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Organic and non-organic mulches – impact on environmental conditions, yield, and quality of Cucurbitaceae

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ABSTRACT

The publication presents the current state of knowledge regarding the importance of mulching in the cultivation of Cucurbitaceae (cucurbit, or gourd family) vegetables. The intensifying climate change – mainly decreasing rainfall – combined with large-scale production of cucurbit vegetables worldwide prompt the application of methods that reduce evaporation and weed infestation. One of the widespread methods is mulching of the soil. The most important advantages of this treatment include the efficient use of water, the reduction in soil erosion and in the leaching of nutrients to the deeper layers. In addition, mulching improves the physical and chemical properties of the soil, and positively affects the surrounding microclimate of the plant. The report includes descriptions of the characteristics of various types of organic, mineral and synthetic mulches used. The results of studies on the environmental conditions forming in mulched soil are presented. Also, the results of research into the physico-chemical properties of mulch-covered soil are collated. The effect of mulching on cucurbit vegetables was evaluated in terms of plant growth and development as well as fruit yield and its biological value. The monograph also deals with the effect of mulching on weed infestation, as well as the occurrence of harmful and beneficial organisms.

Key words: Cucurbitaceae species, growth and development, mulching, pests, soil conditions, weed infestation, yielding

Abbreviations:

C/N – carbon-to-nitrogen ratio, EUW – effective use of water index, k_{sat} – saturated hydraulic conductivity of the soil, ldPE – low-density polyethylene, PA – polyacrylate, PBAT – polybutylene adipate-co-terephthalate, PBS – polybutylene succinate, PCV – polyvinyl chloride, PHA – polyhydroxyalkanoates, PLA – polylactide, PP – polypropylene, PVA – polyvinyl alcohol, WUE – water-use efficiency index

CUCURBITS

Cucurbits belong to the Cucurbitaceae family, the order of Cucurbitales. This covers about 95-120 genera and 800-965 species (Heneidak and Khalik, 2015; Christenhusz and Byng, 2016). The vast majority of these species originate from tropical or subtropical climates of Africa, South America, and Asia. Not many of them, in their natural state, grow in temperate zones. The common feature of all cucurbit plants is their preference for climatic

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conditions that are typical of equatorial zones, where they are cultivated on a large scale, and then transported over long distances (Paris, 2016). Vegetables representing this large group of plants include: cucumber (*Cucumis sativus* L.), summer squash (*Cucurbita pepo* L.), pumpkin (*Cucurbita maxima* Duch. and *Cucurbita moschata* Duch.), watermelon (*Citrullus lanatus* (Thunb.) Matsum. et Nakai), melon (*Cucumis melo* L.), and bottle gourd (*Lagenaria siceraria* (Molina) Standl.).

Global production of cucumbers, gherkins, pumpkins, squashes, gourds, melons and watermelons totalled 240,807,832 tonnes in 2014 (FAOSTAT, 2017). Of the highest utility are the fruits, being the key part of cucurbits harvested during the technological or physiological maturity period (Ajuru and Nmom, 2017). Intensification of the production of cucurbit vegetables is possible thanks to soil and plant protection treatments, especially using nonwoven fabrics and plastic films. Despite the many advantages of using such materials, they are not neutral to the soil environment (Steinmetz et al., 2016). Compared to conventional crops, cropping systems making use of cover plants, based on the limitation of cultivation practices and mineral fertilization, can be associated with a significant drop in yield – by as much as 57% in zucchini cultivation (Nachimuthu et al., 2017).

Environmental conditions

A temperature in the range 18-30°C is considered to be the optimal temperature for growing vegetables from the cucurbit group (melon, cucumber). A longer-lasting temperature of between zero and ten degrees Celsius inhibits the growth of plants, while sub-zero temperatures irreversibly destroy them (Ojo, 2016). The temperature of the soil, which should also be high, is considered important for the normal development of cucurbits. A drop in temperature to 12°C can already cause destabilization in the water management of plants, manifesting itself in limiting the uptake and transport of nutrients, especially phosphorus and potassium, to the aboveground part. This is detrimental to the growth rates in plant height and root length (Yan et al., 2013). The Cucurbitaceae subjected to constant temperatures of 15°C during the day and 25°C during the night, for a week in the early stages of their development, exhibit lower growth rates, as well as lower chlorophyll and dry matter contents. Under these conditions, the concentration of mineral components in the green parts of the plants increases (Inthichack et al., 2014). Exposure of juvenile cucumber plants to a temperature of about 7°C leads to slower initiation of flowering in female flowers, and to a decrease in their numbers, and therefore also to a decrease in the number and weight of the fruit and yield (Sarhan and Ismael, 2014). It is important to emphasize their sensitivity to high fluctuations in temperature as well as to low soil moisture and air humidity, which may lead to the plants shedding both flowers and young buds (Siwek, 2010).

The cucurbit root system, which forms a small part of the entire plant, reaches about 1.8 m deep into the soil, and its lateral roots are located at a depth of up to 60 cm (Kumar, 2016). The shallowest root system is that of the cucumber, with the majority of its root mass remaining in the topsoil layer (25-30 cm). The latter should be permeable, fast heating, and fertile, with regulated soil-water regimes, but with long water retention and a pH of 6.0-7.2. Cucurbit vegetables show a positive response to organic fertilization, which, in addition to providing large amounts of mineral substances in a readily available form, improves the physico-chemical properties of the soil (Sady, 2006).

The highly demanding nature of cucurbits in relation to the microclimate and soil environment, as well as their high dynamics of growth and yielding, combined with their short vegetation period, justify the use of mulching in their cultivation. Very important are also the high demands of cucurbit plants for water in connection with the rapidly diminishing water resources (WWAP, 2015; Yang et al., 2015). A system using synthetic polymers, called "plasticulture", is particularly recommended in areas with low rainfall and low soil temperatures, as confirmed by a number of studies (Siwek, 2010; Haapala et al., 2015). The covering of the soil is carried out on vast areas, especially in developed countries with low rainfall, for instance, in China, Spain, or Israel.

