Using non-woven polypropylene covers in potato production: a review

Wykorzystanie osłon z włókniny polipropylenowej w produkcji ziemniaków – praca przeglądowa

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Abstract

This paper analyzes the effect of non-woven polypropylene covers on plant growth and development, frost protection, tuber yield and quality and the economic effectiveness in early potato production. A high income from early potato production is possible under conditions assuring early setting and rapid gain of tuber yield and its marketing when the price is highest. The application of non-woven polypropylene covers accelerates plant emergence by 2-8 days and the growth and development of plants in the later period, and results in an earlier new potato harvest by up to 2-3 weeks. It also increases the tuber yield and reduces the yield variability in all years. Accelerating plant growth using non-woven polypropylene covers affects not only tuber yield quantity, but also contributes to improvement of the tuber quality, especially by an increase in dry matter, potassium and phosphorus content of tubers and decrease nitrate concentration. Such a method of potato production requires higher incurred input. Increasing the production inputs is effective when the value of the tuber yield increase obtained as a result of plant covering is higher than the costs incurred. A higher productive effect of covering is usually obtained in years with a cold spring and a very early potato harvest date. A considerable tuber yield increase in cultivation under non-woven polypropylene cover results in decreased unit costs and, consequently, the cost-effectiveness of production is higher than without covering. In conditions favouring rapid potato growth, the production costs of 1 kg tuber under cover are higher, which makes production less profitable than cultivation without plant covering.

Keywords: cost-effectiveness, early potato, non-woven polypropylene, plant growth and development, tuber quality, tuber yield

Streszczenie

W pracy omówiono wpływ osłon z włókniny polipropylenowej na wzrost i rozwój roślin, ochronę przed przymrozkami, plon i jakość bulw oraz efekty ekonomiczne w produkcji ziemniaków wczesnych. Uzyskanie wysokiego dochodu z produkcji ziemniaków wczesnych jest możliwe w warunkach zapewniających wczesne zawiązywanie i szybki przyrost bulw, i sprzedaż w okresie, gdy cena jest najwyższa. Zastosowanie osłon z włókniny polipropylenowej przyspiesza wschody roślin o 2-8 dni oraz wzrost i rozwój roślin w późniejszym okresie, i w efekcie powoduje przyspieszenie zbioru młodych ziemniaków o 2-3 tygodnie, zwiększenie plonu i mniejszą zmienność plonu w latach. Przyspieszenie wzrostu roślin przez zastosowanie osłon z włókniny polipropylenowej wpływa nie tylko na wielkość plonu, ale także przyczynia się do poprawy jakości bulw, szczególnie przez zwiększenie zawartości suchej masy, potasu i fosforu w bulwach oraz zmniejszenie zawartości azotanów (V). Taka metoda produkcji ziemniaków wymaga poniesienia większych nakładów. Zwiększanie nakładów na produkcję jest efektywne, jeżeli wartość plonu bulw uzyskanego w wyniku stosowania osłony jest większa niż poniesione koszty. Wysokie efekty produkcyjne stosowania osłony uzyskiwane są zwykle w latach o zimnej wiośnie i bardzo wczesnym terminie zbioru ziemniaków. Znaczny przyrost plonu w uprawie pod osłoną z włókniny polipropylenowej powoduje zmniejszenie kosztów jednostkowych i w efekcie opłacalność produkcji jest większa niż bez osłony. W warunkach sprzyjających szybkiemu wzrostowi roślin ziemniaka, koszty produkcji 1 kg bulw pod osłoną są większe, co czyni produkcję mniej opłacalną niż uprawa bez osłaniania roślin.

Słowa kluczowe: jakość bulw, opłacalność produkcji, plon bulw, włóknina polipropylenowa, wzrost i rozwój roślin, ziemniaki wczesne

Introduction

Potato (*Solanum tuberosum* L.) is a very important crop in the world, both for consumption as a fresh product and for the processing industry. Potatoes play an important role in human nutrition (Camire et al., 2009; Ezekiel et al., 2013; Leszczyński, 2012). The production profitability of edible potatoes for early harvest is higher compared with other uses. The growing period for early potatoes is extremely short, only 50-80 days from planting to harvest. To obtain a highly marketable tuber yield in such a short period, besides the proper selection of very early-maturing cultivar and pre-sprouted seed potatoes, good conditions for plant growth must be ensured (Chotkowski et al., 1995).

The success of potato production for an early crop is dependent to a great extent on the weather conditions in the initial period of plants growth, especially temperature (Nishibe et al., 1989). Too low soil temperature retards the emergence and inhibits the initial plant growth. Pre-sprouting seed-potatoes can be planted when the soil temperature at a depth of 5-10 cm is maintained at the level of 5-6 °C for several subsequent days. Earlier planting into insufficiently heated soil is risky, since even

short, but excessive, over-cooling of young plants strongly weakens their further growth and delays obtaining marketable yield. High income obtained from early potato production is possible under conditions assuring early setting and rapid gain of tuber yield, and its marketing when the price is highest. Early potato production must be located in regions were vegetation begins early (Chotkowski et al., 1995). In the regions with delayed vegetation, new potato crops could enhance using row covers.

