil properties and environmental conditions to promote aggregation would allow for the identification of more effective management practices.

Although agricultural land management is recognised to affect near-surface physical qualities of soil, little is known about how biofilm covering affects physical and chemical soil parameters. In this research, biodegradable film covering tomato and cucumber were tested to estimate the changes in several physical and chemical soil properties. Soil properties selected to indicate physical quality included bulk density, water retention and wet soil aggregate stability, whereas the chemical characteristics considered were total organic carbon, nutrients and heavy metals content.

Material and methods

Soil sampling and analysis

The field experiment was carried out at the experimental farm of the Agricultural University of Krakow in Mydlniki in 2008-2011. The effect of film covering tomato and cucumber on the physical and chemical soil properties was studied. The trials consisted of a randomised complete block design with the following treatments: biodegradable films - Bionnole, PLA and bare soil (control). Bionolle - an aliphatic polyester of butylene glycol, succinic and adipic acid - is a completely mineralised polymer. Poly(lactic acid) or polylactide (PLA) is a thermoplastic aliphatic polyester. Both polymers can biodegrade under certain conditions.

The seeds of the tomato cultivar ‘Mundi’ were sown in a greenhouse on 15 April 2008, 16 April 2009 and 31 March 2010, respectively. Seedlings were planted in the field on 29 May 2008, 27 May 2009 and 25 May 2010, respectively, at a distance of 100 x 50 cm. Black nonwoven PLA 61 $g \cdot m^{-2}$ was used for soil mulching. Plants cultivated without covers were the control.

On the cucumber experimental fields, black nonwoven Bionolle 200 $g \cdot m^{-2}$ (except 2008) and PLA 130 $g \cdot m^{-2}$ were used for soil mulching. The nonwovens were stretched before the seeds were sown. Plants cultivated without covers were the control. Experimental fields with a soil surface of 7.5 m^2 were established with four replications. The seeds of the cucumber cultivar ‘Mirabelle’ were sown into the field on 7 May 2008, 14 May 2009 and 8 July 2010, respectively, at a distance of 200 x 25 cm (two seeds per hole cut in the nonwoven).

The mineral fertilisation of phosphorus, potassium and magnesium was based on the results of chemical analyses of the soil samples. The content of soil P, K and Mg was supplemented before seedling planting. Nitrogen fertilizer was applied at the rate of 100 kg N $\cdot$ ha^{-1}.

Soil samples with their natural structure preserved intact were collected from the plots divided into sections differentiated by covers films. In each section, soil samples were taken at a depth of 0-20 cm after tomato and cucumber cropping. The soil samples were air-dried at room temperature and sieved.

Intact soil cores (250 cm^3) at a depth of 0-10 cm were sampled in four replication to measure soil bulk density (BD) and water retention parameters. The undisturbed soil samples for determining the soil bulk density were oven-dried at 105ºC to a constant weight. Volumetric (%vw) and weight (%ww) water field capacity of the soil was determined by a Kopecki-type procedure [28]. Granulometric analysis was made using the Casagrande aerometric method modified by Proszynski [29]. This procedure is regulated by the PN-R-04032 [30] standard published mostly for agricultural soil analysis in Poland.

Soil aggregates were separated by wet sieving using Yoder's procedures [31]. Previously separated out by dry sieving, a single size soil fraction (< 5 mm) was disrupted under water, where the nest of sieves was suspended in a container of water. For measurements, forty grams of air-dried aggregates in five replications were placed onto the top sieve and immersed in water for a period of time (5 min) before beginning the mechanical sieving process for 20 minutes. A motor and a mechanical arrangement lowered and raised sieves through a distance of 5 cm at a rate of 5 cycles per one minute. There were five size classes used: 0.25, 0.5, 1.0, 1.5 and 2.5 mm. The amount of soil retained on each sieve was determined by drying and weighing. The water-stable aggregate index based on the wet soil fragmentation procedure was calculated as a sum of five size classes of aggregates.

