https://doi.org/10.17221/754/2018-PSE

Early potato cultivation using synthetic and biodegradable covers

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Citation: Kołodziejczyk M., Oleksy A., Kulig B., Lepiarczyk A. (2019): Early potato cultivation using synthetic and biodegradable covers. Plant Soil Environ., 65: 97–103.

Abstract: The cultivation of plants under the covers made of synthetic polymers brings many benefits, however, it is associated with the need to utilize or recycle these materials after the period of their use. Such problems are not caused by the covers made of natural polymers. The aim of the study carried out in the years 2013–2014 was to determine an effect of covers made of biopolymers and synthetic polymers on thermal conditions and potato yield. Field study was carried out under sandy loam and silty clay loam soils conditions. The temperature of silty clay loam soil under the covers was on average by 2.9°C higher than in the unprotected area, whereas sandy loam soil had the temperature higher by 2.5°C under biodegradable foil and by 2.7°C under standard foil. Temperature increase under non-woven fabrics was lower than under foils. The highest increase in marketable tuber yield after 40 days from emergence and in full maturity of potato plants was found after at application of standard non-woven fabric P17 (7.2 and 7.4 t/ha, respectively) and the lowest, i.e., 3.0 and 3.4 t/ha, respectively, under biodegradable foil. Cover type had no effect on the number of tubers formed on the first harvest date, whereas a significantly higher number of tubers was recorded in the full maturity of plants in the year characterized by a longer growing period of potato under non-woven P17 on sandy loam soil, and under biodegradable foil on silty clay loam soil conditions. A significant influence of cover on the average tuber weight on the first harvest date was found only on sandy loam soil under non-woven fabrics in 2013, as compared to full maturity of plants under biodegradable covers on sandy loam soil in 2013 and on silty clay loam soil under all covers in 2014.

Keywords: *Solanum tuberosum* L.; tuber yield structure; soil temperature under covers; tuberous crop; polymeric materials

Profitability of early potato production is determined by obtaining and introducing into the market the earliest possible commercial yield of tubers (Wadas and Sawicki 2009). However, potato cultivation for early harvest is burdened with a significant risk resulting, inter alia, from the possibility of frost occurrence in the initial period of plant vegetation. Large temperature drops damage the aboveground parts of the potato plants, causing the postponement of the harvest to the period of sharp drops in prices due to the increased supply of tubers. The covers, including agro-textile fabrics or perforated plastic foils, are used in order to minimize this risk and speed up the harvest (Wadas 2016). These covers provide protection not only against short-term temperature drops even to –5°C, but also against other adverse meteorological phenomena (Bhullar 2012). The use of covers in early potato production in agro-meteorological conditions of the Central and Eastern Europe enables early planting, accelerates the emergence by 2 to 8 days and the development of plants in the later period (Demmler 1998, Hamouz et al. 2006, Wadas and Kosterna 2007, Cholakov and Nacheva 2009). This results in an increase in the total and marketable yield of tubers. An effect of the applied cover on the yield increase depends on the type of soil, weather conditions, cultivar, as well as the date of planting and harvest. As presented

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in the literature increases in total tuber yields of very early potato cultivars harvested 60 days after planting in Poland may reach even 80% (Wadas et al. 2008). However, the effectiveness of covers application expressed by an increase in tuber yield compared to non-covered objects ranges in most cases from 30% to 50% (Wadas et al. 2001, Hamouz et al. 2006, 2007, Cholakov and Nacheva 2009). In turn, the study by Rębarz et al. (2015) proved that the use of covers in some years may have an unfavourable impact on potato yielding. The change in the initial conditions of plant growth as a result of the use of covers affects the chemical composition of the tubers and thus their quality. In the opinion of Dvořák et al. (2006) and Rębarz et al. (2015), an accelerated development of plants under covers is conducive to dry matter accumulation in potato tubers. Sawicka and Pszczółkowski (2005) disagree, and they believe that the use of covers creates less favourable conditions for dry matter accumulation.

The use of synthetic covers in potato, vegetable and soft fruit cultivation brings many benefits, however, it may cause environmental pollution and involves the need to utilize or recycle these materials after their application. Such problems are not created by environmentally friendly foils and non-woven fabrics made of a natural polymer such as vegetable starch. Biodegradation of such materials is possible due to the presence of microorganisms; enzymes cause the mineralization of the biodegradable polymer to carbon dioxide and/or methane, water and biomass (Kyrikou and Briassoulis 2007). The use of such materials is practiced in many countries and also recommended by the International Federation of Organic Agriculture Movement (Filippi et al. 2011).