Row covers are generally made of flexible transparent or semi-transparent materials and are used to enclose one or more rows of plants in order to enhance crop growth and production by increasing both air and soil temperatures and reducing wind damage (Hamamoto, 1996; Hochmuth et al., 2015; Otto et al., 2000). The row covers provide the same function as low tunnels. The covering is generally either perforated polyethylene film or non-woven polypropylene because it needs to be lightweight, permeable and airy, but the level of crop protection is different. Polypropylene covers were introduced into agriculture on a large scale in the 1990s. Globally, they are commonly known as non-woven fabric (Cholakov and Nacheva, 2009). Non-woven fabric has several other names: non-woven fleece, non-woven polypropylene, polypropylene fleece, polypropylene film, polypropylene sheeting cover, spun-bonded polypropylene, floating row cover or agrotextile (Olle and Bender, 2010). Polypropylene cover typically weighs 17-23 $g*m^{-2}$ and several rolls of material may by joined with adhesive to give a total width of up to 16 m. Since the weight of 1 m^2 of non-woven polypropylene fabric is about 2.5 times lower than the weight of perforated polyethylene film, the covering does not hinder plant development. The polypropylene cover is generally several meters wide and is laid very loosely directly on the planted field and held down along the edges with fabric pins and/or soil. The covering will then float in the wind and expand as plants grow, hence the other name of a "floating cover". The application of polypropylene covers enables earlier potato planting, accelerates plant emergence and the growth and development of plants in the later period and, consequently, results in earlier setting of tubers, rapid yield gain and reduces the yield variability in all years (Cholakov and Nacheva, 2009; Dvořák et al., 2004; Hamouz et al., 2006; Wadas and Kosterna, 2007b).

Plant growth and development

Profitable yield of new potatoes 60 days after planting can be obtained when the period between planting and plant emergence lasts 15-21 days, with 19-24 days from plant emergence to the end of tuber seeding, and the period of yield accumulation lasts a minimum 20 days (Kubiak and Gaziński, 1996). The application of non-woven polypropylene covers enables earlier potato planting, forcing plant emergence and, in the case of unfavourable thermal conditions, protects emerging plants against ground frosts. An increase in soil temperature as a result of applying non-woven polypropylene cover in early potato cultivation shortened the period between planting and plant emergence by 2-8 days and accelerated the growth and development of plants in the later period. The acceleration of potato plant emergence due to covering depends on the soil type and climatic conditions (Table 1). The application of covering results in greater acceleration of individual plant development phases in years with less favourable meteorological conditions during the initial period of potato growth. A higher increase in soil temperature (by 1-2 °C, on average) under

perforated polyethylene film resulted in earlier occurrence of successive plant development phases by only 1 or 2 days compared to non-woven polypropylene (Ban et al., 2011; Cholakov and Nacheva, 2009; Hamouz et al., 2006; Lutomirska, 1995; Prośba-Białczyk and Mydlarski, 1998; Wadas and Kosterna, 2007a).

Table 1. Acceleration of potato plant emergence using non-woven polypropylene cover

Tabela 1. Przyspieszenie wschodów roślin ziemniaka na skutek stosowania osłon z włókniny polipropylenowej

Country	Region	Number of days
Bulgaria	Plovdiv region	2-7[a]
Croatia	Adriatic region	6[b]
Czech Republic	Central Bohemia	4-8[c]
Poland	central	4-5[d]
	east-central	2-6[e]
	south-western	3-6[f]

[a] Cholakov and Nacheva, 2009; [b] Ban et al., 2011; [c] Hamouz et al., 2006; [d] Lutomirska, 1995; [e] Wadas and Kosterna, 2007a; [f] Prośba-Białczyk and Mydlarski, 1998.

Plants growing under non-woven polypropylene were more uniform in size, and developed a higher, larger mass of above-ground parts compared to cultivation without covering (Cholakov and Nacheva, 2009; Rekowska and Orłowski, 2000; Wadas and Kosterna, 2007b; Wadas et al., 2009). In the agrometeorological conditions of east-central Poland, at the time of cover removal, the plants covered 2 weeks after emergence were, on average, 0.094 m higher, and after a 3-week period of plant covering by 0.117 m higher in comparison to plants cultivated without any covering, while the assimilation leaf areas were 2 and 1.6 times higher, respectively (Table 2). The effect of covering on the assimilation leaf area depends on a high degree on weather conditions. In years with more favourable thermal conditions for early crop potato production, leaving the covering for too late over plants after emergence can hinder the development of the assimilation leaf area, while in the lower temperature, the effect is more favourable (Wadas and Kosterna, 2007b; Wadas et al., 2009). When non-woven polypropylene is removed too late after plant emergence, the transmission of photoactive radiation through this cover varied from 85-65%, depending on dust accumulation on the cover and water vapour condensation on the inner surface of the cover (Gimenez et al., 2002). A change of conditions in the initial period of plant growth as a result of applying non-woven polypropylene cover could advance a new potato harvest by up to 2-3 weeks compared to cultivation without plant covering (Bizer, 1994; Hamouz et al., 2005; Sawicka and Pszczółkowski, 2002).