DESCRIPTION OF MULCHES USED IN THE CULTIVATION OF CUCURBITS

Organic mulches

The basic organic material used for mulching is straw, which is a product of agricultural crops, mostly cereals (Kosterna, 2014; Nicholson et al., 2014). Other materials include paper mulches, which are made of wrapping paper, waxed or treated otherwise, providing a cheaper alternative to straw (Haapala et al., 2014). Compost with animal excrement seems to be the best material in terms of the quantity of organic matter it contains (Cabilovski et al., 2014). Organic materials (such as straw, sawdust, bark, or peat) exhibit low bulk density of about 0.06-0.30 g cm^{-3}. During vegetation, this can increase as a result of the natural settling process. Soil-water regime also largely depends on porosity, which is between 78-96% (Chohura, 2007). Mulches developed from biomass are increasingly used to cover the soil around the plants. According to Tan et al. (2016), a biodegradable mulch 0.35 mm thick with a surface weight of 40 g m^{-2}, consisting of 16% corn starch and 84% natural fibre, allowed about 15% of radiation in the range 450-850 mm to pass, exhibited very good water permeability and thermal stability under field conditions. Its degradation rate in soil at 10-25°C and 65% humidity was the highest compared to mulches based on natural polyvinyl alcohol (PVA) and polyacrylate (PA) (Tan et al., 2016).

Another source of organic materials for mulching is wood waste. In general, a broader C/N ratio is typical of coniferous species (such as pine) than deciduous ones (such as hornbeam). Various wood mulches differ among themselves in terms of the carbon-to-nitrogen ratio (C/N), which is 242-1569 for sapwood, and 38 for bark (Bantle et al., 2014), while the optimum range is 12-16:1 (Chohura, 2007). The composting of wood waste should be a pre-mulching activity, preceding the actual mulching of the soil.

A factor that hinders widespread use of organic mulches is the feasibility of delivering them to the field, and evenly distribute them therein. In addition, many of these mulches decompose quickly, which requires systematic replenishment.

Synthetic mulches

From the mid-twentieth century, there has been an upward trend in the use of synthetic polymers as mulch in plant production (Lamont, 1993; Espi et al., 2006). At the present time, most agricultural land is covered with mulch (total mulching area is about 18,000,000 ha) (Mormile et al., 2017). In Poland, the first attempts to mulch the soil with PVC (polyvinylchloride) film were carried out in cucumber cultivation at the turn of the 1970s and 1980s (Libik, 1976). The area of mulched crops in that country exceeds 1000 ha, on which mostly cucumber is cultivated (Siwek and Libik, 2012). The physical properties of inorganic mulches depend on the type of polymer, the manufacturing process, as well as on the substances added during the production (stabilizers, activators, carriers, dyes, fillers, etc.). The latter are also often added to biodegradable polymers in order to improve their physical properties and accelerate degradation (Vieira et al., 2011). The most commonly used mulching thermoplastics include polyethylene films (especially low density ldPE with a dark tint) with a thickness of 0.012-0.05 mm or thicker (Espi et al., 2006; Scarascia-Mugnozza et al., 2011; Orzolek and Lamont, 2013) and polypropylene (PP) nonwoven fabrics with a surface weight of 50 and 60 g m^{-2}, which, unlike PE, allow the penetration of rain water and gas exchange (Siwek, 2010; Siwek and Libik, 2012). Polypropylene is a lightweight polymer, with a density of 0.90-0.91 g cm^{-3}, and it can be processed using three different methods. The "spun-bonded" method produces stronger polypropylene fabrics than the melt-blown method (Maddah, 2016).

Biodegradable mulches

At present, intensive research continues on the production technology, properties and implementation of films and nonwoven fabrics made of (or with) biodegradable polylactide (PLA) (Rudnik and Briassoulis, 2011; Weng et al., 2013; Zawiska and Siwek, 2014), naturally occurring polysaccharides (Ołdak et al., 2015; Touchaleaume et al., 2016; Moreno et al., 2017), thermosetting polymers from vegetable oils (Adekunle, 2015), as well as synthetic polymers including substances responsible for photo-, oxo- or biodegradation (Sulak et al., 2012; Abrusci et al., 2013; Gomes et al., 2014; López-Tolentino et al., 2016a, 2016b). The addition of zinc, iron, cobalt, manganese and magnesium facilitates the oxidation and degradation of long chain polymers under the influence of heat, air and light (Zenner de Polanía and Peña Baracaldo, 2013). These polymers, under aerobic conditions, can be decomposed by microorganisms into carbon dioxide or methane, water, biomass, and other organic compounds. No adverse effects on the nitrification processes occurring in the soil have been observed (Ardisson et al., 2014). Compounds (mixed mulches) composed of standard polymers produced in nature do not degrade completely (Kyrikou and Briassoulis, 2007; Li et al., 2014), while the rate of their environmental degradation is relatively difficult to estimate. The reason for this is their large variety in terms of structure and dependence on environmental conditions (microbial and enzymatic activity in the soil, soil temperature, humidity, the amounts of air and mineral salts, as well as its pH value) (Lucas et al., 2008; Liu et al., 2010; Siwek et al., 2010; Lichocik et al., 2012). The composition and concentration of additives activating the shortening of polymer chains, for instance iron and calcium stearates, are also considered of high importance. Their presence leads to accelerated ageing and deterioration in physical and mechanical properties (Pablos et al., 2010; Sulak et al., 2012). In response to increasing contamination of the environment with standard petroleum polymers, technological efforts have been undertaken aimed at speeding up the degradation processes and finding new solutions (Leja and Lewandowicz, 2010; Siwek et al., 2010; Vieira et al., 2011). Cellulose, which is also the base for polymeric materials, can be obtained from agricultural waste such as wheat straw and soybean seed coat. After chemical and mechanical treatments and homogenization process, fibres with a high α-cellulose content (about 84.6-94.0%) and a low lignin content (about 9.4-2.5%) are obtained, from which nonwoven fabrics are produced (Alemdar and Sain, 2008).