The aim of the study was to determine an effect of covers made of biopolymers and synthetic polymers on the formation of thermal conditions in the initial period of potato development as well as the size and structure of tuber yield.

MATERIAL AND METHODS

A field study was carried out in the years 2013–2014 in the Experimental Stations of the Agricultural University in Krakow, located in Mydlniki (50°08'N and 19°85'E) on the soil classified according to WBR FAO (2014) as Haplic Cambisol and in Prusy (50°08'N and 19°85'E) under conditions of Haplic Chernozem. Soil in Mydlniki had 71% sand, 18% silt, 11% clay, pH 5.9 and contained the following available nutrients: 81.7 mg P/kg, 116.7 mg K/kg, 64.0 mg Mg/kg. In the further part of the work, this soil will be described as sandy loam soil. Soil in Prusy was characterized by the content of 12% sand, 54% silt, 34% clay, pH 6.0 and contained available nutrients in the amounts as follows: 57.3 mg P/kg, 141.0 mg K/kg, 119.0 mg Mg/kg. In the further part of the work this soil will be described as silty clay loam soil.

The experimental factor was the type of cover used in very early potato cultivation. The following materials were used: standard polypropylene non-woven Pegas Agro P17 (17 g/m^2, producer Agrimpex, Jarosław, Poland), biodegradable non-woven produced on the basis of oil plants biomass at the Institute of Biopolymers and Chemical Fibers in Łódź (75 g/m^2), standard perforated foil (100% LDPE (low-density polyethylene), 100 holes ø 10 mm per 1 m^2, thickness 40 µm, producer Butimex, Rybnik, Poland) and perforated biodegradable foil produced from biopolymers at the Central Mining Institute in Katowice (100 holes ø 10 mm per 1 m^2, thickness 65 µm). The experiment was carried out in a system of random blocks in 4 repetitions. The size of experimental plots for harvest was 10 m^2. Before planting, mineral fertilization of 90.0 kg N, 39.3 kg P and 112.5 kg K/ha was applied. A very early cultivar of table potato Denar was used for the evaluation. The previous crop for potato on sandy loam soil was triticale, and on silty clay loam soil it was wheat. The germinated tubers were planted by hand on 18 April 2013 and 14 March 2014 with the spacing of 62.5 × 30.0 cm. The planting date in 2013 was delayed by 3–4 weeks compared to the optimal date for this region of Poland due to the long-standing snow cover. Before covering the plants, a clomazone (96 g a.i. (active ingredient)/ha) was used to reduce weed infestation. The covers were left on the plants until 20 May 2013 and 25 April 2014. During this period, the soil temperature at a depth of 10 cm was recorded continuously using an automatic temperature and humidity recorder ST-171 (Nashua, USA).

Harvesting was carried out 40 days after the emergence (1st date) and in full maturity of potato plants (2nd date). Before potato harvesting, the tuber samples were collected from 10 plants in order to determine the average tuber weight and the number of tubers per plant. The marketable fraction consisted of tubers with a transverse diameter above 28 mm on the first harvest date and above 35 mm on the second harvest date. The marketable yield of tubers was estimated on the basis of the share of marketable tuber frac-

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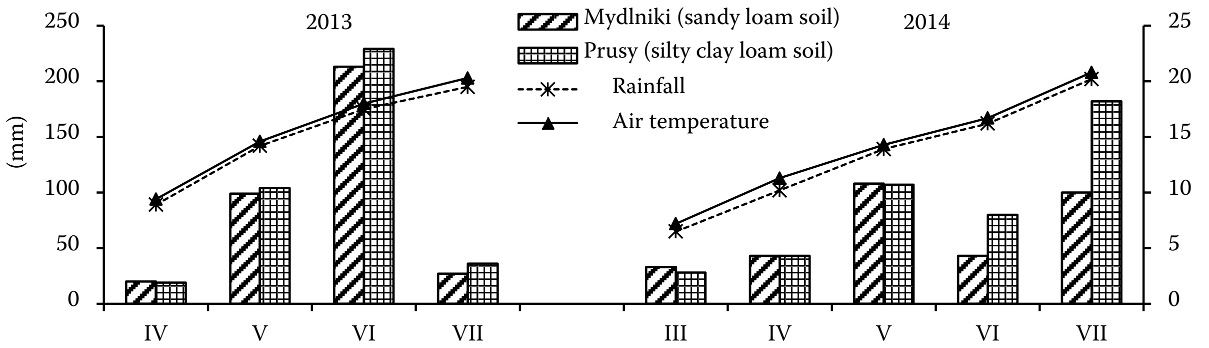

Figure 1. Rainfall and air temperature during the research period

tions, separating greenish tubers, those infected by diseases and deformed to a severe degree. The obtained results were statistically evaluated by an analysis of variance. Honestly significant difference for the examined traits was verified with the Tukey's test at the significance level of $P < 0.05$.

