Pregledni rad

Mulching in vegetable production: effects on growth, yield and pests management

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Abstract

Mulching is a common practice in the production of vegetablesduring last more than twenty years. The technology is applicable to the most vegetable crops grown either outside or in protected cultivation and it is often accompanied with drip irrigation and use of water soluble fertilizers. There are many benefits of soil mulching, and among the most important, are increased soil temperature in root zone which enhances early spring vegetative growth and development, leading to increase of yield in early harvests.In addition, mulching could reduce water use and weed growth, and contribute to better control of pestsattacks. The most used mulches worldwide are plastic and PE mulches,but recently debate was raised about serious environmental constrains due to problems with their disposal and reuse.Therefore, more efforts should be done on development of biodegradable mulches or use of organic mulches that may be incorporated into soil after harvest. The results of different experiments on testing the effect of PE mulches on growth, yield, and quality of watermelon and tomato crops grown in the Mediterranean part of Croatia, as well as comparison to straw mulch are discussed in this paper.

Key words: fruit quality, polyethylene film, straw mulch, pest management, soil temperature, yield

Introduction

Conventional agricultural production systems are defined as cropping systems that are most commonly used for a given area that utilize synthetic agricultural pesticides and fertilizers (Arriaga et al., 2017). These systems are intense in the use of tillage and chemicals and as such, they deteriorate soil health and inevitably lead to poor biological, chemical and physical properties of soil. During the 80's intensive research has been done on agricultural systems that would reduce the problem of environment pollution and soil degradation due to intensive use of conventional agriculture (Hoyt and Hargrove, 1986; Paine and Harrison, 1993).The improvement of water use efficiency has been more accentuated because the water costs contribute to food price but also the quantity of quality water is rather limited for agricultural use. Therefore, the mulching was proposed as feasible strategy contributing to water savings in addition to other advantages.

Mulches can be defined as materials that are applied to (or grown upon) the soil surface, which differs them from materials that are incorporated into the soil surface, such as soil amendments. From this definition any material can be considered a mulch if it is laid or grown over the soil surface, although, all mulches are not equally beneficial. Mulches have been used in

agriculture for various reasons, but water conservation and erosion control are of particular importance especially in arid and semi-arid regions (Bhardwaj, 2013). Other benefits from using mulches are soil temperature modification, improvement of soil fertility and health, reducing weed growth and pest infestation, increase of crop quality and yield, etc. (Van Derwerken and Wilcox, 1988, Dilip Kumar et al., 1990; Ban et al., 2009). Mulching can reduce soil deterioration by preventing runoff and soil loss and it can reduce soil water evaporation, although it is dependent on the soil type, rainfall pattern and evaporative demand (Jalota et al., 2001).

Mulches can be divided in two main categories based on their types: organic and inorganic. Organic mulches are derived from plant and animal materials which includes straw, hay, compost, leaf mold, sawdust, peanut hulls, wood chips, shavings and animal manure (Bhardwaj, 2013). They are important part of sustainable agricultural practice that is directed to environment conservation and long-term ecological balance of the soil ecosystem. The organic mulches could be utilized by growing cover crops during fall, winter and early spring (Teasdale and Abdul-Baki, 1998). Plowing these cultures in spring is not the most efficient way of fertilization due to rapid mineralization of organic matter. Also, weed growth is stimulated and possibility of soil erosion is increased. Research has shown that it is better to leave the cover crops and use the biomass as mulch (Creamer et al., 1996; Tesdale and Abdul-Baki, 1998; Masiunas, 1998).

Benefits of organic mulches include reduction in nitrate leaching, erosion, improvement of soil physical properties, nitrogen balance, soil biological activity, regulation of soil temperature, water retention, etc. (Hooks and Johnson, 2003; Muhammad et al., 2009). Disadvantages of organic mulches include considerable human labor for mulch spreading, expenses and logistical problems of large-scale use of mulch (Bhardwaj, 2011, 2013).

Inorganic mulch includes a wide range of plastic films, mostly polyvinyl chloride and polyethylene based. Most used type of plastic mulch is linear low density polyethylene film (PE). Plastic mulch films have the benefit of increasing temperature around plants in period of low temperature and weed control, as well as, improvement of agronomic parameters in some plants (Arora et al., 2002). Inorganic mulch accounts for the largest volume of mulch that is used in commercial production (Bhardwaj, 2013). In Croatia, mulching is a common practice in vegetable production; with black polyethylene films being most frequently used (Goreta et al., 2005).

