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Effect of degradable mulch on tomato growth and yield under field conditions

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Abstract

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The degradable mulch was synthesized to be as anenvironmentally friendly alternative to polyethylene plastic mulch; its adoption could help in alleviating the environmental pollution as well as the removal and disposal problems of polyethylene mulch. The present study was conducted to evaluate the degradable mulch performance on tomato growth and yield under Jordan environmental conditions. The study consisted of four mulch treatments (polyethylene, oxo-degradable, biodegradable mulches and no mulch (bare soil) as a control).

The current results showed that oxo-degradable and biodegradable mulches are capable of soil moisture preservation similar to polyethylene mulch. All mulching plot had significantly higher soil temperature than bare soil. The benefits of biodegradable mulch on soil microbial community (bacteria and fungi) and soil organic carbon content were well evident with a significant effect. The improvement of tomato plant growth was noticed mainly in leaf area, fresh and dry weight of shoot under biodegradable mulch treatment. The current findings revealed a significant difference in percent visual degradation among mulch treatments. The biodegradable mulch had the highest percent of visual degradation (80%) followed by oxo-degradable mulch (40%). The degradation of polyethylene mulch, as expected (3.17%), was less evident, remained practically intact and had the lowest percentage of visual mulch degradation at the end of the growing season. Based on our results, the using of biodegradable mulch can perform similar and/or better than polyethylene mulch in term of tomato growth and yield, which could be adopted as a sustainable alternative to polyethylene mulch. Whereas, oxo-degradable mulch, despite having a beneficial effect similar to polyethylene mulch on tomato growth and yield, it was not satisfying to be an environmentally friendly alternative to conventional plastic mulch due to fragmented into small pieces, and left too many plastic residues in the experiment site that needs manual removal.

Keywords: polyethylene mulch; oxo-degradable mulch; biodegradable mulch; degradation

Introduction

Plastic mulch is one of the main important agricultural practices used to optimize production and quality of tomato (*Lycopersicon esculentum* Mill.) in Jordan. Polyethylene is used as a plastic material for mulching, because it is low cost, easy to process, high durability, and it is not affected by acids, bases, or salts (Kaseem et al., 2012). Despite its beneficial impact on the commercial production of horticultural systems, the sustainability of producing crops through the use of polyethylene mulch has been called into question (Hakkarainen & Albertsson, 2004). Its utilization led to problems associated with its management at the end of the growing season (Subrahmaniyan & Zhou, 2008). Further, the absence of cost-effective organized disposal techniques available to the farmer is the other limitation to commercial uses of polyethylene mulch (Briassoulis, 2004). In general, much of polyethylene mulch is often burnt by the growers at the end of each growing season, which causes an undesirable environmental effect (Wang & Nomura, 2010). Another problem related to using polyethylene mulch is environmental pollution with plastic residues caused by structural fragility at the end of the growing season, due to continued exposure to environmental conditions. Not all farmers will make the effort to remove polyethylene mulch fragments.

This activity is labor-intensive, and it is considered unnecessary because residual fragments are not perceived to have a negative impact on soil quality and long-term productivity (Kasirajan & Ngouajio, 2012). However, there are studies showing that polyethylene mulch residues bring various unfavorable consequences as a result of the accumulated in the soil (Jiang et al., 2017; Schirmel et al., 2018). Also, plastic residues can cause physical harm to livestock via ingestion, which is considered one of the main problems for farmers in Jordan. These issues have triggered many industrial and academic researchers to create an appropriate alternative to plastic mulch, while maintaining the competitive advantage of polyethylene mulch through the use of biodegradable and environmentally friendly materials (Wang & Nomura, 2010; Kaseem et al., 2012; Siwek et al., 2013).