Another source of polymers are transgenic plants, including tobacco, which are genetically engineered to include bacterial cells such as *Ralstonia eutropha*, for producing bacterial polyesters and polyhydroxyalkanoates (PHA). They are fully degradable and can compete with synthetic polymers used to make films and nonwovens, or to form their composites (Mooney, 2009; Penczek et al., 2013). Laboratory studies have demonstrated lower resistance of polyethylene-starch mixtures to photo- and biodegradation, which are induced faster in those with a high starch content (30%). On the other hand, long-term exposure of a copolymer with a low starch content (5%) to radiation resulted in more effective degradation (Ołdak et al., 2005). Observing the level of degradation of several mulches based on corn and potato starch, PLA and biodegradable paper, Moreno et al. (2017) indicate the importance of the degree of shading of these materials by the crop plants to the progress of this process. López-Tolentino et al. (2016a) observed very fast degradation of photo-biodegradable film based on starch with high concentrations of a photodegradation agent (0.49% iron compounds) and oxo-degradation agent (0.52% calcium compounds) under Mexican climatic conditions. The tested mulch began to degrade as early as 1 week after application in the locations where zucchini seeds had been sown. At the end of the 2-month trial, they assessed the level of film degradation at 94% in areas with solar radiation, and only 10% in the sheltered part. In another experiment, while testing the use of oxo-degradable mulches with varying pigment concentrations and titanium dioxide content (22-23%), they observed a tendency to accelerated degradation in the mulch with increasing dye concentration (López-Tolentino et al., 2016b). The cost of using degradable polymeric materials can vary considerably, depending on the built-in components. There are indications that, taking into account the cost of removal from the field and utilization after standard synthetic mulch production, the total cost of using degradable mulches can be comparable (Minuto et al., 2008; Waterer, 2010).

IMPACT OF MULCHING ON ENVIRONMENTAL CONDITIONS

Light conditions

A study by Siwek (2002) shows that black polyethylene film with a thickness of 0.05 mm does not let through radiation in the range of 400-1100 nm, whereas only about 8.6% of it passes through polypropylene nonwoven fabrics with a surface mass of 50 g m^2. The same material, albeit white in colour, transmits 66.7% of the radiation, while green and blue transmit 37.5% and 28.9% of PAR, and 48.9% and 46.8% of 700-1100 nm, respectively. The photosynthetic activity of plants is most intense at a wavelength of 650-750 nm (red light and infrared) (Espi et al., 2006). However, blue light is required for proper photosynthesis (Hogewoning et al., 2010). As reported by Piszczek and Głowacka (2008), the growth of cucumber seedlings illuminated with fluorescent lamps emitting blue light improved with the increase in quantum radiation (from 50 to 60 μmol m^{-2} s^{-1}), namely: they were taller and had thicker stems. The investigated factors did not significantly affect the number of leaves or anthocyanin content. Measurements made by Meyer et al. (2012) demonstrate a high degree of reflection of PE white films with a thickness of 0.4 and 0.6 mm. They reflected approximately 80 to 60% of PAR and NIR radiation, with the highest rate in the case of blue-colour radiation. To compare, red PE film with a thickness of 0.1 mm reflected about 30-35% of blue and near-infrared radiation. In turn, black- and olive-coloured films with a thickness of 0.1 mm reflected 4% and 24%, respectively. The highest transmittance of radiation in the NIR range occurred in the olive-coloured film (45-75%), followed by red (about 55-65%), and white (about 30-40%) films, with the lowest transmittance recorded for black film (about 1%). Brault et al. (2002) also conducted a comparison of mulching materials in terms of their spectral properties. Their laboratory analysis demonstrated that, at the beginning of the experiment, the transmission in the PAR range for coextruded white/black film, black wrapping paper covered with latex on both sides, and natural-coloured wrapping paper covered with latex on both sides was approximately 2%, 0.08% and 4.3%, respectively. Wrapping paper coated with a biodegradable polymer allowed the sunlight to pass within a given range close to that of latex-coated paper. The black latex-coated paper reflected 6%, and the latex-coated natural beige-coloured paper reflected 33% of sunrays in the PAR range, while it absorbed 90% of those in the 400-1100 nm range. The absorption level in this range for the dichroic film was 40%, and in the infrared, it was 60%. In another experiment, it was demonstrated that squash plants growing in soil covered with blue mulch received more sunlight from the reflected surface, which resulted in higher photosynthesis and vegetative growth. Despite that, the quality of the light that reaches the plants growing on red mulch is more favourable and conducive to generative growth, resulting in higher yields (Fatemi et al., 2013). Thanks to the reflected UV radiation from mulches with high reflectivity (for instance, aluminium), the passage of pests over crop plants is impeded, leading to improved phytosanitary conditions (Shruthi et al., 2017). For a better understanding of the effects and the establishment of mulches that enhance light conditions in the growing of cucurbits, further research is needed.

Thermal conditions

The increase in temperature around the cultivated plants in a mulched soil is one of the effects of this treatment. This is particularly important in countries with temperate climates, where the cultivation of cucurbits is temperature dependent (Kalbarczyk, 2009). By influencing the growth and development processes of plants, including their underground part, higher temperatures advance their coming into the fruiting season (Pramanik et al., 2015). From a physiological point of view, the reduction in the efficiency of photosystem II is due to the reduction in CO_2 assimilation caused by low soil temperature (for cucumber, below 15°C). Therefore, maintaining the optimum temperature for the roots of cucurbits, under stress conditions, prevents the delivery to those parts of high amounts of abscisic acid that inhibits photosynthesis and causes the closing of the stomatal apparatus, thus limiting transpiration (Zhang et al., 2008b).