Table 2. Effect of using non-woven polypropylene cover on growth of early-maturing potato cultivars (Wadas and Kosterna, 2007b; Wadas et al. 2009)

Tabela 2. Wpływ stosowania osłon z włókniny polipropylenowej na wzrost wczesnych odmian ziemniaka (Wadas and Kosterna, 2007b; Wadas et al. 2009)

Specification	Weeks after emergence	Non-covered	Under non-woven polypropylene
Plant height (m)	2	0.177	0.271
	3	0.220	0.337
Weight of leaves (kg)	2	0.031	0.057
	3	0.052	0.077
Weight of stems (kg)	2	0.020	0.047
	3	0.033	0.071
Assimilation leaf area (m^2)	2	0.0918	0.1867
	3	0.1632	0.665
Leaf area index (LAI)	2	0.49	0.99
	3	0.87	1.42

Frost protection

The use of the covers with non-woven polypropylene in potato cultivation provides effective protection from low temperature and frost and significantly reduces plant damage (Bhullar, 2012). A non-woven polypropylene cover creates a favourable microclimate for potato emergence and growth, even when the ground temperature drops to -7 °C. According to Bizer (1997) and Dvořák et al. (2004) soil temperature at a depth of 10 cm was 3 °C higher compared to the uncovered field.

The increase in soil and air temperatures under cover during daytime depends on the soil type and climatic conditions. A study carried out in the Czech Republic, Germany and Poland showed that soil temperature at a depth of 5 cm under non-woven polypropylene was higher by 1-2 °C, and at the depth of 10 cm by 2-3 °C than the temperature of uncovered soil, while the air temperature at the ground level was higher by 2 °C (Demmler, 1998; Hamouz et al., 2006; Lutomirska and Szutkowska, 1999; Prośba-Białczyk and Mydlarski, 1998; Wadas and Kosterna, 2007a). Soil temperature under non-woven polypropylene was, on average, 1-2 °C lower than under perforated polyethylene film. The difference in temperatures in afternoon hours was up to 5 °C (Wadas and Kosterna, 2007a). In Bulgaria, soil temperature at a depth of 5 cm under non-woven polypropylene at 8:00 a.m. was higher by 0.4-2.4 °C in comparison to the uncovered soil, and at 2:00 p.m. on sunny days, up to 4.6 °C (Cholakov and Nacheva, 2009). Higher soil temperature, as well as isolation by means of the non-woven polypropylene cover from a relative drop in air temperature

at night creates a more favourable microclimate for plant growth. With the use of covers, potato planting can be started when the soil temperature at the depth of 10 cm is about 3-4 °C (Bizer, 1994; Lutomirska, 2006).

Weed management, diseases and pest control

Non-woven polypropylene covers not only enhance crop development, but also promotes weed growth and development. Pre-plant herbicide should be used prior application of the covers. The use of covers can enhance the development of phytotoxic symptoms of herbicides in potato plants, but with plant growth these symptoms gradually disappears (Pszczółkowski, 2003; Pytlarz-Kozicka, 2011).

Covers applied in early potato cultivation can contribute to a faster rate of *Phytophthora infestans* and *Alternaria solani* spreading on plants. Higher soil moisture under cover can contribute to a decrease in tubers infected with *Streptomyces scabies* and *Rhizoctonia solani*. According to Pszczółkowski and Sawicka (1998) and Masheva et al. (2012) the non-woven polypropylene covers protect potato plants from the Colorado potato beetle *Leptinotarsa decemlineata*.

Tuber yield

Total and marketable yield of potato are higher when using non-woven polypropylene covers in comparison to non-covered plants. The effect of applied cover on the potato yield increase depends on soil type, climatic conditions, cultivar, and planting and harvesting date (Table 3).

In conditions of east-central Poland (the Siedlce Region), covering the crop with non-woven polypropylene resulted in an increase in marketable tuber yield (diameter above 30 mm) of very early-maturing potato cultivars, on average, by 4.63 $t*ha^{-1}$ (33%) after 60 days from planting (9-25 June), and by 3.72 $t*ha^{-1}$ (13%) after 75 days from planting (Wadas et al., 2001). A similar increase in the early tuber yield of potato was obtained in the central part of Poland (Lutomirska, 1995). In a later study carried out in east-central Poland (Wadas et al., 2008b), 60 days after planting (9-16 June), the marketable tuber yield of early-maturing potato cultivars using non-woven polypropylene was higher, on average, by up to 5.82 $t*ha^{-1}$ (81%). In south-eastern Poland (the Lublin region), the average tuber yield increase as a result of non-woven polypropylene covering amounted to 7.34 $t*ha^{-1}$ (72%) 60 days after planting (8-15 June) and 5.51 $t*ha^{-1}$ (22.5%) at harvest two weeks later (Pszczółkowski and Sawicka, 1999). According to Rębarz et al. (2015) in conditions of west-central Poland (the Poznań region), plant covering with non-woven polypropylene resulted in an increased marketable yield 60 days after planting (8-9 June), on average, by 1.85 $t*ha^{-1}$ (28%), and 75 days after planting by 2.88 $t*ha^{-1}$ (23%). In north-western Poland (the Szczecin region), 55 days after planting (15 June), the marketable tuber yield of new potatoes in cultivation using non-woven polypropylene was higher, on average, by 9.84 $t*ha^{-1}$ (52%) and 65 days after planting by 7.52 $t*ha^{-1}$ (27%) in comparison to non-covered plants (Rekowska et al., 1999). On the other hand, in south-western Poland (the Wrocław region), plant covering with non-woven polypropylene increased marketable tuber yield of very early-maturing potato