Soil pH was measured in water and 1 mol $\cdot$ dm^{-3} KCl at a soil to solution ratio of 1:2. Soil organic carbon (SOC) was determined using the dichromate oxidation method [29]. The available form of nitrogen ($N\text{-}NO_3$ and $N\text{-}NH_4$), phosphorus, potassium, magnesium and calcium was determined by the universal method as described by Nowosielski [32]. The extractable forms of metals were measured in 1 mol $\cdot$ dm^{-3} HCl extractant [29]. This soil extractant and procedure is currently used to estimate the availability and critical levels for soil micronutrient cations in Poland. Available N was detected using the Flow Injection Analysis (FIA) technique with spectrometric detection [33], and P, K, Mg and Ca were determined using the inductively coupled argon plasma atomic emission spectroscopy ICP-OES technique (ICP-OES Teledyne Prodigy, Leeman Labs spectrophotometer).

Statistical analysis

Data collected from the study were analysed using the one-way analysis of variance test based on the ANOVA module in Statistica 8.0. Means for each treatment were separated using the Fisher test at the $p \leq 0.05$ level of significance.

Climatic conditions

In 2008 and 2009 temperatures were near the average for the Krakow area from April to October (Table 1). Rainfall during the growing season in 2010 was very high, especially in May and September. This growing season was characterized as warm (July) but very wet (May and September) in compared with the years 2008-2009.

Table 1

Precipitation sums and mean monthly temperatures during the vegetation period 2008-2010

Year	**April**		**May**		**June**		**July**		**September**		**October**	
	[ºC]	**[mm]**	**[ºC]**	**[mm]**	**[ºC]**	**[mm]**	**[ºC]**	**[mm]**	**[ºC]**	**[mm]**	**[ºC]**	**[mm]**
2008	10.1	35.2	14.4	26.8	19.5	26.7	19.0	142.6	18.0	41.6	12.5	96.7
2009	12.0	0.5	13.3	91.0	15.4	128.0	19.4	82.7	18.9	53.1	15.1	34.8
2010	8.5	37.5	12.7	297.9	17.6	122.0	21.8	110.4	18.8	138.2	12.4	92.4

Results and discussion

Data from three tomato/cucumber growing seasons were collected. We determined several physical and chemical soil parameters as related to the impact of biofilms on soil characteristics after harvest. In the presented study, the particle size analysis showed a silty clay soil texture (14% of size particles 1.0-0.1 mm, 45% were 0.1-0.02 mm and 41% were < 0.02 mm). Soil texture has a significant influence on aggregation. Clay content affects aggregation through swelling and dispersion. Increasing clay concentration is usually associated with increased soil organic content in soil and wet soil structure stability [18].

Soil bulk density and water capacity

A minor effect of the treatments on soil bulk density was observed. In 2008, in the tomato season, the bulk density (BD) measured for the control soil was 1.39 g · cm^{-3} (Table 2). In the 2009-2010 seasons, the average BD for the control soil was 1.39 and 1.17 g · cm^{-3}, respectively. There was no significant impact of covering with biodegradable films on the soil bulk density, although soil collected from under PLA covering demonstrated a relatively low value (1.28 and 1.07 g · cm^{-3} in 2009 and 2010, respectively) as compared to the control treatments. According to Reynolad [34], the optimal BD range at the field site is 1.10 to 1.23 Mg · m^{-3} for medium to fine-textured soils (*ie* 18-60 wt.% particle sizes < 0.002 mm) for a soil depth of 0-10 cm. Soils often react individually to agricultural practices such as tillage, cropping system, mulching, etc. Reynolds et al [35] indicated that most of the soil physical quality indicators show complex and site-specific interactions. The nature and amount of the changes are often inconsistent, or predictable only in a general way.

In all of the tomato cropping seasons, the use of covering films did not affect the field water capacity expressed as a per cent of mass units [% ww]. Only in 2009 was the weigh water field capacity relatively higher in soil covert PLA biofilm in relation to the bare soil (34.9 and 33.0% ww, respectively). Results from a study by Ndubuisi [36] indicates that polymer film mulches improved the physical properties of the soil, such as the soil water content and the temperature in top soil layers, prompting the emergence of seedlings and greater root distribution in the soil. Martin-Closas [27], Moreno and Moreno [6] and Moreno et al [7] found similar results.