Effect of PE mulch on plant growth and development

Mulches have frequently been used to enhance the establishment of woody and herbaceous species. Mulching provides a more favorable environment for plant growth which results in enhanced vigor and healthier plants. It was demonstrated by Sarolia and Bhardwaj (2012) that mulched plants grow more uniformly than unmulched plants. Tomato growth was shown to be stimulated with the application of black PE film as it increased plant height and number of laterals (Lourduraj et al., 1996).Similar results have been reported on tomato grown under nutrient paper mulch (Gao et al., 2001).Similarly to tomato, black plastic mulch, compared to other mulches, has been shown to have the greatest effect on plant height, plant spread and highest number of branches in marigold (Chawla, 2006).

Cucumbers, watermelons, peppers, muskmelons, and similar warm season vegetables respond to mulching by early maturation and yield increase. Early maturation is probably due to temperature modification and maintenance of favorable temperatures during the growth season. In general, black polyethylene mulches that are applied to planting beds before planting will warm up the soil and promote growth, which results in earlier harvest (Lamont, 2005). The use of polyethylene films for enhancing earliness and increasing yield has been demonstrated in different vegetable crops

(Goreta et al., 2005; McCann et al., 2007). Similar results of beneficial effect of PE mulches on early harvest and higher yield were obtained by Romic et al. (2003) for watermelon and Walters (2003) for zucchini. Effects of different types (colors) of PE mulch on watermelon production have been investigated by Ban et al. (2009). Black and clear films had advantage over white and semitransparent brown and green films due to higher soil temperature and positive effect on vegetative growth and yield.Generally, during the first 60 days after planting, a significant correlation of vine length, leaf number, early and total yield with both the sum and average soil temperatures at 5 cm depth under PE films was observed (Table 1). Lack of response was observed when the soil temperatures were optimal for watermelon growth (Pula, 2003) or too low for any growth (Opuzen, 2004).

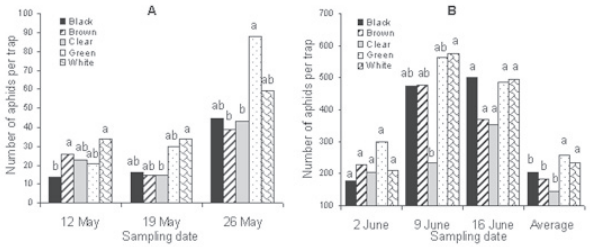
Table 1. Coefficient of determination (r^2) between vine length, leaf number, early and total yield and sum of temperatures (Sum) or average daily temperatures (Avg) measured in root zoneduring the first 60 days after plantingof watermelon grown on colored PE films at Pula andOpuzen in 2003, 2004, and 2005 (adapted from Ban et al., 2009)

		Vine length		Leaf number		Early yield		Total yield	
Location	**Year**	Sum	Avg	Sum	Avg	Sum	Avg	Sum	Avg
Pula	2003	0.78^{ns}	0.79^{ns}	0.57^{ns}	0.56^{ns}	0.03^{ns}	0.03^{ns}	0.38^{ns}	0.39^{ns}
	2004	0.95*	0.96*	0.98**	0.99**	0.96*	0.95*	0.85*	0.84*
	2005	0.92*	0.91*	0.70^{ns}	0.68^{ns}	0.95*	0.95*	0.88*	0.89*
Opuzen	2004	0.33^{ns}	0.33^{ns}	0.74^{ns}	0.73^{ns}	0.01^{ns}	0.01^{ns}	0.05^{ns}	0.05^{ns}
	2005	0.89*	0.88*	0.94**	0.93**	0.95**	0.94**	0.96**	0.96**

Significant linear regressions are denoted as: ns, *, **, ***, insignificant or significant at $P \leq 0.05$, 0.01, 0.001, respectively.

In addition, to positive effect on growth and yield as a consequence of soil warming at early season, mulch controls weed growth by providing a physical barrier which reduces germination, suppresses seedling emergence and reduces growth of many weeds (Vander Zaag et al., 1986). Compared to black, blue, brown, white on black mulches, white or clear mulches have little effect on weed control (Bond and Grundy, 2001).