cultivars, on average, by 4.50 t*ha^{-1} (74%) after 60 days from planting (8-15 June), and by 4.70 t*ha^{-1} (30%) when the harvest was carried out two weeks later (Prośba-Białczyk and Mydlarski, 1998). In soil and climatic conditions of the central part of Czech Republic, plant covering with non-woven polypropylene brought about an increase in marketable tuber yield on average by 6.28 t*ha^{-1} (50%) 60 days after planting (28 May-7 June), and by 5.38 t*ha^{-1} (22%) when the harvest was carried out one week later (Hamouz et al., 2006, 2007), while in Adriatic region of Croatia (Ban et al., 2011), the increase in tuber yield 60 days after planting (2-10 June) was 3.70 t*ha^{-1} (12%). In south-eastern Europe (in Bulgaria) the increase in new potato yield as a result of using the non-woven polypropylene cover amounted, on average, to 8.98 t*ha^{-1} (32%) 60 days after plant emergence (5-27 May), and 6.21 t*ha^{-1} (16%) 75 days after plant emergence (Cholakov and Nacheva, 2009). In South Asia (Bhullar, 2012), in the soil and climatic conditions of India's Punjab region, covering the crop with non-woven polypropylene resulted in an increase in total tuber yield 50 days after planting (10 February), on average, by 6.09 t*ha^{-1} (25%) and marketable tuber yield by 9.17 t*ha^{-1} (57%).

Table 3. Effect of using non-woven polypropylene cover on marketable tuber yield of early potato

Tabela 3. Wpływ stosowania osłon z włókniny polipropylenowej na plon handlowy ziemniaków wczesnych

Country	Region	Increase in tuber yield (t*ha^{-1})
Bulgaria	Plovdiv region	1.91-14.31[a]
Croatia	Adriatic region	3.70[b]
Czech Republic	Central Bohemia	1.01-15.66[c]
Poland	east-central	1.19-11.80[d]
	west-central	1.58-3.55[e]
	south-eastern	2.87-9.97[f]
	north-western	6.36-10.04[g]
	south-western	4.00-5.40[h]
India	Punjab region	7.68-10.67[i]

[a] Cholakov and Nacheva, 2009; [b] Ban et al., 2011; [c] Hamouz et al., 2005, 2006, 2007; [d] Wadas et al., 2001, 2008b; [e] Rębarz et al., 2015; [f] Pszczółkowski and Sawicka, 1999; [g] Rekowska et al., 1999; [h] Prośba-Białczyk and Mydlarski, 1998; [i] Bhullar, 2012.

A higher increase of tuber yield as a result of applying the cover is obtained in years with less favourable thermal conditions in the initial period of potato growth. In east-central Poland in years with very cold springs, covering the crops with non-woven polypropylene made it possible to obtain, 60 days after planting, up to

four times higher marketable tuber yield than in cultivation without covering (Jabłońska-Ceglarek and Wadas, 2005; Wadas et al., 2008b), whereas in the central part of Czech Republic, potato cultivation under non-woven polypropylene in a year with an exceptionally cold spring resulted in six times higher marketable tuber yield 60 days after planting (Dvořák et al., 2004; Hamouz et al., 2005).

Cover has the greatest effect on the potato tuber yield at a very early harvest date, but when harvest is delayed, the yield-increasing effect of covering is reduced (Rębarz et al., 2015). The study carried out in the central part of Czech Republic showed an increase in tuber yield as a result of applying covers in the period before the end of June, while along with the delay of the harvest date, the difference in the tuber yield in cultivation with and without covering was reduced, to reach an insignificant level by the end of June (Hamouz et al., 2005).

The application of non-woven polypropylene covers assures a high yield of potato tubers at an early harvest date, provided that the covers are removed at the proper time (Dvořák et al., 2007; Lutomirska and Szutkowska, 1999; Wadas et al., 2008b). The covers are often removed two to three weeks after plant emergence. Leaving the cover over the plants for too late after emergence can hinder the development of leaf assimilation area and reduce the number of setting tubers. In conditions of east-central Poland, the length of plant covering period (two or three weeks after plant emergence) did not have any significant effect on the tuber yield 60 days after planting, while for the harvest date delayed by two weeks, the yield was higher when the covers were removed two weeks after plant emergence (Wadas et al., 2008b).

The application of a non-woven polypropylene cover in the new potato production assures not only a higher tuber yield, but also contributes to improvement in its marketable value due to a decreased share of small tubers, with a diameter below 30 mm, and a simultaneous increased share of large tubers in the yield, with a diameter above 50 mm (Ban et al., 2011; Prośba-Białczyk and Mydlarski, 1998; Pszczółkowski and Sawicka, 2003; Pytlarz-Kozicka, 2011; Rekowska et al., 1999; Rębarz et al., 2015; Wadas et al., 2001, 2008b).