The course of weather conditions in particular years of the study and in particular localities was differentiated (Figure 1). Potato vegetation period in 2013 (April–July) was shorter than in 2014 (March–July) but was characterized by a higher average air temperature, especially in May and June. Regardless of the research period, potato cultivation on silty clay loam soil (Prusy) took place under conditions of higher rainfall and higher air temperature, by 29 and 114 mm and 0.6°C and 0.7°C, respectively, than on sandy loam soil (Mydlniki). Unfavourable humidity conditions resulting from low rainfall were recorded in April and July 2013 in both localities and in June 2014 in conditions of potato cultivation on sandy loam soil.

RESULTS AND DISCUSSION

The largest transmission for PAR (photosynthetically active radiation) was demonstrated for standard perforated foil (Table 1). It amounted to 87.5% and was by 15.5% higher than standard non-woven fabric, by 22.4% higher than biodegradable foil and 27.7% higher than biodegradable non-woven fabric, which was characterized by the lowest radiation permeability in this range. Gimenez et al. (2002) showed that the radiation transmission through the cover can be reduced by up to 20% compared to the beginning of the cultivation cycle as a result of water vapour condensation on the inner surface of the cover or dust pollution. Therefore, in years with favourable thermal conditions, the cover should not be left upon the plants for too long, since worse light conditions have an adverse effect on the formation of plants assimilation surface (Wadas et al. 2009).

The average daily temperature of sandy loam soil not covered during the application of covers in 2013 was 16.5°C, whereas that of silty clay loam soil was 13.5°C (Figure 2). The highest rises in soil temperatures as a result of covers application were observed on objects covered with foils (Figure 3). Average daily temperature increase of sandy loam soil under biodegradable foil ranged from 0.4°C to 5.2°C, and under standard foil from 0.3°C to 5.1°C. A wider range of temperature increase was found in silty clay loam soil conditions, 0.1–5.8°C and 0.2–5.2°C, respectively. Thermal conditions under non-woven fabrics were worse but more stable than under the foils. The temperature of sandy loam soil under non-woven fabrics was on average by 0.6°C (0.0–1.6°C) higher compared to unprotected plots, whereas on silty clay loam soil it was by 0.8°C (0.0–1.8°C) higher under biodegradable non-woven fabric and by 1.1 (0.1–2.3°C) under standard non-woven fabric, respectively. In 2014, the average daily temperature of sandy loam soil in unprotected area was 10.6°C, and in case of silty clay loam soil it was 9.8°C. The application of covers increased the temperature of sandy loam soil by 2.4°C under biodegradable foil and by 2.8°C under standard foil, while on silty clay loam soil by 3.0°C and 3.7°C, respectively (Figure 4). Soil temperature under non-woven fabrics in 2014,

Table 1. Mean PAR (photosynthetically active radiation) transmission under covers (%)

Type of cover	PAR transmission
Biodegradable foil	65.1
Standard foil	87.5
Biodegradable non-woven	59.8
Standard non-woven P17	72.0