Effect of mulching on insect pest control has been observed in reduction of whitefly population on plants grown on transparent polyethylene mulch and in catching aphids on yellow traps (Bhardwaj, 2013). Repellent effect of transparent mulch has been demonstrated for aphids (Jones, 1991), whiteflies (Kelly et al., 1989) and trips (Greenough et al., 1990). The effect of mulching in controlling aphid populations in watermelon production was reported in Ban et al. (2009) where the number of winged aphids on black, brown and clear PE films was generally lower than ongreen or white films (Graph 1). Additional value for black and clear PE films was the positive effect on growth parameters and watermelon yield.



Graph1. Number of winged aphids caught in yellow water traps on different colored polyethylene mulches in watermelon (adapted from Ban et al. (2009))

Žanić et al. (2009) showed that four most economically relevant aphid species (Acyrtosiphonpisum (Harris), Aphis craccivora Koch, Aphis gossypii Glover and Myzuspersicae (Sulzer)) showed different responses to mulch color. Their results demonstrate that mulch affects total number of aphid populations, and the presence of individual species is dependent on mulch color which infers that certain mulches can be used in crop protection management. Results of this study, for overall season number of aphid species per yellow pan trap by mulch color are presented in Table 2.

Table 2. Overall season number of aphid species per yellow water pan trap in watermelons grown on differently colored mulches (adapted from Žanić et al. (2009))

	Mulch colour				
	Black	Brown	Clear	Green	White
Aphid species	(No. of aphids per trap)				
Overall season					
Aphis fabae*	35.3 bc	14.0 c	52.0 ab	29.3 bc	80.3 a
Aphis gossypii	231.0 a	210.3 ab	114.7 b	164.0 ab	250.3 a
Brachycaudushelichrysi	8.7 a	4.3 ab	4.0 ab	4.0 ab	1.3 b
Brevicorynebrassicae	65.7 a	46.0 b	7.3 c	33.3 b	45.7 b
Cavariella sp.	0.0 b	0.3 ab	0.0 b	0.3 ab	2.0 b
Dysaphisplantaginea	0.3 ab	2.0 a	0.3 ab	1.3 ab	0.0 b
Hyadaphisphoeniculi	0.3 b	3.3 a	5.0 a	2.7 ab	4.3 a
Hyalopteruspruni	5.0 ab	6.0 ab	5.3 ab	9.3 a	1.7 b
Hyperomyzuslampsane	26.3 bc	15.0 c	27.0 bc	59.3 ab	81.7 a
Hyperomyzuspieridis	3.3 b	6.3 ab	4.3 ab	8.0 ab	9.3 a
Macrosiphumrosae	0.0 b	0.0 b	0.0 b	1.0 a	0.3 b
Myzuspersicae	93.0 b	117.3 b	103.3 b	270.7 a	261.3 a
Phyllaphisfagi	1.7 ab	3.7 ab	3.0 ab	5.0 a	1.3 b
Tetraneurasp.	3.0 ab	6.3 a	2.0 ab	2.7 ab	1.3 b
Therioaphistrifolii	0.0 ab	0.0 ab	1.7 a	0.0 ab	0.0 ab

*Means within rows followed with different letters are significantly different at P ≤ 0.05 by LSD test

When the black PE film was compared to bare soil and straw mulch the total number of aphids per trap was the highest at black PE film on two dates, however, there was no significant difference among treatments for overall season (Table 3).

Table 3. Number of winged aphids per trap in watermelon grown on bare or mulched soil during spring and overall season (adapted from Žanić et al. (2013))

Treatment	**Number of aphids per trap**					
	16 May	23 May	30 May	6 June	13 June	Season
Bare soil	38.3 a*	2.0 c	101.0 a	65.7 b	76.3 a	302.0 a
Black PE mulch	44.0 a	97.7 a	84.3 a	105.3 a	97.3 a	427.3 a
Straw mulch	61.3 a	60.7 b	92.7 a	47.3 b	43.0 a	305.0 a

*Means within column followed with different letters are significantly different at p ≤ 0.05 by LSD test.