Tuber quality

A change in the initial growth conditions of potato plants by applying a non-woven polypropylene cover affects the chemical composition of tubers, and thus their nutritional value. Accelerating plant growth as a result of using covers results in an increase in the amount of dry matter in tubers. New potato tubers usually contain large quantities of water in proportion to their weight. While applying non-woven polypropylene, the dry matter content in tubers was higher by 0.69-2.17% than in cultivation without plant covering (Dvořák et al., 2006, 2008; Hamouz et al., 2006; Jabłońska-Ceglarek and Wadas, 2005; Rębarz et al., 2015; Wadas et al., 2003, 2006). A greater beneficial effect of applying covers, in the form of an increase of dry matter content in tubers, is found for an early harvest date. On the other hand, some authors reported that the application of non-woven polypropylene covers created less favourable conditions for the accumulation of dry matter in tubers of very early-maturing potato cultivars (Prośba-Białczyk and Mydlarski, 1998; Sawicka and Pszczółkowski, 2005).

Changed conditions for the initial growth of potato plants as a result of applying the covers resulted in an increase in the starch content in tubers by 0.45-1.46% (Dvořák et al., 2006, 2008; Hamouz et al., 2006; Jabłońska-Ceglarek and Wadas, 2005; Rębarz et al., 2015; Wadas et al., 2003, 2006;). The application of a cover also created favourable conditions for the accumulation of total sugars, reducing sugars and saccharose in tubers (Sawicka and Pszczółkowski, 2005). Although covering with non-woven polypropylene did not effect on protein accumulation in tubers. A tendency was observed towards an increase in the ascorbic acid (vitamin C) concentration and a decrease in the concentration of carotenoids and polyphenols compared to cultivation without plant covering (Dvořák et al., 2006, 2008; Jabłońska-Ceglarek and Wadas, 2005; Lachman et al., 2003; Pszczółkowski and Sawicka, 2009; Rębarz et al., 2015; Wadas et al., 2003, 2006). Plant growth acceleration as a result of a non-woven polypropylene covering contributes to an improvement of the tuber quality by reducing the concentration of nitrates, especially for the early harvesting date. The nitrate content of tubers was lower by 29 to 239 mg NO_3*1kg^{-1} of fresh weight while applying covers than in a cultivation without plant covering (Dvořák et al., 2006; Lachman et al., 2003). Covering the plants with non-woven polypropylene created favourable conditions for the accumulation of potassium and phosphorus in tubers, but did not affect the accumulation of magnesium (Wadas et al., 2007, 2008a).

Economic results

The use of non-woven polypropylene cover increases the direct costs of new potato production by 30-124% compared to cultivation without plant covering, with the cost of non-woven polypropylene adding around 20-50% to the direct costs. Higher inputs are related not only to the purchase of non-woven polypropylene, but also to labour input for its spreading and removing, as well as for harvesting the crops (Jarka and Chojnacki, 2008; Krzysztofik, 2013; Prośba-Białczyk et al., 1997; Pszczółkowski et al., 2000/2001; Rębarz et al., 2015; Wadas and Sawicki, 2005, 2009). The amount of actually incurred costs depends, first of all, on how many times the non-woven polypropylene cover is reused. The reuse rate of non-woven polypropylene depends on its mechanical damage, sun radiation and degree of contamination. The physical properties of non-woven polypropylene row cover worsen after UV radiation (Demšar et al., 2011). When non-woven polypropylene is appropriatelly used and stored, it can be utilized for three consecutive growing season, which significantly decreases its impact on the cost of potato production. Increasing the production inputs is effective when the value of the tuber yield increase obtained as a result of plant covering is higher than the costs incurred. While assessing the costs-effectiveness of early potato production under polypropylene cover, it is important that unit costs provide information about the level of selling price which will balance the costs incurred. In the agro-meteorological conditions of Poland, the production costs of 1 kg of tubers under non-woven polypropylene were 1.2 to 2.1 times higher than cultivation without the cover (Prośba-Białczyk et al, 1997; Wadas and Sawicki, 2005, 2009). Unit production costs were lower than in cultivation without covering only in the year with unfavourable thermal conditions for early crop potato culture, due to high yields obtained in cultivation under non-woven polypropylene. It is more efficient to increase inputs for early potato production by applying non-woven polypropylene

under less favourable thermal conditions during the initial period of potato growth. In such a case, a significant yield increase in cultivation under covers balances the costs incurred and makes it possible to obtain a higher direct surplus from production than without covering. The costs-effectiveness of early potatoes production under non-woven polypropylene cover depends on the income-to-costs ratio. Applying a non-woven polypropylene cover in an early crop potato production ensures high costs-effectiveness of production in years with cold springs. In conditions favouring rapid growth of potatoes, the production costs of 1 kg tubers under cover are higher, which makes production less profitable compared to cultivation without plant covering.

The application of a non-woven polypropylene cover facilitates a significant increase in income from potato production at a very early harvest date. Along with a delay in harvesting, the effect of applying the cover, reflected in an increase in the tuber yield, decreases in comparison to cultivation without covering (Oplanić et al., 2010; Pszczółkowski et al., 2000/2001; Rębarz et al., 2015).