Table 2

Physical and chemical properties of soils from tomato plantations covered with biodegradable film, 2008-2010

Treatment	**Bulk density [Mg · m^{-3}]**	**Water capacity [% ww]**	**Water capacity [% ww]**	**[% C]**
2008				
Before planting	*1.33*	*39.5*	*52.5*	*2.07*
Control	1.39 a	36.0 a	49.9 a	2.01 a
PLA	1.44 a	35.0 a	50.4 a	2.25 a
2009				
Before planting	*1.25*	*40.1*	*49.9*	*1.38*
Control	1.39 a	33.0 a	46.0 a	1.36 a
PLA	1.28 a	34.9 a	46.0 a	1.35 a
2010				
Before planting	*1.20*	*30.8*	*43.8*	*1.68*
Control	1.17 a	40.1 a	46.8 a	1.63 a
PLA	1.07 a	38.7 a	43.7 a	1.59 a

α = 0.05. Fisher test - the same letter indicates no significant differences between means

In 2010, the soil bulk density differed significantly between treatments on the cucumber plantation. We measured higher BD for soil covered by biofilms than for the bare soil (Table 3). This controversial result was possibly the effect of very high precipitation in that year (798.4 mm in April-October). The increase in the soil density led to a reduction of the water capacity parameters. The some trend was observed for tomato soils. In 2008-2009, no significant effects of treatments on water retention parameters were demonstrated in the cucumber cropping seasons.

Table 3

Physical and chemical properties of soils from cucumber plantations covered with biodegradable films, 2008-2010

Treatment	**Bulk density [Mg · m^{-3}]**	**Water capacity [% ww]**	**Water capacity [% vw]**	**[% C]**
2008				
Before planting	*1.37*	*37.4*	*51.4*	*2.07*
Control	1.39 a	36.0 a	49.9 a	2.01 a
PLA	1.44 a	35.0 a	50.4 a	2.25 a
2009				
Before planting	*1.30*	*39.7*	*51.6*	*1.41*
Control	1.34 a	35.7 a	47.8 a	1.44 a
PLA	1.31 a	38.7 a	51.1 a	1.36 a
Bionolle	1.33 a	37.0 a	49.1 a	1.37 a
2010				
Before planting	*1.32*	*37.1*	*49.6*	*1.34*
Control	1.11 a	42.2 b	46.8 a	1.35 a
PLA	1.34 b	34.7 a	46.6 a	1.39 b
Bionolle	1.33 b	35.0 a	45.0 a	1.42 b

α = 0.05. Fisher test - the same letter indicate no significant differences between means

Soil water-stable aggregates

High soil aggregate stability is an important factor for improving soil fertility and increasing agronomic productivity. Aggregate analysis may help to explain most aspects of soil water properties, including runoff and infiltration, as well as soil aeration and root growth [37]. Aggregates are susceptible to disruption by physical disturbances such as clay swelling, tillage and rainfall impact [18]. Mulching and covering improve soil structure and enhance soil water-stable aggregate contents by decreasing soil erosion, reducing raindrop impact and increasing the magnitude of soil organic carbon in the soil pool.

In the 2008 tomato season, there were no significant differences between wet-stable amounts of aggregates in any of the size classes under different treatments (Table 4). The sum of wet-stable aggregates in the diameters 0.25-4.0 mm ranged from 83.8% (Control) to 84.1% (PLA). In 2009, the wet-stable aggregate index was high and varied from 94.4% (Control) to 98.7% (PLA). The PLA biofilm significantly increased the amount of large aggregates 4-2.5 mm in diameter (41.8%) in comparison with the bare soil (23.6%) in 2009. An adverse effect for aggregates in the diameter of 0.50-0.25 mm was found. There is evidence that macroaggregates are very susceptible to land use modifications and agricultural practices, and are less stable than microaggregates. They are weakly cemented by SOM [38]. In extremely wet 2010, we measured from 90.8% (PLA) to 94.2% (Control) of water-stable aggregates in soil after tomato harvest. Paradoxically, the results of the 2010 season showed the highest content of large water-stable aggregates 4.0-2.5 mm in diameter (45.6%) in relation to 2009 and 2008 (32.7 and 18.0%, respectively) (Table 4). In extremely wet 2010, the lowest amount of small aggregates was measured in relation to the years 2008 and 2009 (21.5 and 14.3%, respectively). The processes responsible for forming aggregates include drying and wetting, freezing and thawing, tillage and the activity of roots and the soil biota. Soil moisture and wet-dry cycles have a variable effect on aggregation.