Basis of soil solarization process is the fact that mulches can produce soil temperatures that are high enough to control weeds, plant pathogens and nematodes (Stapleton et al., 2005).

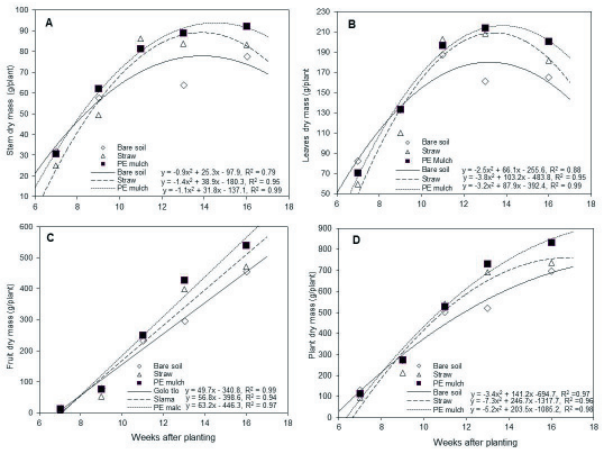
Positive effects of mulching on pest and weed control and reduction of plant stress may lead to decrease in the use of chemicals used for pest and weed control. Reduction in the use of these chemicals reduces the cost production and may have positive effect on beneficial insects, bacteria and fungi and contribute to overall soil health.

There is also an economic importance of using mulch. Sutagundi (2000) reported higher net returns and benefit to cost ratio in chili production using straw mulch. Cost saving are also noticeable in reduction of pesticide use and weed control management. However, the use of PE mulch or straw mulch in tomato production causes the need for hand picking tomato fruit which increases production costs by up to 50% (Oplanić et al., 2008).

Comparison of PE and straw mulch in vegetable production

A side to all benefits of PE mulches and positive effects on yield, earliness and particularly improvement of water use efficiency, the main disadvantage is that it must be removed and disposed of at the end of each season. However, PE mulch could not be completely removed from a field and it remains in soil for decades andcan inhibit plant growth, affect soil physically and may enter the food chain (Bandopadhyay et al., 2018). The cost and effort of recovering and recycling used mulching films may be a problem in the long term. Therefore, much effort has been done to develop biodegradable mulches or to use organic remains form agriculture that could be incorporated into soil after season. Materials that are locally available prove to be a good choice for mulch, such as timber harvest residues, unprocessed bark and straw mulch (van Nierop and White, 1958; Ringe and Graves, 1990). Aref et al. (1996) showed that tomato yield significantly increased under hairy vetch mulch compared to bare soil.

Straw is widely available and can be good alternative to plastic, particularly for organic agriculture.Ban et al. (2008) reported that straw mulch decreased plant growth, delayed flowering and branching of tomato compared to PE mulch. Increase in tomato plant mass, leaf mass, as well as increase in tomato fruit yield on black PE film compared to straw or bare soil was observed by Grbac et al. (2010) (Graph 2). Similar results were obtained in watermelon where black PE mulch compared to straw and bare soil increasedwatermelon stem length, improved vegetative growth and early maturation and increased early and late yield (Ban et al., 2010).



Graph 2. Increase in dry mass of tomato stem (A), leaf (B), fruit (C), above ground plant parts (D) grown on bare soil, mulched with straw and PE film (adapted from Grbac et al. (2010))

The superior influence of black PE mulch on growth and yield of vegetable grown in early spring is directly liked to its ability to increase root zone soil temperature(Díaz-Pérez, 2010), while decrease of root zone temperature was found under straw mulch compared to bare ground (Kar and Kumar, 2007). Similar results were observed in study of Perkovic et al. (2018), and accumulation of growing degree days (T_{base} =15 oC) was higher under black PE mulch compared to straw and bare soil in watermelon production and the results are presented in Table 4.

Table 4.Growing degree days (GDD T_{base} =15 °C)
in years 2010 and 2011. Adopted from Perković et al. (2018)

Treatment	GDD	
	2010	2011
Bare soil	247 b*	200 b
Black PE film	284 a	228 a
Straw mulch	224 b	154 c

*Means within column followed with different letters are significantly different at p ≤ 0.05 by LSD test.