Conclusions

To obtain a high early potato tuber yield, good conditions for plant growth must be ensured. The success of potato production for an early crop depends to a great extent on the soil and air temperature in the initial period of plant growth. The application of non-woven polypropylene covers accelerated plant emergence by 2-8 days, and the growth and development of plants in the later period, and consequently, resulted in an earlier new potato harvest by up to 2-3 weeks. It also increased the marketable tuber yield and reduced the yield variability in all years. The direct costs of new potato production under non-woven polypropylene cover were 30-124% higher than cultivation without plant covering, and the cost of non-woven polypropylene accounted for 20-50% of incurred costs. The amount of actually incurred costs depended, above all, on how many times the non-woven polypropylene cover was reused. When non-woven polypropylene is appropriately used and stored, it can be utilized for three consecutive growing season, which significantly decreases its impact on the direct cost of potato production. The yield-increasing effect of applying cover depends on weather conditions and potato harvesting date. A higher productive effect of covering is usually obtained in years with a cold spring and at a very early date of potato harvest. The considerable tuber yield increase in cultivation under non-woven polypropylene cover resulted in an decrease of unit costs and consequently, the cost-effectiveness of production was higher than without covering. In conditions favouring rapid potato growth, the application of covers increased unit costs, which made production less profitable than cultivation without covering.

Acceleration plant growth using non-woven polypropylene covers not only affected tuber yield quantity, but also contributed to improving of the tuber quality, especially by an increase in dry matter, potassium and phosphorus content in tubers and a decreased nitrate concentration.

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References

Ban, D., Vrtačić, M., Goreta Ban, S., Dumičić, G., Oplanić, M., Horvat, J., Žnidarčič, D. (2011) Utjecaj sorte, izravnog prekrivanja i roka berbe na rast i prinos mladog krumpira. Proceedings of 46th Croatian and 6th International Symposium on Agriculture, 14-18 February 2011, Opatija, Croatia, 496-500.

Bhullar, K. S. (2012) Effect of polypropylene covers on frost protection and yield of potato crop. Journal of Krishi Vigyan, 1 (1), 18-20.

Bizer, E. (1994) Frühkartoffelanbau under Vlies und Foile. Kartoffelbau, 45 (12), 462-466.

Bizer, E. (1997) Ernteverfrühung durch Vliesabdeckung. Kartoffelbau, 48 (1/2), 60-61.

Camire, M. E., Kubow, S., Donnelly, D. J. (2009) Potatoes and Human Health. Critical Reviews in Food Science and Nutrition, 49 (10), 823-840. http://dx.doi.org/10.1080/10408390903041996

Cholakov, T. L., Nacheva, E. K. (2009) Results from using polypropylene cover in production of early potatoes. Acta Horticulturae (ISHS), 830, 603-608. http://dx.doi.org/10.17660/actahortic.2009.830.87

Chotkowski, J., Gaziński, B., Rembeza, J. (1995) Ocena warunków przyrodniczych uprawy ziemniaka w Polsce. Postępy Nauk Rolniczych, 42 (6), 47-58.

Demmler, D. (1998) Vergleich von Folie und Vlies zur Ernteverfrühung in Frühkartoffeln. Kartoffelbau, 49 (12), 429-430.

Demšar, A., Žnidarčič, D., Svetec, D. G. (2011) Impact of UV radiation on the physical properties of polypropylene floating row covers. African Journal of Biotechnology, 10 (41), 7998-8006.

Dvořák, P., Hamouz, K., Bicanova, E., Prasilova, M., Jursik M. (2007) Effect of the date of polypropylene textile removal and site on yield-forming components of early potatoes. Scientia Agriculturae Bohemica, 38 (4), 162-167.

Dvořák, P., Hamouz, K., Čepl, J., Pivec, J. (2004) The non-woven fleece as an implement for acceleration of early potatoes harvest. Scientia Agriculturae Bohemica, 35 (4), 127-130.

Dvořák, P., Hamouz, K., Jůzl, M., Erhartowa, D. (2006) Influence of row covering with non-woven textile on tubers quality in early potatoes. Zeszyty Problemowe Postępów Nauk Rolniczych, 511, 225-231.

Dvořák, P., Hamouz, K., Lachman, J. (2008) Effect of the polypropylene textile cover on tubers quality of early potatoes. Proceedings of 43rd Croatian and 3rd International Symposium on Agriculture, 18-21 February 2008, Opatija, Croatia, 628-631.

Ezekiel, R., Singh, N., Sharma, S., Kaur, A. (2013) Beneficial phytochemicals in potato – a review. Food Research International, 50 (02), 487-496. http://dx.doi.org/10.1016/j.foodres.2011.04.025

Gimenez, C., Otto, R. F., Castilla, N. (2002) Productivity of leaf and root vegetable crop under direct cover. Scientia Horticulturae, 94 (1-2), 1-11. http://dx.doi.org/10.1016/s0304-4238(01)00356-9

Hamamoto, H. (1996) Effect of non-woven rowcover on plant environment and growth. Japan Agricultural Research Quarterly, 30 (1), 49-53.

Hamouz, K., Dvořák, P., Čepl, J., Pivec, J. (2005) The effect of polypropylene fleece covering on the yield of early potatoes. Horticultural Science (Prague), 32 (2), 56-59.