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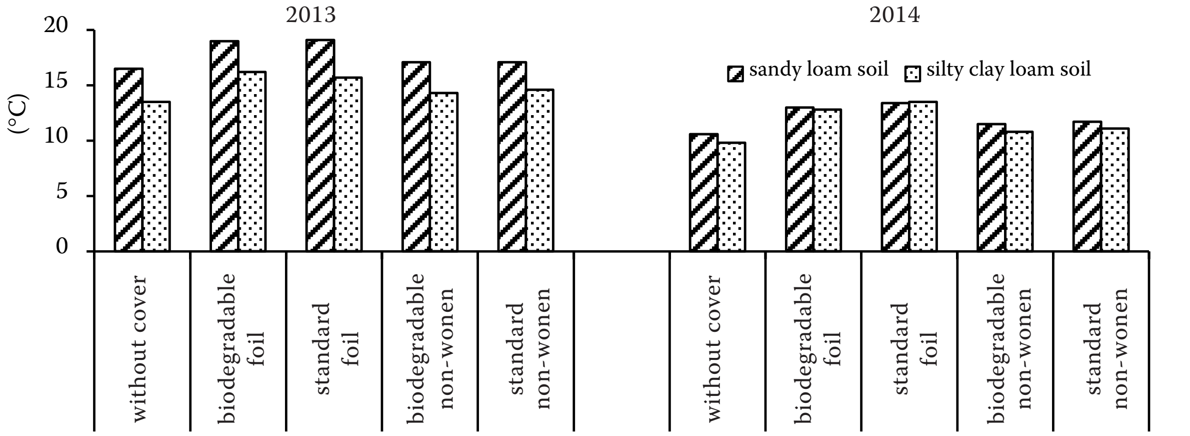

Figure 2. Soil temperature at a depth of 10 cm during the use of covers

similarly as in 2013, was lower than under the foils. The average temperature increase of sandy loam soil under biodegradable non-woven fabric was 0.8°C, and under standard non-woven fabric it was 1.1°C, whereas under silty clay loam soil conditions the temperature increases were 1.8°C and 2.3°C, respectively. The studies carried out in Germany, Czech Republic and Poland showed that soil temperature at the depth of 10 cm under polypropylene non-woven fabric is by 2–3°C higher than in unprotected area, and under perforated foil by 1–2°C higher than under non-woven fabric, which causes that the emergence is 1–2 days earlier (Demmler 1998, Hamouz et al. 2006, Wadas and Kosterna 2007).

The marketable yield of potato tubers harvested after 40 days from emergence ranged from 10.1 to 35.6 t/ha depending on the type of cover, soil conditions and year of harvesting (Figure 5a). In the two-year study cycle, potatoes cultivated in silty clay loam soil conditions were characterized by a higher tuber yield, on average by 1.8 t/ha. Differences in the yield were particularly visible on uncovered objects, 4.2 t/ha in 2013 and 2.3 t/ha in 2014, respectively. However, despite worse yields, higher increases in marketable tuber yield after cover in application sandy loam soil conditions (3.4–9.0 t/ha) were found compared to silty clay loam soil (3.8–7.5 t/ha). Regardless of soil conditions, the use of non-woven fabrics compared