The degradable mulch has been designed to be incorporated into the soil profile, eliminating the need for polyethylene mulch removal at the end of the growing season (Subrahmaniyan & Zhou, 2008). It is one of the agricultural practices that take into account the preservation of the environment compared with polyethylene mulch, which is one of the recognized priorities in the world. Investigations of degradable mulch have proven their favorable impact on crop yields and the ecosystem (Kasirajan & Ngouajio, 2012; Siwek et al., 2013; Lopez-Tolentino et al., 2017). Recently, the biodegradable mulch and oxo-degradable mulch have been introduced into the market as an effort to deal with the serious problem of managing plastic waste from polyethylene mulch (Briassoulis et al., 2015a). The biodegradable mulch is synthesized from natural polymers such as starch or from synthetic polymers such as polylactic acid made from lactic acid, a monomer found in nature (Goldberger et al., 2013). Also, it could use polymer blends such as starch with polyvinyl alcohol to synthesize biodegradable mulch (Tan et al., 2016). The biodegradable mulch possesses low permeability and is mineralized into harmless products (carbon dioxide, water, and biomass) when placed in contact with the soil moisture and microorganisms (Moreno et al., 2009). Oxo-degradable mulch is often synthesized from conventional polymers (polyethylene) with pro-oxidants substances such as cobalt acetylacetonate and magnesium stearate to accelerate the breakdown of polyethylene to small fragment and promote biodegradation process (Briassoulis et al., 2015b).

Since the biodegradable and the oxo-degradable are the common types of degradable mulch, they were used in the current study to be assessed under arid environmental conditions as an alternative to polyethylene mulch, also to explore the ability of degradable mulches to provide optimal conditions for open-field tomato crop.

Materials and Methods

Site and experimental design

The study was conducted at Rabba Agricultural Research Station, Mutah University (920 m above sea level, Longitude 35° 45′ E and Latitude 31° 16′ N) during the period from May 15th to Dec 15th, 2018. The main soil physical and chemical properties are shown in Table 1. A randomized complete block design (RCBD) was adopted with three replications. Each replicate contains four mulch treatments. The treatments used were black polyethylene plastic mulch, black oxo-degradable mulch, black biodegradable mulch, and no mulch (bare soil) as a control. The characteristics of the different tested mulches are shown in Table 2.

Plant material and cultural practices

A hybrid ‘956’ tomato seedlings (*Lycoperscon escullentum* Mill.) with 3-4 mature leaves were planted in the open field on 17 May 2018 in a single row per bed at 1.5 m spacing, 4 m in length, and 0.70 m width. Ten tomato seedlings were planted in each bed with a spacing of 0.40 m. Drip lines were laid under the mulch placed on the soil surface at the center of each bed. The tomato seedlings were transplanted. Irrigation was performed at the time of planting and continued twice per week. Weeds growing in bare soil treatment and along mulch edges were manually controlled throughout the growing season. Plants were fertigated through drip irrigation at the following rate: 150 kg N/ha, 120 kg P_2O_5 /ha, and 200 kg K_2O/ha. No fertilization was applied before transplanting. Protection against insects and diseases was accomplished by the spraying of pesticide.

Soil properties measurements

The soil temperature was measured at 10 cm soil depth once every week and recorded in all plots using a soil digital thermometer. Soil moisture content was measured every week in all plots using a handheld time domain reflectometer (TDR) (ThetaProbe, ML2x, Delta-T Devices, Cambridge, UK). Representative soil samples were taken twice at the end of the growing season and 90 days after the end of the growing season. The samples were taken 90 days after the end of the growing season to evaluate any significant difference occurred in soil pH, electrical conductivity, and soil organic carbon content after the residues of degradable mulch was plowed with soil at the end of the growing season compared to polyethylene mulch and bare soil. Three subsamples were collected within each plot, subsamples were mixed gently to obtain one composite sample. The composite samples were air-dried in the laboratory and sieved through a 2 mm screen. The extracts of saturated soil paste were prepared from each sample. The pH reading was taken using the pH meter, the same extract was used to estimate the electrical conductivity using the conductivity meter. The percentage of organic carbon in the soil samples was estimated according to Walkley and Black method (1934). Total N was estimated using the Kjeldahl procedure (Fleige et al., 1971). Available P content was determined by the Olsen method using the spectrophotometer (Watanabe & Olsen, 1965). Available K content was analyzed by an ammonium acetate method using a flame photometer (Meiwes et al., 1984).