Table 4

Percentage of soil water-stable aggregates (means, standard deviation and *LSD* for $\alpha = 0.05$) in soil from the tomato plantation covered with biodegradable film, 2008-2010

Treatment	**Aggregates in diameter of [mm]**					
	4.0-2.5	**2.5-1.5**	**1.5-1.0**	**1.0-0.50**	**0.50-0.25**	**∑ 0.25-4.0**
2008						
Before planting	*14.4±5.9*	*6.9±2.0*	*18.8±2.8*	*27.4±2.8*	*16.2±1.8*	*83.8*
Control	19.6±3.1 a	5.3±0.5 a	10.9±0.3 a	25.8±1.7 a	22.1±2.8 a	83.8
PLA	18.0±5.0 a	6.4±1.0 a	11.7±1.2 a	26.4±2.5 a	21.5±2.1 a	84.1
mean	*18.8*	*5.8*	*11.3*	*26.1*	*21.8*	
2009						
Before planting	21.3±3.3	6.0±0.6	14.4±0.9	37.7±3.2	18.0±1.7	97.5
Control	23.6±1.4 a	7.9±1.5 a	13.6±0.2 a	31.5±2.5 b	18.2±2.2 b	94.4
PLA	41.8±2.6 b	7.6±0.2 a	14.0±1.3 a	25.4±1.8 a	10.3±0.5 a	98.7
mean	*32.7*	*7.8*	*13.8*	*28.4*	*14.3*	
2010						
Before planting	36.6±3.3	6.7±0.5	13.9±0.9	23.8±0.6	11.3±2.0	92.4
Control	44.0±2.3 a	9.3±0.7 a	15.5±0.9 a	16.2±1.3 b	10.0±0.8 b	94.2
PLA	41.2±4.0 a	9.5±1.1 a	15.3±0.8 a	14.0±0.5 a	7.1±0.8 a	90.8
mean	*42.6*	*9.4*	*15.4*	*15.1*	*8.5*	

During wetting, clay particles tend to disperse in soils and form bridges and coatings while drying. This influence on closer contact between particles increases bridging, especially in the presence of bivalent cations (Ca^{+2} and Mg^{+2}) in the clay colloidal complex [18].

In the 2009 and 2010 cucumber cropping seasons, a direct trend to increase the water-stable aggregate index, calculated as a sum of five size classes of aggregates, was observed for covered soil in regard to the control soil (Table 5).

Table 5

Percentage of soil water-stable aggregates (means, standard deviation and *LSD* for α = 0.05) in soil from the cucumber plantation covered with biodegradable film, 2008-2010

Treatment	**Aggregates in diameter of [mm]**					
	4.0-2.5	**2.5-1.5**	**1.5-1.0**	**1.0-0.50**	**0.50-0.25**	**∑ 0.25-4.0**
2008						
Before planting	*22.1±7.9*	*7.2±1.1*	*22.8±1.9*	*21.3±4.8*	*11.4±2.8*	*84.8*
Control	19.6±3.1 a	5.3±0.5 a	10.9±0.3 a	25.8±1.7 a	22.1±2.8 a	83.8
PLA	18.0±5.0 a	6.4±1.0 a	11.7±1.2 a	26.4±2.5 a	21.5±2.1 a	84.1
mean	*18.8*	*5.8*	*11.3*	*26.1*	*21.8*	
2009						
Before planting	*30.5±2.6*	*8.2±0.4*	*16.9±1.6*	*26.8±1.7*	*15.0±2.6*	*97.3*
Control	29.0±3.3 a	10.9±4.8 a	16.9±3.2 a	25.9±3.8 a	16.9±5.3 a	91.3
PLA	34.5±1.8 b	8.9±0.8 a	15.3±1.3 a	24.0±1.1 a	12.0±0.7 a	94.8
Bionolle	38.4±2.7 b	9.7±0.4 a	15.1±1.2 a	21.5±1.2 a	11.6±0.8 a	96.2
mean	*36.2*	*9.9*	*15.2*	*21.8*	*13.2*	
2010						
Before planting	*36.6±3.4*	*6.7±0.5*	*13.9±0.9*	*23.8±0.6*	*11.3±1.7*	*92.4*
Control	44.1±4.7 a	7.52±0.95 b	13.4±2.3 a	14.6±2.0 a	10.9±0.6 a	90.5
PLA	44.4±2.2 a	7.77±0.21 b	12.2±0.7 a	15.4±0.3 a	10.7±1.1 a	90.6
Bionolle	48.0±4.3 b	5.97±0.90 a	10.7±2.0 a	19.0±1.9 b	11.5±0.7 a	95.3
mean	*45.5*	*7.1*	*12.1*	*16.3*	*10.6*	