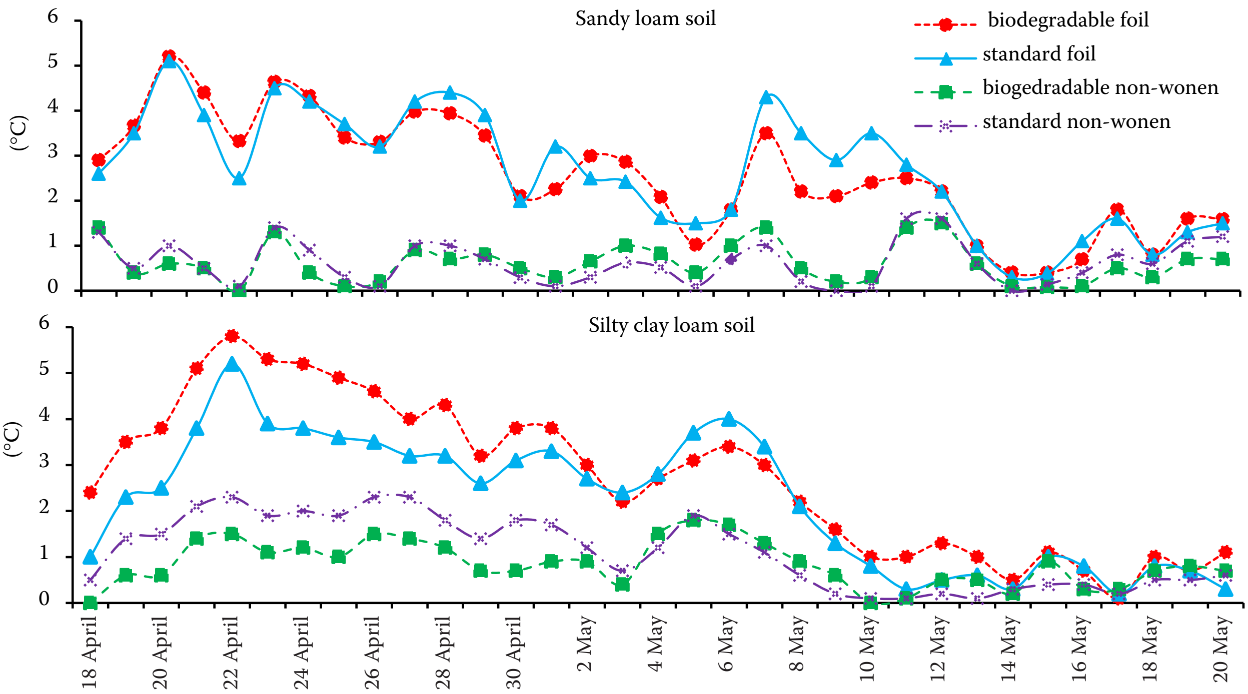

Figure 3. Differences in the mean daily soil temperature between the site without a cover and the covers used in 2013

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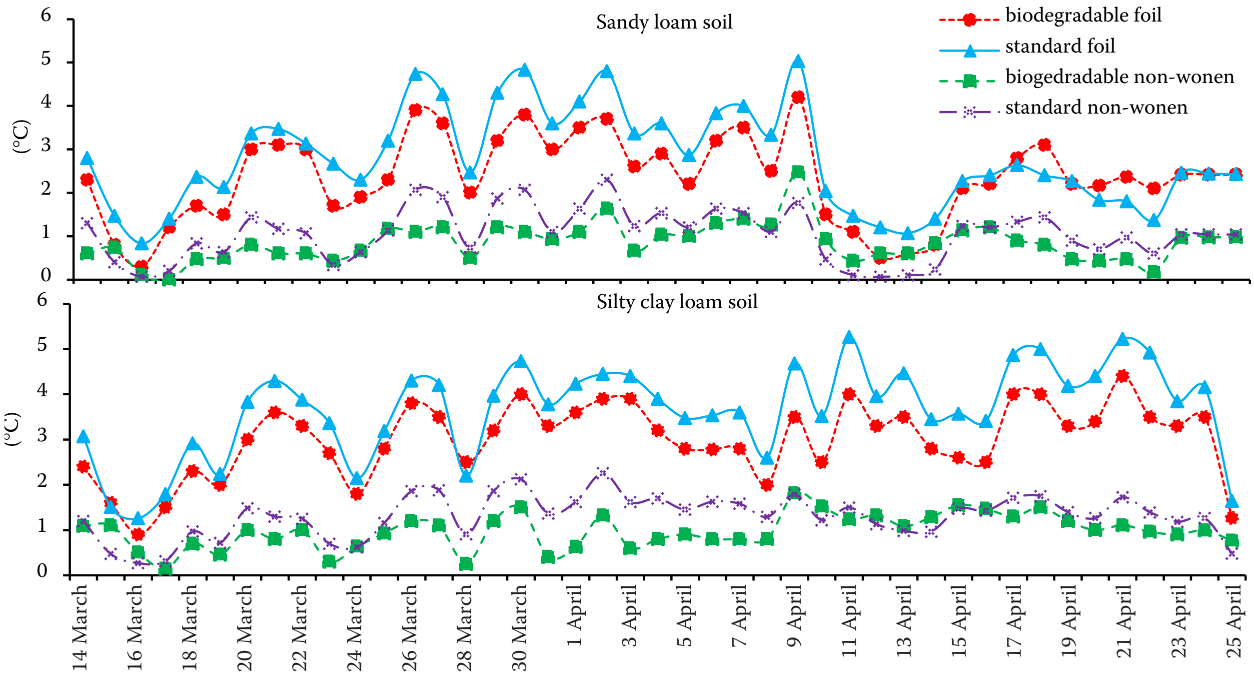

Figure 4. Differences in the mean daily soil temperature between the site without a cover and the covers used in 2014

to foil, especially standard non-woven fabric P17, turned out to be more beneficial for potato yielding in cultivation for a very early harvest. Moreover, the study showed higher productivity of plants covered with standard foil compared to biodegradable one. Differences in potato yields under covers made of synthetic polymers and biopolymers may be related to radiation permeability. Less transmission for PAR of biodegradable covers creates worse light conditions for plants in the potato emergence period.