Bacteria and fungi in term of numbers of colony-forming units (CFU) per gram of fresh soil on culture media were measured using serial dilutions of 10 g of soil samples that collected from all treatments 90 days after the mulch residues buried into the soil at the end of the growing season. 100 μL from each dilution were applied to Petri dishes containing nutrient agar that were incubated at 37°C for a 24 h for bacterial culture. The potatoes dextrose agar with 1 mL serial dilutions was incubated at 25°C for 72 h for culturing the fungi. The total number of colonies on each of the plates was counted and the results were expressed as colony-forming unit per gram of fresh soil ($CFUg^{-1}$).

Plant growth measurement

Plant height of five random plants from each plot was measured from soil surface up to the highest point of the plant canopy once every week from the fourth week after transplanting until the eighth week after transplanting using a meter. Five random leaves from each plot were selected at the mid of the growing season for the leaf area measurement. Leaves were then scanned into digital format; images were then digitally analyzed, using Image J software (Cox, 1972) to estimate the leaf area of tomato plants. After termination of the growing season, five plants from each plot were cut down to the soil surface; fresh weights of shoots were measured by a digital balance. Then, the samples were dried in an oven at 70°C until a constant dry weight was obtained, then shoots dry weight were measured by a digital balance.

Leaf chlorophyll content (SPAD unit)

Leaf chlorophyll content was measured weekly in five randomly plants per plot using the chlorophyll meter (SPAD-502, Minolta, Japan). The average values were presented as SPAD unit.

Leaf mineral content

Leaf samples were randomly collected from each plot at mid of the growing season. The leaves were washed with normal tap water and then with distilled water, the leaves were dried in an oven at 70°C for two days and were ground into a fine powder for determination of mineral content. The dry samples were homogenized and leaf N content was determined by using the Kjeldahl procedure (Fleige et al., 1971). Leaf P content was determined using Watanabe and Olsen method, (1965) by atomic absorptions spectrophotometer. K content was measured by means of the flame photometry method (Meiwes et al., 1984).

Yield components

Tomato fruits were harvested twice a week for duration of 5 weeks when the fruit was a minimum of 75% red ripe. At each harvest, fruits were counted, weighed, and sorted into marketable (the fruits that met quality standards demanded by the market) and unmarketable fruits (cracked, undersized, sunscald, blossom-end rot and diseased).The average fruit weight was measured by dividing the marketable weight by its number for each harvest.

Evaluation of visual mulch degradation

The degradation of all mulches was weekly evaluated throughout the growing season by means of a percent visual degradation from an area of 1 m^2 which was determined for each mulching plot in all replicates. Using the method described by Lopez-Tolentino et al. (2017) with some modifications, ranging from 0% = intact mulch to 100% = completely degradation mulch.

Statistical analysis

Analysis of variance (ANOVA) was performed using the SAS software (9.1). Fisher's least significant difference test at 95% significance level was used to compare treatment means for significant differences. Correlation and regression analysis were used for determination of the relations between variables.

Table 1. Some physical and chemical soil properties of the experimental site

Texture	pH	EC (dSm^{-1})	Organic matter (%)	N (ppm)	P (ppm)	K (ppm)
Clay loam	7.96	1.04	0.73	900	11.1	378

Table 2. Characteristics of the tested mulches

Type of mulch	Trade name	Material	Color	Thickness µm	Width (m)	Supplier company
Polyethylene plastic mulch	Plastic mulch	LDPE*	Black	20	0.8	Local
Oxo-degradable mulch	Eco-one	Polyethylene** polymers plus additive	Black	12.7	1.22	Growers Solution Tennessee, USA
Biodegradable mulch	Eco planet	Biodegradable** polymers	Black	12.7	1.22	Eco Planet California, USA

*LDPE = Low density polyethylene.
** The composition of the mulch is the confidential intellectual property of the suppliers