Fruit quality is particularly important in vegetable production and there is ample evidence that it could be improved with mulching. Mulch keeps fruits cleaner by preventing contact with soil, reduces soil rot, blossom end rot and fruit cracking (Bhardwaj, 2013).

Horvat et al. (2010) showed that the use of PE mulch combined with increased fertilization significantly increased lycopene and sucrose concentration in tomato fruit, whereas glucose, fructose and ascorbic acid content were higher for bare soil (Table 5).

The effect of mulching on sensory properties was observed in watermelon, and the fruit of watermelons grown on black PE mulch were better scored compared to ones grown on bare soil or straw mulch (unpublished data).

Table 5. The effect of mulch on tomato fruit quality(adapted from Horvat et al. (2010))

Treatment	**Glucose** (g/kg)	**Fructose** (g/kg)	**Sucrose** (g/kg)	**Lycopene** (mg/100g)	**Ascorbicacid** (mg/100g)
Bare soil	13.4 a	16.4 a	0.46 b	32.4 c	28.6 a
Black PE film	11.5 b	11.3 b	0.85 a	41.3 a	16.7 c
Straw mulch	9.3 c	9.5 c	0.52 b	38.9 b	18.9 b

*Means within column followed with different letters are significantly different at p ≤ 0.05 by LSD test.

Ample of evidence is reported on positive effect of plastic mulch in vegetable production, but impact of plastic mulching as a standard agricultural practice on soil quality is still unknown in terms of potentially deteriorating soil or negatively influence soil microbiome. The holistic approach is needed that will develop the production technology ensuring high yield and food quality with less environment pressure. The testing of different cover crops and/or living mulches adjusted to each particular pedo-climatic condition could be sustainable alternative to plastic in vegetable production.

Conclusion

Positive effects of mulches (organic or inorganic) in crop production have been widely discussed. It has been demonstrated that mulch provides benefits through conservation of soil and water; it enhances soil biological activity and improves chemical and physical properties of soil, either directly or indirectly through the decrease in pesticide, herbicide and fungicide use. In

arid and semi-arid regions, mulch improves soil moisture, reduces runoff and soil erosion. It also helps in weed and pest control. Added to these benefits are also the benefits of early maturation, increase in vegetative growth, quality and crop yield. Different types of mulching materials are used (organic and inorganic) but black PE film has been proven to be superior, and preferred by growers. Due to inevitability of water problems in the future, mulching is imposed as the easiest solution for water and soil conservation. However, intensive work on development of biodegradable and/or organic mulches comparable to PE mulches is needed in order to reduce micro plastic residues in agricultural soils.

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Upotreba malča u povrćarskoj proizvodnji: Utjecaj na rast, prinos i kontrolu štetočina

Sažetak

Upotreba malča u povrćarskoj proizvodnji je ustaljena praksa u zadnjih nešto više od dvadeset godina. Malčiranje se može primijeniti u uzgoju većine povrćarskih kultura koje se uzgajaju na otvorenom ili u zaštićenom uzgoju, te je često popraćeno navodnjavanjem kap po kap i upotrebom vodotopivih gnojiva. Mnoge su prednosti upotrebe malča od kojih je jedna od najvažnijih povećanje temperature tla u zoni korijena koja poboljšava rani proljetni vegetativni rast i razvoj, te dovodi do povećanje prinosa u ranoj berbi. Uz to, malčiranje može smanjiti upotrebu vode i rast korova, te doprinijeti boljoj kontroli napada štetočina. Plastični i PE malčevi su najkorištenije vrste malčeva u svijetu, ali u zadnje vrijeme stavljen je naglasak na ozbiljna okolišna ograničenja takvih malčeva zbog problema sa zbrinjavanjem i ponovnom upotrebom. Stoga su napori usmjereni ka razvoju biorazgradivih malčeva i korištenju organskih malčeva koji se mogu usvojiti u tlo nakon berbe. Rezultati različitih istraživanja na utjecaj PE malčeva na rast, prinos i kvalitetu lubenice u rajčice uzgajanih u mediteranskom dijelu Hrvatske u odnosu na malč od slame su raspravljeni u ovome radu.

Ključne riječi: kontrola štetočina, kvaliteta ploda, malč od slame, polietilenski film, prinos, temperatura tla