In 2009, 94.8 and 96.2% of the water-stable aggregate index were noted, respectively, for PLA and Bionolle biofilms in relation to the control (91.3%). In 2010 the highest value for this parameter was found for biodegradable Bionnole (95.3%) in comparison with the control soil (90.5%).

In 2010, similar to the tomato study, the highest content of water-stable aggregates in cucumber soils was measured for 4.0-2.5 mm diameters (47.3%) in relation to 2008 and 2009 (18.8 and 36.2%, respectively). Consequently, the percentage of small wet-stable aggregates (∅ 1.0-0.5 and 0.5-0.25 mm) decreased in the wetter 2010. The highest amount of the smallest aggregates were found in 2008 (21.8%) followed by 2009 (13.2%), while the lowest was in 2010 (10.6%) (Table 5).

In 2009 of the cucumber season, the PLA and Bionolle biofilms, and the Bionolle biofilm in 2010, significantly increased the percentage of large aggregates (4.0-2.5 mm in diameter) in relation to the control treatment (Table 5). The uncovered soil was directly exposed to the destructive effects of rain (raindrop splash), wind and solar radiation. The film covering (physical protection) showed a beneficial effect on the number of large soil water-stable aggregates. Indeed, the water stability of macroaggregates is known to prevent the detachment of easily transportable particles, and thereby surface clogging and runoff. It is generally considered that large aggregates are more indicative of a good soil structure for most agricultural purposes (availability of O_2, water and resistance to penetration by roots and shoots in seedbeds created by tillage) than small aggregates [18]. Soil structure not only affects the ability of roots to grow and to supply the leaves with water and nutrients. Macropores provide places for microorganisms, both symbiotic and pathogenic [39]. The process of soil aggregate stabilisation is complex and involves a variety of binding mechanisms. Plant roots and the organisms that live in the soil are influential both in the creation of pores and aggregates. Jastrow et al [40] demonstrated the importance of fine roots and mycorrhizal hyphae as driving factors for macroaggregate stabilisation. Under biofilms, more stable aggregates were probably formed in favourable conditions for rooting and intense soil microbial activity.

Soil organic carbon

The soil organic carbon (OC) content in the analysed tomato soils ranged from 1.35 to 2.25% (Table 2). At the cucumber plantation we determined from 1.34 to 2.25% of OC (Table 3). The obtained results do not point out clear differences between treatments. However in 2010, a higher organic carbon amount than in the control treatments was noted on cucumber fields under PLA and Bionolle mulch. A similar observation was found in leak and onion soils under polypropylene and Bionolle film covering [41]. Nevertheless, it can be concluded that the use of soil film covering systems that lead to greater organic matter contents also results in higher values of soil physical quality as measured by soil structure stability. Stable microaggregates are bound to form macroaggregates with organic compounds. Soil organic matter forms complexes with primary mineral particles and secondary structural units [18]. The consequence of the high organic matter content is good soil structure and high strength in wet conditions [42]. Candan and Broquen [38] showed a significant relationship between aggregate stability and organic carbon (r = 0.57). Management practices include film covering and mulching a moderate moisture and temperature regime in the soil and altering the biogeochemical cycling of C, and can result in organic matter accumulation [7, 43]. The biological status of the soil depends strongly on the physical and chemical conditions of the soil.