Results and Discussion

Soil properties

The effects of degradable mulch on the soil temperature at depth 10 cm during the growing season of tomato are shown in Figure 1. The highest mean soil temperature during the growing season was recorded under polyethylene mulch (25.7°C) followed by oxo-degradable mulch (25.4°C) without any significant difference. The biodegradable mulch showed significantly lower mean soil temperature (24.4°C) than polyethylene and oxo-degradable mulch. All mulching plots showed higher mean soil temperature than bare soil treatment (23.4°C). The present results are in agreement with that of Moreno et al. (2009) who exhibited that the soil temperature under biodegradable mulch was lower than polyethylene mulch. While, Waterer (2010), as well as Costa et al. (2014), reported that the soil temperature under biodegradable mulch exhibited good performance with no significant difference compared to polyethylene mulch. Lopez-Tolentino et al. (2017) found that mean soil temperature was higher under polyethylene mulch compared to the oxo-degradable mulch. The thermal effect of biodegradable mulch in the present study was lower than polyethylene and oxo-degradable, which might be due to a higher visual mulch degradation of biodegradable mulch. Consequently, affected the amount of heat retained under biodegradable mulch that had been reflected in the soil temperature data. It was also noted that, despite mulch degradation, the thermal effect of biodegradable mulches remained higher than bare soil until the end of the crop season. This result is in contrary to the Moreno and Moreno (2008) as well as Sintim et al. (2019) who mentioned that biodegradable mulch behaved similarly to bare soil during the late period of the growing season.

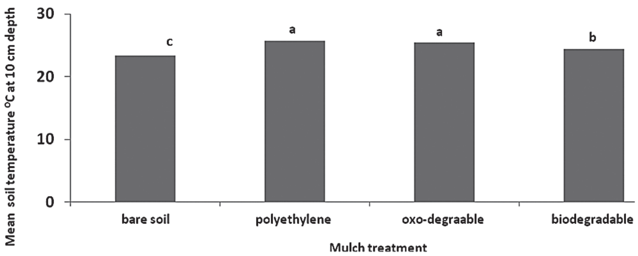

Fig. 1. The mean soil temperature °C at 10 cm depth

There was an obvious difference in soil moisture content between mulching plots and bare soil over the time (Table 3). The average soil moisture content under degradable mulch including oxo-degradable and biodegradable mulch did not show any significant difference than polyethylene mulch (Table 3). Our results are in agreement with Wang et al. (2014) and Saglam et al. (2017) who concluded that the effect of biodegradable mulch in preserving moisture is similar to polyethylene mulch. While, Shu-Min et al. (2017) found that biodegradable and polyethylene mulch showed a similar effect on soil moisture content during the earlier stages of plant growth. Sintim et al. (2019) indicated that soil cover-

Table 3. Effect of degradable mulch on soil moisture content at 10 cm depth

Treatment	Soil moisture content, %				
	June	July	Aug.	Sept.	Average
Bare soil	15.92 b*	14.53 c	15.48 c	17.68 b	15.75 b
Polyethylene mulch	21.42 a	18.77 ab	20.89 a	21.44 a	20.63 a
Oxo-degradable mulch	22.90 a	19.57 a	19.97 ab	23.25 a	21.42 a
Biodegradable mulch	24.63 a	17.84 b	19.41 b	21.79 a	20.92 a
CV%	11.62	3.24	3.64	3.64	2.74
Pr > F	0.0149	0.0005	0.0003	0.0146	0.0001

*Means followed by the same letter within each column are not significantly different at $p \leq 0.05$

ing with polyethylene and biodegradable mulch resulted in a higher soil water content than bare soil. It is worth to note that although of visual degradation of degradable mulch in the present study, it showed a similar ability of polyethylene mulch in soil moisture preservation. This finding could be attributed to the shading caused by plant canopy cover, as degradable mulch exhibited a positive effect on vegetative growth, which reduced solar radiation reached the soil surface and hence reduce evaporation.