Currently, in many countries (for instance, in China and Israel) large areas are mulched with black film, nonwoven fabrics, or other dark-coloured materials, which are highly absorbent of sunlight, causing considerable heating of the soil (Lamont, 1993; López et al., 2009). These are especially recommended for growing cucurbit vegetables and nightshade plants, thus enabling higher – though not always earlier – yields. Thanks to the use of black film for mulching, these plants can be successfully grown in temperate regions (Ladakh region, western part of the Tibetan Highlands), where the average temperature of mulched soil in summer has been observed to rise by 2-5°C during the day (Stobdan, 2015). This is confirmed by the results of the studies into using black film-coated biodegradable paper mulch conducted by Haapala et al. (2015), as well as Moreno and Moreno (2008) and López-Tolentino et al. (2016b), who recorded the highest increase in soil temperature under black PE mulch. Numerous literature reports, however, indicate that the strongest warming of the soil occurs under colourless film (Attallah, 2016; Martín-Closas et al., 2017), with selective transmission of solar radiation (Waterer, 2010).

In Mexico, the temperature of the soil mulched with 0.038 mm thick black PE film was higher than the temperature under oxo-degradable mulches of the same thickness coloured red, blue, green, and in unprotected soil on average by 2.4°C, 2.2°C, 2.3°C, and 4.2°C, respectively (López-Tolentino et al., 2016b). In the same country, the usefulness of PE film (0.03 mm thick) of different colours in cucumber cultivation was also investigated. As a result of covering the soil, the temperature at a depth of 10 cm increased significantly on all the test sites, and the highest average increase in the maximum, minimum and average temperatures for the test years amounted to: 7.8°C for brown film, 3.6°C for black embossed film, and 5.2°C for brown embossed film. In addition, it contributed to the accumulation of heat, expressed by the sum of active temperatures (Ibarra-Jiménez et al., 2008). As reported by Siwek (2002), the soil temperature at a depth of 10 cm during the initial stage of cucumber growth under black PP nonwoven and under PE film was higher by 0.5°C and by 1.9°C, respectively, than in the unprotected soil. According to Filippi et al. (2011), the maximum temperature of the soil under the influence of mulching with green-coloured biodegradable films (0.015 mm) was higher than that for black film of the same thickness, for black ldPE (50 µm), and for unprotected soil. The observed increase in temperature occurred especially in the first days after the application of the mulches. Soil temperature analysis performed by El-Shaikh and Fouda (2008) in their experiment using polyethylene (black, transparent and yellow) and organic mulch (wheat straw) in cucumber cultivation showed considerable variation. All the mulches from synthetic polymers raised the temperature of the soil during the day between 6 a.m. and 2 p.m., and then radiated the heat out until the following morning. The highest increase (by about 7°C) relative to the unprotected soil occurred under the colourless film. On the other hand, in the case of the organic mulch, an increase in soil temperature was recorded only at night (1°C), while at 2 p.m. it decreased by an average of 2°C relative to the control site. At night, as a result of thermal radiation, the temperature was the lowest at the soil surface. Similar results of soil temperature decreasing under an organic mulch composed of wood chips have been observed by van Donk et al. (2011). Their studies have shown a correlation between the decrease in soil temperature during the day with increasing depth. In the Florida area, White (2004) reported a higher soil temperature at a depth of 6 cm between 3 p.m. and 4 p.m. under black polyethylene film compared to black biodegradable, silver, white and bicolour (black-and-white) films. In Ontario, it was observed over 11 days that the soil temperature under black film was about 1.5°C higher during the day, while at night the minimum temperature was as much as 2-3°C higher than the temperature of the unprotected soil. The authors also noted a negative correlation between the soil temperature under films of different colours and the temperature of soil without mulch application, and the absolute value of temperature in the unprotected soil (Snyder et al., 2015). Homez and Arouiee (2016) investigated the effect of the type and colour of mulch on the accumulation of heat in the soil in unheated greenhouses. The highest degree of heat accumulation was noted under black PE film, slightly lower under transparent PE foil, and then under organic mulch of rice husks. The amount of heat absorbed was the lowest in unprotected soil in winter and spring. The results show that mulches of synthetic polymers are worthy of even more extensive use for thermophilic vegetables in relatively cold countries, while mulches of natural origin are more suitable in countries with hot climates, in order to reduce temperature or minimize excessive thermal fluctuations throughout the day.

Soil moisture

Maintaining a high moisture content of the soil during the cucurbit vegetation period allows advancement and prolongation of the cropping season, leading to an increase in yield (Kuslu et al., 2013). The barrier posed by both synthetic and organic mulches limits soil evaporation, the intensity of which is determined mainly by the type and thickness of the material. It is estimated that mulching makes it possible to retain about 20-41% more water in the soil (Abouziena et al., 2014; Ingman et al., 2015; Stobdan, 2015).

Under laboratory conditions, during the first 4 days of drying, the evaporation index of a soil covered with black film (0.01 mm), pine bark, wheat straw, chopped vine shoots, and natural jute fibres was, respectively: 81%, 55%, 34%, 23% and 11% lower than of the same soil without mulch (Zribi et al., 2015). High effectiveness of water loss prevention in soil has been observed especially in desert and semi-arid areas (Yang et al., 2015). Evaporation is most effectively limited by the use of organic mulches (except for wheat straw) and mineral mulches (gravel mulch), less so in the case of synthetic mulches based on hydrogels and organic polymer emulsions (Farzi et al., 2017). Some studies show that the soil moisture content increases with organic mulching only in deeper layers (80-220 cm), while at a depth of 30-80 cm, soil moisture may be lower (Li et al. 2017). A positive correlation was found between the thickness of organic mulch and the water content of the shielded soil (van Donk et al., 2011). There are indications of soil humidity being lower by about 5-10% under synthetic mulches immediately after precipitation, while during the dry period, the index is about 5% higher (Snyder et al., 2015). Also, a negative correlation was observed between the size fraction of the material used (gravel) and the degree of blocking the evaporation (Xie et al., 2006; Yuan et al., 2009).