Generally, relatively high organic matter and clay content could explain the high wet aggregate stability in arable silty clay soils from the tomato and cucumber plantations.

Chemical soil analyses

The data from the soil chemical analysis are presented in Tables 6-9. In both tomato and cucumber cropping seasons, the soil pH was near 7.0 or higher, and any significant differences among the treatments were not observed (Tables 6 and 7). A high level of bivalent cations (about 1000-2000 mg Ca and 100-200 mg Mg $\cdot$ m^{-3} of soil) encouraged high water-stable aggregate content irrespective of the treatments. Bivalent cations improve the soil structure by binding clay and soil organic matter particles [44, 45]. A high pH raises the negative surface charge on clay particles and flocculate dispersive clays [46]. Increased pH often resulted in increased microbial activity and higher organic matter content and consequently encouraged soil particle aggregation [45].

Table 6

Acidity, pH, electrical conductivity, *EC* and available form of macronutrients [mg · dm^{-3}] in soil from the tomato plantation covered with biodegradable film, 2008-2010

Treatment	**pH H_2O [-]**	**pH KCl [-]**	***EC* [µS · cm^{-1}]**	**N-NH_4**	**N-NO_3**	**P**	**K**	**Mg**	**Ca**
2008									
Before planting	*7.17*	*6.35*	*620.0*	*11.8*	*70.1*	*62.1*	*73.6*	*140.3*	*1734*
Control	7.27	6.52	323.0	0.4	9.5	7.5	59.3	93.4	2249
PLA	7.52	6.66	186.5	1.1	6.6	6.6	82.6	96.9	1773
2009									
Before planting	*6.63*	*5.77*	*155.6*	*3.4*	*15.7*	*55.1*	*225*	*123*	*1164*
Control	6.77	5.90	136.7	1.9	9.3	34.7	89.4	99	978
PLA	7.07	6.10	90.5	3.1	4.9	30.2	81.8	106	1025
2010									
Before planting	*7.58*	*6.45*	*127.5*	*0.70*	*2.30*	*45.3*	*129*	*241*	*2031*
Control	7.86	6.89	111.0	0.68	1.50	53.8	118	185	1736
PLA	7.84	6.89	130.0	1.02	2.20	69.8	207	149	2396

Electrical conductivity estimates the concentration of ions in the soil solution, and predominantly consists of the cations sodium, calcium, potassium and magnesium, and the anions chlorines, sulphates and bicarbonates. Soils under PLA and Bionolle covers had low ion concentrations in relation to the bare soils. These results were recorded for tomato (with the exception of 2010) and cucumber fields in all years.

Table 7

Acidity, pH, electrical conductivity, *EC* and available form of macronutrients [mg · dm^{-3}] in soil from the cucumber plantation covered with biodegradable film, 2008-2010

Treatment	**pH H_2O [-]**	**pH KCl [-]**	***EC* [µS · cm^{-1}]**	**N-NH_4**	**N-NO_3**	**P**	**K**	**Mg**	**Ca**
2008									
Before planting	*7.17*	*6.35*	*620.0*	*11.8*	*70.1*	*62.1*	*73.6*	*140.3*	*1734*
Control	7.27	6.52	323.0	0.4	9.5	7.5	59.3	93.4	2249
PLA	7.52	6.66	186.5	1.1	6.6	6.6	82.6	96.9	1773
2009									
Before planting	*6.29*	*5.82*	*421.3*	*30.0*	*91.0*	*48.9*	*95*	*128*	*1097*
Control	6.87	6.02	232.7	1.7	17.3	35.2	115	104	1313
PLA	6.90	5.96	87.6	1.6	9.5	31.8	69	142	1262
Bionolle	6.93	6.01	91.5	2.8	10.5	36.2	71	124	1167
2010									
Before planting	*7.02*	*6.13*	*67.3*	*0.76*	*6.90*	*40.5*	*86.0*	*116.0*	*1075*
Control	7.19	6.15	182.0	1.39	4.80	31.4	83.3	129.8	1117
PLA	7.28	5.88	91.0	0.84	9.00	39.5	89.2	137.0	1204
Bionolle	7.18	6.02	110.0	0.91	6.50	36.3	94.6	125.0	1027

The most probable explanation of these results is that better plant growth and higher plant biomass in places where moisture and temperature were most favourable (data not presented) resulted in higher nutrient uptake. The benefits of polyethylene mulch to crop production are well documented and include greater root growth and nutrient uptake [11].