The soil pH showed that there was no significant variation observed between all mulch treatments at the end of the growing season, and 90 days after the end of the growing season (Table 4). Similar results have been reported by Li et al. (2014) who indicated that there was no variation in soil pH between polyethylene and biodegradable mulch and bare soil. Moreover, no significant effect was observed with mulching application on electrical conductivity at the end of the growing season and 90 days after the end of the growing season (Table 4). Domagala-Swiatkiewicz & Siwek (2013) as well as Siwek et al. (2015) found no impact of biodegradable mulch on electrical conductivity compared to the bare soil.

The soil content of organic carbon was higher under biodegradable mulch than other mulch treatments at the end of the growing season. The biodegradable mulch continued in its positive effect on soil organic carbon content compared to polyethylene and oxo-degradable mulch 90 days after the end of the growing season, while bare soil treatments had the lowest soil organic carbon content (Table 4). The oxo-degradable mulch, showed a similar effect on soil organic carbon content to polyethylene.

The current data are in accordance with those of Manna et al. (2018) who reported that the soil organic carbon content was higher under biodegradable mulch than polyethylene mulch. The present results support the hypothesis that biodegradable mulch is beneficial in term of organic matter improvement, as mentioned by English et al. (2016) who postulated that the utility of the biodegradable mulch will add new carbon to the soil which could help improve soil quality. There were no significant differences observed between biodegradable, oxo-degradable, polyethylene mulch, and bare soil in soil N, P, and K contents (data not shown). Similarly, the findings of Domagala-Swiatkiewicz & Siwek (2013) appeared that there were no significant differences in soil N, P, and K between biodegradable mulch and bare soil.

The mulch treatments revealed a highly significant variation in soil microbial counting (Table 5). The beneficial effect on bacterial count was observed under degradable mulches compared to polyethylene and bare soil. The biodegradable mulch treatment significantly recorded highest bacterial count (449×10^4 cfug^{-1}) followed by oxo-degradable mulch treatment (118×10^4 cfug^{-1}). The polyethylene mulch treatment showed significantly lower bacterial count (30×10^4 cfug^{-1}) than degradable mulch, but without any significant difference than bare soil treatment. A similar trend was observed in fungi count, the highest fungi count was obtained under biodegradable mulch (5600 cfug^{-1}) followed by oxo-degradable mulch (4133 cfug^{-1}). The lowest fungi count was found under polyethylene mulch and bare soil (Table 5). All treatments in the current study showed a positive effect on bacteria and fungi count compared to pre-planting soil except polyethylene which had a very slight effect. Moreno & Moreno (2008) observed that polyethylene mulch had a more negative effect on soil microbial population than the biodegradable mulch, while bare soils had the highest soil microbial population.

Tan et al. (2016) observed that the population of bacteria was higher under biodegradable mulch than polyethylene, coincides with our results. On the other hand, they found that the highest number of fungal was under polyethylene than biodegradable treatment, while the lowest number found in the bare soil, which is inconsistent with our results. Manna et al. (2018) obtained similar results and mentioned that the highest fungal and bacteria population were recorded under biodegradable mulch than polyethylene and bare soil. The current findings indicated that there is a significant correlation ($r = 0.95$; $p = 0.02$) between the number of bacteria in term of colony forming unit per gram of fresh soil and the

Table 4. Effect of degradable mulch on soil pH, EC and soil organic carbon

Treatment	At the end of the growing season			90 days after the end the growing season		
	pH	EC (dSm^{-1})	SOC%**	pH	EC (dSm^{-1})	SOC %
Bare soil	7.76a*	1.53a	0.42 b	7.66a	1.99a	0.43c
Polyethylene mulch	7.73a	1.15a	0.45 b	7.63a	1.33a	0.54b
Oxo-degradable mulch	7.72a	0.89a	0.50 b	7.66a	1.50a	0.57b
Biodegradable mulch	7.66a	1.39a	0.60 a	7.66a	1.97a	0.64a
CV %	0.98	22.35	8.27	0.75	30.05	3.96
Pr > F	0.3801	0.1102	0.0067	0.857	0.3764	0.0001

*Means followed by the same letter within each column are not significantly different at $p \leq 0.05$

organic carbon content of the soil. Also, the positive correlation ($r = 0.96$; $p = 0.01$) between the number of fungi in term of colony forming unit per gram of fresh soil and organic carbon content in the soil. Moreover, the biodegradable and oxo-degradable mulch increased the organic carbon content in the soil, particularly biodegradable mulch, which might be explained the positive impact of degradable mulch on soil microbial counting (bacteria and fungi).