Hamouz, K., Dvořák, P., Erhartova, D. (2007) Effect of polypropylene covering on the yield formation dynamics of early potatoes. Acta Phytotechnica et Zootechnica, 3, 57-60.

Hamouz, K., Lachman, J., Dvořák, P., Trnková, E. (2006) Influence of non-woven fleece on the yield formation of early potatoes. Plant,Soil and Environment, 52 (7), 289-294.

Hochmuth, G. J., Hochmuth R. C., Kostewicz S., Stall, W. (2015) Row covers for commercial vegetable culture in Florida. Horticultural Sciences Department, UF/IFAS Extension, University of Florida, Circular 728.

Jabłońska-Ceglarek, R., Wadas, W. (2005) Effect of nonwoven polypropylene covers on early tuber yield of potato crops. Plant,Soil and Environment, 51 (5), 226-231.

Jarka, S., Chojnacki, S. (2008) Opłacalność produkcji ziemniaków na wczesny zbiór. Roczniki Naukowe Stowarzyszenia Ekonomistów Rolnictwa i Agrobiznesu, 10 (3), 248-245.

Krzysztofik, B. (2013) Efekty uprawy ziemniaków wczesnych pod osłonami. Inżynieria Rolnicza, 3 (2), 169-177.

Kubiak, K., Gaziński, B. (1996) Rynek ziemniaków wczesnych w Polsce. Postępy Nauk Rolniczych, 43 (5), 43-51.

Lachman, J., Hamouz, K., Hejtmánková A., Dudjak, J., Orsák, M., Pivec, V. (2003) Effect of white fleece on the selected quality parameters of early potato (*Solanum tuberosum* L.) tubers. Plant, Soil and Environment, 49 (8), 370-377.

Leszczyński, W. (2012) Żywieniowa wartość ziemniaka i przetworów ziemniaczanych (Przegląd literatury). Biuletyn Instytutu Hodowli i Aklimatyzacji Roślin, 266, 5-20.

Lutomirska, B. (1995) Stosowanie agrowłókniny dla przyspieszenia plonowania ziemniaków. Ziemniak Polski, 3**,** 14-19.

Lutomirska, B. (2006) Przyspieszanie zbioru ziemniaków bardzo wczesnych. Ziemniak Polski, 1, 12-15.

Lutomirska, B., Szutkowska, M. (1999) Powierzchnia asymilacyjna i plon wczesny w warunkach zastosowania okryw w uprawie ziemniaków. Konferencja Naukowa „Ziemniak jadalny i dla przetwórstwa spożywczego – czynniki agrotechniczne i przechowalnicze warunkujące jakość". 23-25 lutego 1999. Instytut Hodowli i Aklimatyzacji Roślin Oddział w Jadwisinie, Radzików, 169-171.

Masheva, S., Yankova, V., Cholakov, T., Boteva, H. (2012) Diseases and pest attack in early potatoes grown under polypropylene covers. Agrarni Nauki, 4 (10), 47-51.

Nishibe, S., Satoh, M., Mori, M., Isoda, A., Nakaseko, K. (1989) Effects of climatic conditions on intercepted radiation and some growth parameters in potato. Japanese Journal of Crop Science, 58 (2), 171-179. http://dx.doi.org/10.1626/jcs.58.171

Olle, M., Bender, I. (2010) The effect of non-woven fleece on the yield and production characteristics of vegetables. Journal of Agricultural Science, 21 (1-2), 24-29.

Oplanić, M., Ban, D., Ban, S. M., Dumičić G. (2010) Ekonomska analiza proizvodnje mladog krumpira (*Solanum tuberosum* L.) 45. hrvatski i 5. međunarodni simpozij agronoma. 15-19 veljače 2010, Opatija, Hrvatska, 293-297.

Otto. R. F., Gimenez, C., Castilla N. (2000) Evapotranspiration and dry matter production of horticultural crops under cover. Acta Horticulturae (ISHS), 516, 23-30. http://dx.doi.org/10.17660/actahortic.2000.516.2

Prośba-Białczyk, U., Mydlarski, M. (1998) Uprawa ziemniaka na wczesny zbiór przy zastosowaniu osłony z agrowłókniny. Fragmenta Agronomica, 1 (57), 74-84.

Prośba-Białczyk, U., Paluch, F., Mydlarski, M. (1997) Efektywność ekonomiczna produkcji ziemniaka wczesnego przy zastosowaniu agrowłókniny. Bibliotheca Fragmenta Agronomica, 3, 181-188.

Pszczółkowski, P. (2003) Próby ograniczenia zachwaszczenia łanu ziemniaka w uprawie pod osłonami. Część I. Reakcja roślin na herbicydy. Biuletyn Instytutu Hodowli i Aklimatyzacji Roślin, 228, 249-260.

Pszczółkowski, P., Harasim, A., Sawicka, B. (2000/2001) Efektywność ekonomiczna technologii produkcji wczesnego ziemniaka jadalnego w różnych terminach zbioru. Roczniki Nauk Rolniczych, Seria G, 89 (1), 89-99.

Pszczółkowski, P., Sawicka, B. (1998) Stosowanie osłon i różnych sposobów pielęgnacji w uprawie wczesnych odmian ziemniaka w aspekcie zdrowotności roślin. Roczniki Akademii Rolniczej w Poznaniu CCCVII, Rolnictwo, 52, 191-196.