The results of the soil chemical analysis demonstrated the low impact of treatments on macro- and microelement concentration measured after tomato and cucumber harvesting.

Mulching is known to contribute to augmenting mineral nutrient availability to enhance nitrification. Mulching creates better biological activates and thus has a consequent beneficial effect on soil fertility [11]. In our study, NH_4-N concentration in tomato soils after harvest ranged from 1.02 to 3.1 mg N for the PLA treatment and from 0.4-1.9 mg N for the bare soils. Nitrate concentration varied between 2.2-6.6 mg NO_3-N for the PLA treatment and 1.5-9.5 mg N for the control soils (Table 6). In 2008-2009, the cucumber plantation soil with PLA and Bionolle treatments had a slightly elevated NH_4-N concentration and lowered NO_3-N content (Table 7). An inverse effect of this was observed in the extremely wet 2010.

Table 8

Micronutrient and heavy metals content [mg · kg^{-1} d.m. of soil] in soil from the tomato plantation covered with biodegradable films, 2008-2010

Treatment	**Zn**	**Cu**	**Mn**	**Fe**	**B**	**Cd**	**Pb**	**Cr**	**Ni**
				2008					
Before planting	*57.2*	*5.88*	*276.5*	*2428*	*1.84*	*1.06*	*33.4*	*1.38*	*2.97*
Control	48.5	5.92	221.8	2347	1.33	0.87	24.9	1.15	3.19
PLA	42.6	4.20	183.2	2356	1.00	0.74	17.9	0.88	3.12
				2009					
Before planting	*42.3*	*5.81*	*182*	*1844*	*1.47*	*0.92*	*25.2*	*1.34*	*2.73*
Control	51.3	5.33	161	1739	2.10	0.96	29.6	1.30	2.61
PLA	48.4	5.67	182	1846	2.57	0.97	30.4	1.43	2.82
				2010					
Before planting	*83.2*	*6.81*	*170.3*	*1467*	*2.67*	*3.53*	*36.5*	*1.04*	*1.96*
Control	74.8	7.80	196.5	1768	2.77	1.06	34.6	1.24	2.24
PLA	66.9	8.45	195.9	1751	2.65	1.02	33.3	1.32	2.30

Table 9

Micronutrient and heavy metals content [mg · kg^{-1} d.m. of soil] in soil from the cucumber plantation covered with biodegradable films, 2009-2011

Treatment	**Zn**	**Cu**	**Mn**	**Fe**	**B**	**Cd**	**Pb**	**Cr**	**Ni**
				2008					
Before planting	*47.8*	*5.12*	*247.4*	*2250*	*1.54*	*0.87*	*27.2*	*1.10*	*3.09*
Control	48.5	5.92	221.8	2347	1.33	0.87	24.9	1.15	3.19
PLA	42.6	4.20	183.2	2356	1.00	0.74	17.9	0.88	3.12
				2009					
Before planting	*42.6*	*5.83*	*184*	*1841*	*1.44*	*0.89*	*24.9*	*1.32*	*2.75*
Control	54.5	7.39	233	1878	2.38	1.03	32.4	1.33	2.82
PLA	61.4	6.70	230	2042	1.81	1.07	33.2	1.42	3.10
Bionolle	51.2	5.94	204	1984	1.64	1.07	31.4	1.38	2.89
				2010					
Before planting	*46.2*	*5.27*	*162.5*	*1459*	*1.63*	*0.98*	*27.1*	*1.22*	*2.66*
Control	46.5	6.28	159.5	1520	1.53	0.99	26.5	1.20	2.60
PLA	47.0	5.75	138.5	1450	1.36	1.00	27.2	1.13	2.76
Bionolle	50.7	6.29	170.2	1619	1.58	0.97	28.6	1.25	2.87

In both tomato and cucumber cropping seasons, plant covering did not affect heavy metal concentration in soils (Tables 8 and 9). Li at al [47] studied the effect of plastic mulching on copper and zinc bioavailability in the soil in Chinese cabbage. Results showed that the mulched field had lower soil pH and SO_4^{2-} contents; however, this did not have a significant effect on the distribution and translocation of Cu, while it did affect Zn.