White (2004) reported no significant effect of mulch colour (white, silver, black, blue and red, biodegradable and bi-coloured) on soil moisture. The lowest value of water field capacity was measured in uncovered soil. It amounted to 37%, compared with the average of 40-68% under the mulches. In a test conducted in the conditions of extreme dryness (Central Sudan, annual rainfall of <400 mm), mulching with colourless film contributed to a decrease in soil water loss by 6 to 11% (Abdelrahman et al., 2016). Other authors, studying the use of synthetic dyed materials for mulching, have obtained similar results (Mahadeen, 2014).

As a result of mulching, a decreased need for irrigation water has been observed in cucumber cultivation (El-Shaikh and Fouda, 2008; Spiżewski et al., 2010) as well as in melon cultivation (Alenazi et al., 2015). The index of water-use efficiency (WUE, t m^{-3}) under straw mulch as well as under black, yellow and transparent ldPE film amounted to, respectively: 6.22, 7.76, 8.34, and 8.51 kg m^{-3}, which was >160% higher than on the control site (2.32 kg m^{-3}) (El-Shaikh and Fouda, 2008). This is expressed as a quotient of the crop yield of the plant (t hm^{-2}) and the amount of water consumed during the vegetation period (total sum of evapotranspiration) (m^3 hm^{-2}) (Zhuo and Hoekstra, 2017). Opinions are divided as to the importance of the efficient use of water (EUW) and water-use efficiency (WUE), which determines the yield under drought stress. The more important determinant of plant yield under such conditions is the EUW calculated from the maximum transport of soil water, used in the transpiration process, to the stomatal apparatus of plants (Blum, 2009).

Physical and chemical properties of the soil

Mulches of organic origin typically enter into a relationship with the soil, increasing the activity of the enzymes which break down plant residues. As a result of the use of such mulches, increased presence of worms as well as their greater mass is also observed (Jodaugienė et al., 2010). Organic mulches with a high carbon to nitrogen ratio (such as sawdust) may cause temporary soil impoverishment in nitrogen due to the activity of microorganisms. The differences also concern the levels of macro- and micronutrients in the mulched soil and its acidity (Sas-Paszt et al., 2014). During vegetation, as the decomposition processes proceed, the mulch gradually enriches the soil with humus, which is the source of nutrients in an easily digestible form. Estimation of the organic matter mineralization rate is one of the principles of optimum management of mineral components in the soil for successive crops in crop rotation (Tittarelli et al., 2014). Mulching with flaked paper, on sites where municipal compost and sludge were used, increased the amount of microorganisms involved in the nitrogen and phosphorus cycle compared to synthetic mulches (Forge et al., 2003). Fang et al. (2007) reported that as a result of mulching with grass (*Imperata cylindrica* var. *major*) over 55% of the available nitrogen was released to the soil during the first 4 months of application. The layers of organic mulches applied at 2.5, 5.0 and 7.5 kg m^2 released, respectively: 69, 161 and 322 kg of nitrogen per ha during the year. Broschat (2007) reported an increased concentration of nutrients in the soil after 6 weeks of applying wood mulches, such as cypress chips (K), pine bark, and eucalyptus chips (Mg).

The exposed soil is exceptionally susceptible to the destructive effects of heavy rainfall, which causes the soil structure to break apart and intensifies the elimination of nutrients. This is evidenced by the results obtained by Siwek et al. (2015), where the lowest nitrogen level (especially in the nitrate form) was recorded on the unprotected control site. In turn, Cabilovski et al. (2014), in strawberry mulching with organic fertilization, reported higher concentrations of micronutrients under the surface of synthetic mulches compared to straw. Under the influence of the protective mulch of fodder radish, an increase in the number of soil macropores with a diameter of 50-500 µm was observed in the upper soil layer (0-10 cm) (Głąb and Kulig, 2008). At the same depth, the largest water-borne soil macroaggregates (>250 µm) and the highest saturated hydraulic conductivity (k_{sat}), defined as the degree of water conductivity (mm h^{-1}), were found in studies conducted in China (Zhang et al., 2008a). According to the authors, mulching with organic matter combined with no-tillage cultivation results in improved physical properties of the soil and increases organic carbon content. Similar results for the improvement of soil porosity were obtained by Blanco-Canqui and Lal (2007), but only in the topsoil. On the site with mulching, k_{sat} was 123 times higher, while the water content was 40-60% higher compared to the control. Joy and Varghese (2017), who investigated flaked straw, natural rubber, cardboard and wood chips as mulch, recorded reduced soil permeability. The permeability coefficient (cm s^{-1}) for all the mulches decreased with each 1 cm increase in thickness of their layer by an average of 0.5; 0.9; 1.2; 1.7 × 10^{-3} cm s^{-1} for straw, natural rubber, wood chips and cardboard, in that order. Kahlon et al. (2013), after several decades of experiments, have demonstrated positive changes, among others, in the organic carbon content, k_{sat}, the structure of soil aggregates, and other physical and chemical properties of the soil, when using organic wheat straw in zero tillage and conservation tillage. In another experiment, it was demonstrated that soil under the layer of 10 cm-thick mulch of maize residue possessed better properties (all except porosity) as compared to unprotected soil and mulch layers 5 and 15 cm thick (Kakaire et al., 2015).

Soil analysis carried out by Domagała-Świątkiewicz and Siwek (2015) after cucumber and tomato cultivation showed a decrease in the number of small soil aggregates and an increase in the number of large ones under PLA and PBS (polybutylene succinate) mulches. During the high humidity season, a reverse effect was observed. In addition, protecting the soil contributed to an increase in its bulk density and a reduction in its water capacity in a year with high precipitation. In another experiment, as a result of mulching with black ldPE film, an increased share of 0.6-1.5 mm aggregates was observed, along with better physical parameters of the soil, and a reduction in the concentration of nitrate-N form, with an increase in ammonium-N form, in comparison with non-woven PP and unprotected soil (Siwek, 2002). As evidenced by the study, soil responds to mulching in various ways depending on the type and thickness of the mulch. In most cases, this results from the biological interaction with the mulch, as well as the changes in their physical properties due to the protection against rain erosion.