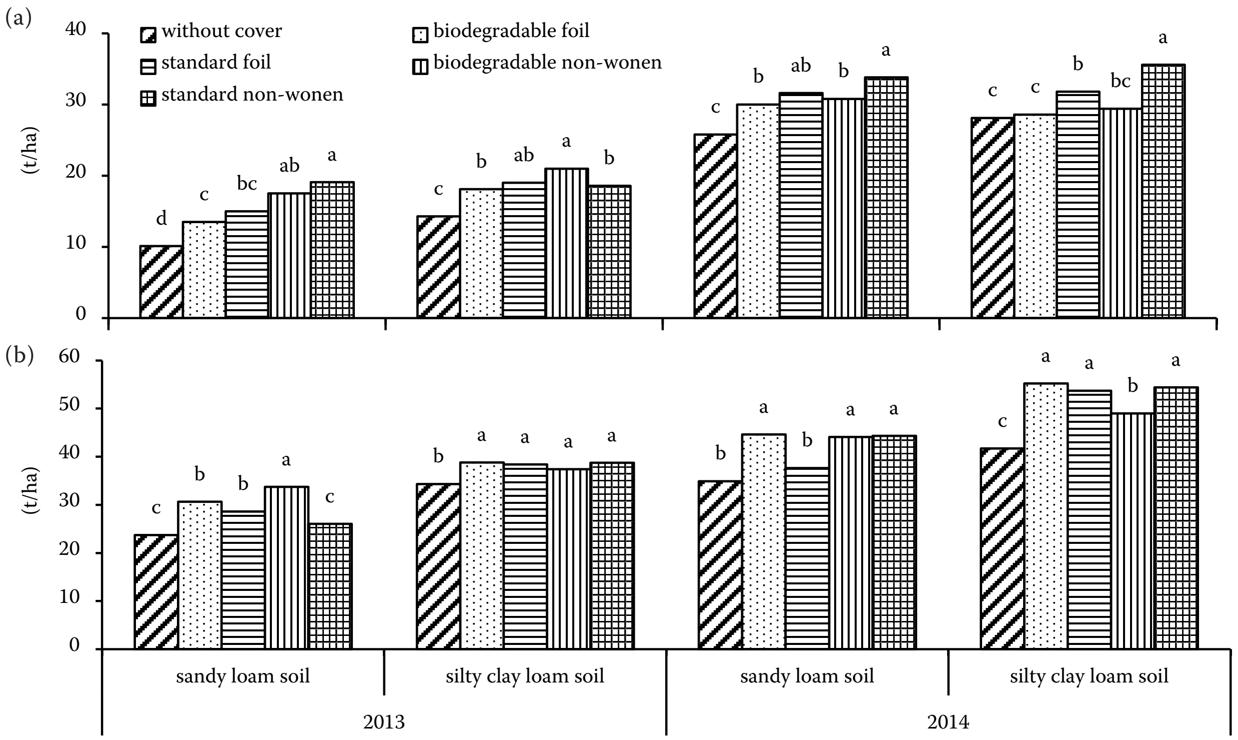

Figure 5. Marketable yield of tubers at (a) the 1st harvesting date (40 days from emergence) and (b) the 2nd harvesting date (in full maturity). Different letters within a column denote *HSD* (honestly significant difference) at $P < 0.05$

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Cover application also significantly differentiated the marketable yield of tubers harvested at full maturity of potato plants (Figure 5b). Under sandy loam soil conditions in 2013, the marketable yield on the control object – without the cover – was 23.7 t/ha on average, while on silty clay loam soil it was 34.3 t/ha. An increase in tuber yield of objects in which cover was applied under sandy loam soil conditions ranged from 2.3 t/ha under non-woven fabric P17 to 10.0 t/ha under non-woven biodegradable fabric, while on silty clay loam soil from 3.1 t/ha under non-woven biodegradable fabric to 4.5 t/ha under biodegradable foil. In 2014, more favourable for potato yielding due to, inter alia, longer vegetation period in relation to the control, an increase in marketable tuber yield ranged from 2.7 t/ha under standard foil to 9.7 t/ha under biodegradable foil under sandy loam soil conditions, and from 7.3 t/ha under biodegradable non-woven fabric to 13.5 t/ha under biodegradable foil in silty clay loam soil conditions, respectively, compared to the control. A higher increase in tuber yield as a result of covers application was obtained in years with less favourable thermal conditions in the initial period of potato development. Literature reports show that in the conditions of cold spring it is possible to obtain four or even six times higher yield of tubers after 60 days from planting under cover compared to an exposed area (Dvořák et al. 2004, Hamouz et al. 2005, Wadas et al. 2008). In our study carried out in various thermal conditions determining the date of planting in particular years, an increase in the marketable yield of tubers after 40 days from emergency ranged from 0.5 to 9.0 t/ha (2–89%) and depended on the locality and type of cover. It can be concluded from the studies of Hamouz et al. (2005) and Rębarz et al. (2015) that the effect of cover application is the highest at a very early stage of harvest and decreases to an insignificant level at the end of vegetation. The study conducted did not confirm this relation, as the increase in tuber yield at full maturity of plants was at a higher level than in the first harvest time and ranged from 2.3 to 13.5 t/ha.