Conclusions

There is an increasing interest in the use of degradable plastic mulching for protected cultivation. Determining the effects of biodegradable synthetic polymer mulch in crop production with regards to microclimate modification, physical, chemical and biological properties of soil, weed control and pest and disease management requires many studies. Little is known about how biofilm covering affects physical and chemical soil parameters, however soil quality has been of increasing concern in recent years.

The soils in our study had high clay content, neutral or slight alkaline pH, and a high level of available Ca and Mg concentration. These parameters guaranteed a very good soil structure (wet-stable). The obtained results generally showed that biofilm covering with PLA increased the amount of large aggregates and decreased the percentage of the smallest size aggregates in soils in tomato and cucumber cropping, though only in 2009. In the wet year 2010, the inverse effect was observed. The Bionolle treatment in the cucumber plantation also increased large aggregates in both 2009 and 2010. During wet conditions, mulching increased bulk soil density and decreased soil water capacity in the cucumber field.

It should be emphasised that the obtained results were very dependent on weather conditions. This study only addressed arable silty clay soil managed conventionally using typical crop rotation, tillage machinery and levels of vehicular traffic. We observed a slight tendency to encourage some physical soil parameters with biofilm treatments. The investigation should be carry out in different soils and climatic conditions. As stated elsewhere, individual soils may differ significantly in behaviour from typical values and trends.

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WPŁYW MULCZOWANIA Z WYKORZYSTANIEM WŁÓKNIN BIODEGRADOWALYCH NA JAKOŚĆ GLEBY W UPRAWIE WARZYW CIEPŁOLUBNYCH

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Abstrakt: Mulcze z tworzyw sztucznych tworzą fizyczną barierę dla parowania wody, pozwalają zachować dobrą strukturę gleby, kontrować zachwaszczenie oraz chronią rośliny przed zanieczyszczeniami glebowymi. Usuwanie i unieszkodliwianie po zbiorach odpadów z tworzyw sztucznych nienadających się do recyklingu i niepodlegających degradacji jest trudne i kosztowne. W ostatnich latach stosowanie alternatywnych włóknin biodegradowalnych jako mulczy lub okryć w uprawie roślin cieszy się coraz większym zainteresowaniem. Praca jest prezentacją wyników dotyczących właściwości fizycznych i chemicznych gleb mulczowanych biodegradowalnymi włókninami. W badaniach oceniano zmiany niektórych fizycznych właściwości gleby, takich jak: gęstość objętościowa, pojemność wodna i wodoodporność agregatów glebowych po uprawie pomidora i ogórka. Do ściółkowania gleby wykorzystano włókninę PLA (polilaktyd) i Bionolle (poliester butylenu, alifatycznego glikolu, kwasu bursztynowego i adypinowego). Chemiczne właściwości gleby oceniano, oznaczając w nich odczyn, stężenie soli, zawartość węgla organicznego, dostępne dla roślin składniki pokarmowe oraz zawartość metali ciężkich. Okrywanie powierzchni gleby włókninami z polimerów biodegradowalnych wpłynęło korzystnie na strukturę gleby. Biowłókniny PLA i Bionolle zwiększały ilość makroagregatów wodoodpornych, a zmniejszały odsetek najmniejszych agregatów w glebie, jednak obserwowane zmiany były silnie modyfikowane poprzez warunki atmosferyczne w poszczególnych latach prowadzenia badań. W bardzo mokrym roku okrywanie gleby zwiększało jej gęstość objętościową oraz zmniejszało pojemność wodną. Mulczowanie gleby z użyciem biodegradowalnych włóknin nie wpływało znacząco na zawartość składników pokarmowych i metali ciężkich w glebie. Obserwowano nieznaczny spadek EC w glebach pod ściółkami w porównaniu do gleby nieokrywanej.

Słowa kluczowe: biowłókniny, gęstość objętościowa, agregaty wodoodporne, materia organiczna, pomidor, ogórek