WEED INFESTATION

The elimination of undesirable plants should take place in the period preceding the sowing or planting of vegetables (Brainard et al., 2013). The reduction of weed infestation using herbicides is performed on a small scale due to the limited availability of herbicides authorized for use (Matyjaszczyk and Dobrzański, 2017). Multiple mechanical weeding of the field is associated with high energy and financial cost. It also contributes to the excessive drying of the soil and disturbing its structure. Manual weeding is problematic due to the overgrowth of the shallow root system of cucurbits with the roots of weeds, so that the damage becomes unavoidable. Soil mulching, on the other hand, is an effective and safe method (Abouziena and Haggag, 2016). In the case of mulching with material that transmits solar radiation to a large extent, herbicides or other techniques are used, for instance, application of heat energy (Martín-Closas et al., 2017). Under conditions of water stress, the presence of weeds can reduce the crop yield by up to 50% (Abouziena et al., 2014). According to Schonbeck (2015), who quotes several other authors, the critical period of competition, for cucurbits, falls on the first 4-6 weeks after planting. During this time the plants grow rapidly, and they cover the soil in the spaces between the rows.

The diminishing effect of mulches on weed populations is reduced to the creation of a physical barrier and blocking of the PAR radiation. It is also important that mulches transmit heat waves in the far-infrared range, which inhibits the growth of undesirable plants at an early stage of their development. This is confirmed by the results of studies conducted by Ngouajio and Ernest (2004) on the assessment of weed infestation using PE mulches with different wave transmittance in the 400-1100 nm range. The largest numbers of weeds and their largest biomass were observed under white film, followed by grey. The remaining black, brown and green mulches effectively limited the development of weeds, the number of which did not exceed 25 plants per m^2. The effectiveness of weed protection when using a thick layer of organic mulch is so high that the simultaneous application of chemical preparations may not produce the expected result, e.g. due to the difficulty in displacement of or interaction with organic matter (Marble, 2015).

A study by Broschat (2007) found that wood mulches (bark and pine needles, finely flaked eucalyptus and cypress chips) significantly reduced the development of dicotyledonous weeds. A positive correlation was observed between the thickness of organic material and the reduction in overall weed infestation (van Donk et al., 2011; Jodaugienė et al., 2014). In addition, allelopathins (for instance, phenols, or benzoxazine) can reduce the amount of herbicides used, for example, by decreasing weed germination rate (Tabaglio et al., 2008), but they can also affect the development of crop plants (Bantle et al., 2014). As reported by Gill et al. (2011), the vegetal mass of a 3-5 cm thick mulch of *Vigna unguiculata* plants degraded the fastest compared to a mulch consisting of the biomass of *Crotalaria juncea*, *Sorghum bicolor* × *S. sudanense* and pine bark of the same layer thickness. As a result, the site mulched with the leaves of *Vigna unguiculata* plants, as well as the unmulched one, had a higher level of weed infestation with dicotyledonous species compared to the other organic mulches.

Under the specific conditions of the environment inside the high plastic tunnel, from among several types of organic mulch, newspaper sheets degraded the most, followed by flaked newspapers, and wheat straw the least. The ratio of degradation of these mulches, assessed visually at the end of vegetation, was 4.9 : 3 : 1. However, all of these mulches significantly reduced the level of weed infestation in the summer cultivation of cucumber (end of June-early September) (Sanchez et al., 2008). Biodegradable mulches made from waste products consisting of short cotton fibres, crushed immature seeds and small pieces of vegetative material are equally effective in reducing weed infestation as the standard ldPE films (Johnson et al., 2014).

Taking into account the rapid growth of cucurbits, the use of mulches is of great importance in limiting weed infestation, especially at the beginning of the growing season, when the soil is not fully covered with the crop.

PEST OCCURRENCE

For a long time now, non-chemical methods of combating pathogens and weeds have been sought in many countries. One of them is the so-called soil solarisation based on the use of colourless film mulches, such as PE, PVC, or EVA. They must be mechanically strong and as transparent to sunlight as possible in order to facilitate the maximum possible heating of the soil during the day and reduce heat loss at night. After solarisation, the availability of mineral components in the soil is increased, which reduces the cost of production associated with fertilization (Puoci et al., 2008; Pramanik et al., 2015). The key parameter for the effectiveness of the treatment is the temperature, which remains above 50°C for subsequent days. This causes many pathogens to die. An increase in the amount of beneficial microorganisms (e.g. *Bacillus* bacteria or *Trichoderma* fungi) has been observed in the soils subjected to solarisation. This may be due to their increased resistance to high temperatures, or to the relatively rapid reproduction and re-colonization of the soil. The effectiveness of this method is strongly dependent on climatic conditions, which, in consequence, justifies its practical application only in warm climate regions. One modification may be the use of solarisation together with chemical preventive measures against pests. Under conditions of elevated temperature, it is also preferable to use organic fertilizers whose decomposition proceeds faster with more rapidly growing microorganisms (Dai et al., 2016).

It has long been known that pests are also responsible for the spread of viruses. According to Ali et al. (2012), in the southern part of the United States, more than half of viral infections in cucurbits were caused by species from Aphidoidea and Aleyrodoidea superfamilies. Mulching the soil using polymers with a UV-reflecting surface (280-400 nm) is a method for limiting or delaying viral vectors, which merits a broader dissemination, as confirmed by the study (Nyoike et al., 2008; Murphy et al., 2009). For example, in the cultivation of watermelon, 71.4% fewer thrips and 24% less damage by the *Watermelon bud necrosis virus* (WBNV) were recorded on sites using silver mulch (30 μ) compared to the control (Shruthi et al., 2017). Owing to its properties, silver mulch can make it considerably more difficult for the insects to locate the plants, but on the other hand, the number of predatory insects can also be reduced (Diaz and Fereres, 2007).