An increase in potato tuber yield is a result of an increase in the average tuber weight and the number of developed tubers (Galarreta et al. 2006, Kołodziejczyk 2014). Knowledge of relations between the yield components is an important issue in potato cultivation, especially in relation to habitat conditions, agrotechnology and cultivar-related properties of the plants. In the study presented, there was no significant influence of the type of cover and year of the study on the number of tubers in the first harvest date, whereas in the full maturity of plants, a significantly higher number of tubers was recorded in 2014 under the P17 non-woven fabric on sandy loam soil and under the biodegradable foil under the conditions of silty clay loam soil (Table 2).

Table 2. Number of tubers per plant and average weight of the tuber

Type of cover	1st harvest date				2nd harvest date			
	sandy loam soil		silty clay loam soil		sandy loam soil		silty clay loam soil	
	2013	2014	2013	2014	2013	2014	2013	2014
Number of tubers per plant (pcs.)								
Without cover	7.8^a	11.0^a	11.2^a	15.2^a	9.4^a	11.6^b	14.3^a	13.4^b
Biodegradable foil	8.7^a	11.3^a	11.5^a	15.6^a	10.1^a	12.4^{ab}	14.3^a	14.8^a
Standard foil	8.7^a	11.7^a	11.5^a	15.1^a	10.0^a	11.9^{ab}	14.1^a	14.0^{ab}
Biodegradable non-woven	8.2^a	11.3^a	11.3^a	15.0^a	10.5^a	12.4^{ab}	15.1^a	13.9^{ab}
Standard non-woven	8.9^a	11.7^a	11.2^a	15.4^a	10.0^a	12.9^a	14.7^a	14.5^{ab}
Mean	9.9^b		13.3^a		11.1^b		14.3^a	
Average weight of the tuber (g)								
Without cover	35^b	55^a	33^b	43^a	52^c	70^a	58^a	68^b
Biodegradable foil	40^{ab}	61^a	42^{ab}	45^a	63^{ab}	73^a	58^a	78^a
Standard foil	43^{ab}	60^a	41^{ab}	48^a	60^{bc}	71^a	57^a	78^a
Biodegradable non-woven	48^a	60^a	44^a	47^a	67^a	73^a	61^a	74^a
Standard non-woven	49^a	64^a	42^{ab}	53^a	58^{bc}	73^a	59^a	78^a
Mean	52^a		44^b		66^a		67^a	

Different letters within a column denote *HSD* (honestly significant difference) at $P < 0.05$

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Higher number of tubers was formed by potato plants on silty clay loam soil compared to sandy loam soil. In the two-year research cycle, more favourable weather conditions for tuber formation occurred in 2014, characterized by a longer period of potato vegetation. In 2013, due to the delayed planting date, high air temperature and high rainfall in June, the number of tubers in the second harvest date was significantly higher than in the first one, especially in silty clay loam soil conditions. Although the use of cover in potato cultivation caused an increase in the average tuber weight, significant differences in the first harvest date were noted only in 2013 after the use of biodegradable and standard non-woven fabric under sandy loam soil conditions (Table 2). An effect of the cover on the average tuber weight at full maturity of plants was observed in 2013 on sandy loam soil under biodegradable covers and in 2014 on silty clay loam soil under all covers. Different results were demonstrated by Wadas et al. (2008), who in the conditions of potato cultivation on sandy loam soil found a higher average weight of tuber under cover made of foil than from non-woven fabric. On the other hand, the study conducted by Rębarz et al. (2015) in the conditions of lessive soil demonstrated that the use of perforated foil resulted in a decrease in the share of tubers with a diameter of more than 45 mm in relation to objects covered with non-woven fabric.

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Received on November 20, 2018
Accepted on January 3, 2019
Published online on January 29, 2019