Pszczółkowski, P., Sawicka, B. (1999) Plon bulw bardzo wczesnych odmian ziemniaka uprawianych pod agrowłókniną. Materiały VIII Ogólnopolskiego Zjazdu Naukowego „Hodowla Roślin Ogrodniczych u progu XXI wieku". 4-5 lutego 1999. Akademia Rolnicza, Lublin, 31-34.

Pszczółkowski, P., Sawicka, B. (2003) Produkcyjność bardzo wczesnych odmian ziemniaka uprawianych pod osłonami. Cz. I. Plon i jego struktura. Acta Scientiarum Polonorum, Agricultura, 2 (2), 61-72.

Pszczółkowski, P., Sawicka, B. (2009) Zawartość białka i azotanów w bulwach bardzo wczesnych odmian ziemniaka uprawianych pod osłonami. Zeszyty Problemowe Postępów Nauk Rolniczych, 542, 413-426.

Pytlarz-Kozicka, M. (2011) Wpływ sposobu uprawy na plon i jego strukturę dwóch bardzo wczesnych odmian ziemniaka. Zeszyty Naukowe Uniwersytetu Przyrodniczego we Wrocławiu, Rolnictwo XCVIII, 581, 127-140.

Rekowska, E., Orłowski, M. (2000) Wpływ metody uprawy na wielkość i jakość plonu ziemniaka wczesnego. Annales Universitatis Mariae Curie-Skłodowska, Sectio EEE Horticultura, 8, Suppl., 129-135.

Rekowska, E., Orłowski, M., Słodkowski, P. (1999) Wpływ stosowania osłon oraz terminów zbioru na plonowanie ziemniaka wczesnego. Zeszyty Problemowe Postępów Nauk Rolniczych, 466, 181-189.

Rębarz, K., Borówczak, F., Gaj, R., Frieske, T. (2015) Effects of cover type and harvest date on yield, quality and cost-effectiveness of early potato cultivation. American Journal of Potato Research, 92, 359-366. http://dx.doi.org/10.1007/s12230-015-9441-0

Sawicka, B., Pszczółkowski, P. (2002) Postęp w technologii uprawy wczesnych odmian ziemniaka pod osłonami. Pamiętnik Puławski, 130 (2), 673-683.

Sawicka, B., Pszczółkowski, P. (2005) Dry matter and carbohydrates content in the tubers of very early potato varieties cultivated under coverage. Acta Scientiarum Polonorum, Hortorum Cultus, 4 (2), 111-122.

Wadas, W., Jabłońska-Ceglarek, R., Kosterna, E. (2003) Wpływ stosowania włókniny w uprawie bardzo wczesnych odmian ziemniaka na zawartość wybranych składników w młodych bulwach. Żywność (Nauka, Technologia, Jakość), 3 (36), 110-118.

Wadas, W., Jabłońska-Ceglarek, R., Kosterna, E., Łęczycka, T. (2007) Zawartość potasu w młodych bulwach ziemniaka w zależności od sposobu uprawy. Roczniki Akademii Rolniczej w Poznaniu CCCLXXXIII, Ogrodnictwo, 41, 643-647.

Wadas, W., Jabłońska-Ceglarek, R., Kurowska, A. (2008a) Effect of using covers in early crop potato culture on the content of phosphorus and magnesium in tubers. Journal of Elementology, 13 (2), 275-280.

Wadas, W., Jabłońska-Ceglarek, R., Rosa, R. (2001) A possibility of increasing the yield of young potato tubers by using a polypropylene fibre covers. Electronic Journal of Polish Agricultural Universities, Horticulture, 4 (2), #06.

Wadas, W., Kosterna, E. (2007a) Effect of perforated foil and polypropylene fibre covers on development of early potato cultivars. Plant, Soil and Environment, 53 (3), 136-141.

Wadas, W., Kosterna, E. (2007b) Effect of perforated foil and polypropylene fibre covers on assimilation leaf area of early potato cultivars. Plant, Soil and Environment, 53 (7), 299-305.

Wadas, W., Kosterna, E., Kurowska, A. (2009) Effect of perforated foil and polypropylene fibre covers on growth of very early potato cultivars. Plant, Soil and Environment, 55 (1), 33-41.

Wadas, W., Kosterna, E., Sawicki, M. (2008b) Effect of perforated film and polypropylene nonwoven covering on the marketable value of early potato yield. Vegetable Crops Research Bulletin, 69, 51-61. http://dx.doi.org/10.2478/v10032-008-0020-5

Wadas, W., Kosterna, E., Żebrowska, T. (2006) Wpływ stosowania osłon w uprawie wczesnych odmian ziemniaka na zawartość wybranych składników w bulwach. Zeszyty Problemowe Postępów Nauk Rolniczych, 511, 233-243.

Wadas, W., Sawicki, M. (2005) Ocena opłacalności produkcji ziemniaków wczesnych w warunkach środkowo-wschodniej Polski. Pamiętnik Puławski, 139, 289-297.

Wadas, W., Sawicki, M. (2009) The economic effectiveness of early potato production depending on the kind of cover. Polish Journal of Agronomy, 1, 56-61.