Observations have shown differences in the number of aphids and their preferences or repellent effects depending on the colour of the mulch (Žanić et al., 2009a). However, it is difficult to fully determine the relationship between the type and colour of mulch used and the scale of the occurrence of live organisms. Differences in the infestation of cultivated plants with pests may be due to their variable abundance during the growing season (Žanić et al., 2009b). In addition, allelopathic substances released in the decomposition process may deter pests (Roger-Estrade et al., 2010). It is also desirable to emphasize the significant role of weeds as a feeding place for both harmful and beneficial arthropods. As a result of mulching, Blanco-Canqui and Lal (2007) observed an upward trend in the number of earthworms in proportion to the wheat straw layer thickness.

Covering the soil with the biomass of Fabaceae plants accelerated, by rapid degradation, the colonization of the site by fauna such as Hemiptera and other insects; silmilarly so on the control site (Gill et al., 2011). Mulching also protects the fruit – for example, watermelon – from direct contact with the soil, and thus prevents the development of diseases.

GROWTH, DEVELOPMENT, YIELD, AND QUALITY OF CUCURBITS GROWN ON MULCHED SOIL

The response of plants to changing structural properties of the soil and to environmental factors under mulching is generally an increase in yield, as well as positive changes in plant growth and development.

Phytometric measurements conducted by Habimana et al. (2014) on mulch-grown watermelons, at varying spacing, 60 days after sowing, clearly emphasize the beneficial effect of mulching on the length of the main shoot, the number of leaves and lateral shoots. There was a trend that, as the spacing increased, so did the values of the tested parameters. In addition, the fastest growing and highest yielding plants were those on the mulch of polyethylene film, followed by wheat straw, as compared to unprotected soil. Also on black film (PE 0.125 mm), statistically significant faster emergence and earlier coming into the flowering period as well as 76% higher fresh weight of the aboveground part were noted in pumpkin plants (Mahadeen, 2014). Earlier development of this plant species was also noted in Egypt in February, outside the typical cropping season. The overall yield was 38.8 and 51.1% higher, and the average fruit dry matter was 0.9 and 2.05% higher due to the use of black and colourless PE mulch, compared to the plants cultivated on unprotected soil (Attallach, 2016). In a pot experiment, it was also observed that mulching with red PE film with a thickness of 0.05 mm resulted in a decrease in the relative water content of watermelon leaves. On the site with the mulch, watermelon plants formed greater biomass of the subterranean and aboveground parts, and the assimilation area of the leaves was larger, which increased transpiration but decreased evaporation (Ferus et al., 2011). The increase in the transpiration level, in the absence of significant differences in the intensity of cucumber photosynthesis, was confirmed using straw as a mulch (Hnilička et al., 2012). After growing *Cucumis melo* var. *reticulatus* on biodegradable films, Filippi et al. (2011) expressed their belief about the importance of the high rate of mulch degradation for the quality of the fruit, while adherence should be avoided due to limit skin colouration during ripening of fruits. Furthermore, the plants growing on these mulches generated higher yields of better quality fruit, that is, with higher sugar concentrations. In the conditions of northeastern Poland, a beneficial effect of mulching with black film on the dry matter content of melon has been observed. Concentration of nitrates increased in places where mulch and direct cover were combined (Majkowska-Gadomska, 2010). Crop residues mulch with the addition of peat, also had a beneficial effect on the synthesis of dry matter, crude fibre, protein as well as ash content in oilseed pumpkin (Černiauskienė et al., 2015).

Studies conducted in the United States, in Wyoming, testify to the high utility of dark blue polyethylene mulch for yielding cucurbit vegetables, that is, cantaloupe melons, cucumbers and zucchinis. The commercial fruit yield of plants of these species was approximately 35, 30 and 20% higher, respectively, than of those grown on black film. The lowest yields were obtained from sites with black-and-white mulch (melon), and yellow mulch (cucumber and zucchini). In the authors' opinion, the response of plants to the colour of the film may vary depending on the location of the crop, that is, depending on climatic factors (Orzolek and Lamont, 2013). As reported by Minuto et al. (2008), the total yield of zucchini obtained from cultivation on PE and biodegradable mulches can exceed up to two times the crop yield on unprotected soil.

In an arid climate (Iran), Fatemi et al. (2013) observed a significantly increased total yield of summer squash grown on red and blue plastic films by 100% and 31.5%, respectively, in comparison with bare soil. López-Tolentino et al. (2016b) recorded that the leaves of cucumber plants growing on an oxo-degradable mulch had a larger assimilation surface, which, according to the authors, was a physiological response to the increase in soil temperature. Similar results have been reported by other authors with regard to the intensity of photosynthesis and fruit yield of this plant (Ibarra-Jiménez et al., 2008). The same authors and Torres-Olivar et al. (2016) under Mexican climatic conditions recorded increased marketable, early and total yields of cucumber grown on coloured polyethylene mulch (including oxo-degradable) by, respectively, 12.9-46.6, 32.5-136.9, 10.8-48.5 (blue), 19.4-62.1, 36.1-148.6, 17-58.8 (red), 22.3, 60.3-165.9, 20.3-43.9 (white), and 63.4, 29.3, 58.8% (green film). Also White (2004) in central Florida (USA) observed higher marketable and total yields of summer squash cultivated on soil mulched with white, white on black, silver, silver on black, blue and red PE films by 50.3 and 60; 60 and 69.6; 58.9 and 80.2; 55.4 and 70; 56 and 52.2; 26.3 and 30%, respectively, relative to bare soil. Higher yields of cucumber fruits were also harvested using non-woven fabrics: photodegradable PP (0.02% iron stearate) and PLA, both with a surface weight of 50 g m^{-2}. The fruits showed a decreased dry matter content, with a similar amount of soluble sugars compared to the fruit from the control site (Siwek et al., 2015). Kosterna et al. (2010) observed increases in dry matter, total and reducing sugars, and vitamin C in melon as a result of mulching with black polyethylene film. In the experiment where mulches of rice husks (2 cm thick layer) and of white and black ldPE films were used, higher solubility (°Brix index) and higher yields of watermelon (Saraiva et al., 2017) were obtained. The yield of cucumbers cultivated on a soil mulched with wheat straw and with black, yellow, and transparent PE films increased by 67.7, 109.2, 124.8 and 129.3%, respectively, relative to the non-mulched site (El-Shaikh and Fouda, 2008).

In temperate climates (southern Finland), the yield of cucumbers increased by 39-91% as a result of covering the soil with packaging paper lined with black biodegradable film, and it was comparable to that obtained from plants growing in a soil mulched with only the film of that same colour (Haapala et al., 2015). On the other hand, Kołota and Adamczewska-Sowińska (2011) observed a decrease in early and total yields of summer squash cultivated on soil mulched with white PE film by 20.1 and 13.3%, respectively. No significant differences in yield and amounts of individual components were reported by Saraiva et al. (2012) for *Cucumis melo* var. *inodorus* cultivated on black ldPE film (0.025 mm) as well as black and green (0.015 mm) starch-based biodegradable films; also, Johnson et al. (2014), for cantaloupes and watermelons, using a mulch of black ldPE film (0.025 mm) and compressed fibres coated with black latex or cooked linseed oil, approximately 1 cm thick. In an experiment with zucchini and cantaloupe melons, it has been demonstrated that the colour of the mulch has more impact on the yield than whether or not it is degradable (Waterer, 2010).

In China, covering the soil with gravel had a beneficial effect on the yield of watermelons, which more than doubled. Also the sugar content in the fruit was observed to increase, irrespective of the size fraction of the material used for mulching (Xie et al., 2006). Among the organic and synthetic mulches tested in the cultivation of sponge gourd, black polyethylene film has proven to be the best, as confirmed by the yield results (increase by 169.7%). Other mulches such as farmyard manure, white PE film, grass and rice straw increased yields by 92.5%, 8.1%, 26.5% and 15%, respectively, compared to bare soil (Khan et al., 2015). Differences in

Table 1. Marketable, early and total yields of cucurbit crops grown on black mulches

Type of climate	Authors	Country	Crop	Kind of mulch	Marketable (MY), early (EY) and total (TY) yield increase/ decrease as compared to uncovered control (%)
temperate	Kołota and Adamczewska-Sowińska, 2011	PL	summer squash	black PP nonwoven fabric	-5.1 EY, -13.1 TY
	Kołota and Adamczewska-Sowińska, 2011	PL	summer squash	black PE film	10.4 EY, 1.9 TY
	Kołota and Balbierz, 2015	PL	summer squash	black PE film	15.8 MY, 15.7 EY
	Kołota and Balbierz, 2015	PL	summer squash	black agrotextile	13.2 MY, 13.2 EY
	Siwek, 2002	PL	cucumber	black PE film	184.1 MY
	Siwek, 2002	PL	cucumber	black PP nonwoven fabric	138.4 MY
	Siwek et al., 2015	PL	cucumber	black PP nonwoven fabric	24 MY
	Siwek et al., 2015	PL	cucumber	black PP photo. nonwoven fabric	8 MY
	Siwek et al., 2015	PL	cucumber	black PLA	64 MY
	Spiżewski et al., 2010	PL	cucumber	black PE film	≈8.4 MY, ≈6.5 TY
warm	Attallah, 2016	EG	summer squash	black PE film	38.8 TY
	Ibarra-Jiménez et al., 2008	MX	cucumber	black PE film	147.9 EY, 36.1 TY
	Lopez-Tolentino et al., 2016b	MX	cucumber	black PE film	50 MY, 34.6 EY, 42.6 TY
	Mahadeen, 2014	JO	summer squash	black PE film	63.6 EY, 61.4 TY
	Torres-Olivar et al., 2016	MX	cucumber	black film	21.2 MY, 79.3 EY, 21.6 TY
	White, 2004	USA	summer squash	black PE	44.6 MY, 52.2 TY
	White, 2004	USA	summer squash	black bio.	27.4 MY, 31.9 TY

marketable, early and total yields of cucurbit crops grown on black mulches are shown in Table 1.

The effects of mulching on the growth and development, and on the yielding and chemical composition of cucurbits are not clear. This is especially due to the nature of the mulching materials and the underlying environmental conditions, resulting in the differences in plant responses.

Literature on the influence of mulching on the quality of yield during and after storage of cucurbits vegetables was not found.

CONCLUSIONS

The beneficial impact of soil mulching around cultivated plants is well known, and has long been practiced. It mainly amounts to the protection against erosion and evaporation, coupled with the modification of microclimatic conditions. The end result of vegetable cultivation using mulching is often an increase in yield and its biological value. A comparative analysis of the discussed research results suggests that there is a strong correlation between the variable environmental conditions produced by the mulch and the size and quality of the yield of cucurbit vegetables. Diverse climatic conditions, prevailing in various geographical regions of the world, as well as the differences in the physical and chemical properties of coloured mulches, should determine the right selection for a particular region. With the development of organic farming around the world, more data is needed on the effectiveness of using cover crops subjected to natural or mechanical disintegration before the cultivation of cucurbits. Taking into account the strong growth parameters and the long shoots, typical of most of the vegetables in this family, the possible practical use of so-called live mulches seems to be limited.

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AUTHOR CONTRIBUTIONS

P.B. – reviewed the relevant literature, wrote the manuscript and prepared it for submission; P.S. – concept of paper, contributed to such aspects of this manuscript as development of the idea and critically revised the text.

CONFLICT OF INTEREST

The Authors declare no conflict of interest.

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