Table 5. Effect of degradable mulch on soil microbial counting

Before planting	$CFUg^{-1}$**	
	Bacteria ($\times 10^4$)	Fungi
	29	2200
Treatment		
Bare soil	62 c*	2933 c
Polyethylene mulch	30 c	2666 c
Oxo-degradable mulch	118 b	4133 b
Biodegradable mulch	449 a	5600 a
CV %	10.07%	7.78%
Pr>F	< 0.0001	< 0.0001

*Means followed by the same letter within each column are not significantly different at $p \leq 0.05$

** $CFUg^{-1}$: Colony forming unit per gram of fresh soil

Plant growth

Tomato plants didn't show any significant differences in the plant height under all mulch treatments during the growing season (Table 6). The present results are in agreement with those of Ngouajio et al. (2008) for tomato plants, as well as Lee et al. (2015) for garlic, who concluded that there was no significant difference between polyethylene and biodegradable mulch in plant height. The effect of biodegradable mulch was clearly reflected on tomato leaf area; it exhibited the highest leaf area than other mulch treatments (Table 7). Oxo-degradable mulch had a similar effect on leaf area as polyethylene mulch. The significantly lowest leaf area was found in plants grown in bare soil treatment. These findings reconciled with the results obtained by Lopez-Tolentino et al. (2017) who demonstrated that the leaf area of cucumber under oxo-degradable mulch (with 12% pigment) was similar to polyethylene mulch and higher than bare soil.

We might conclude that the proper soil temperature under biodegradable mulch treatment led to a beneficial effect on plant growth mainly, leaf area. Supporting the conclusion obtained by Brouwer (1962) who reported that root zone temperature plays an important role in the growth of roots. The optimal soil temperature improves the root growth, water uptake, and mineral uptake and consequently better shoot growth, mainly leaf growth through improving cells elongation. The shoot fresh and dry weight exhibited a significant response to the degradable mulch treatments including the biodegradable and oxo-degradable mulch compared to the bare soil (Table 7). The biodegradable treatment had a pronounced positive effect on shoot fresh and dry weight compared to polyethylene and bare soil treatments. This result contradicts a

Table 6. Effect of degradable mulch on '956' tomato height

Treatment	Height, cm Weeks after transplanting				
	4	5	6	7	8
Bare soil	39.40a*	56.17a	63.20a	66.97a	68.83a
Polyethylene mulch	40.10a	55.30a	64.30a	68.20a	70.43a
Oxo-degradable mulch	38.87a	57.93a	67.20a	71.40a	73.63a
Biodegradable mulch	38.63a	54.20a	65.00a	71.27a	72.73a
CV%	5.20%	6.89%	5.9%	6.02%	6.28%
Pr > F	0.8210	0.6940	0.6474	0.5161	0.5798

*Means followed by the same letter within each column are not significantly different at $p \leq 0.05$

Table 7. Effect of degradable mulch on leaf area and shoot fresh and dry weight of '956' tomato

Treatment	Leaf area, cm^2	Shoot fresh weight, g	Shoot dry weight, g
Bare soil (Control)	78.68 c*	540.7 c	173.38 c
Polyethylene mulch	102.00 b	702.3 bc	206.59 bc
Oxo-degradable mulch	105.81 b	848.2 ab	238.90 ab
Bio-degradable mulch	123.37 a	937.7 a	280.45 a
CV%	7.83 %	14.54 %	13.26 %
Pr > F	0.0026	0.0188	0.0215

*Means followed by the same letter within each column are not significantly different at $p \leq 0.05$

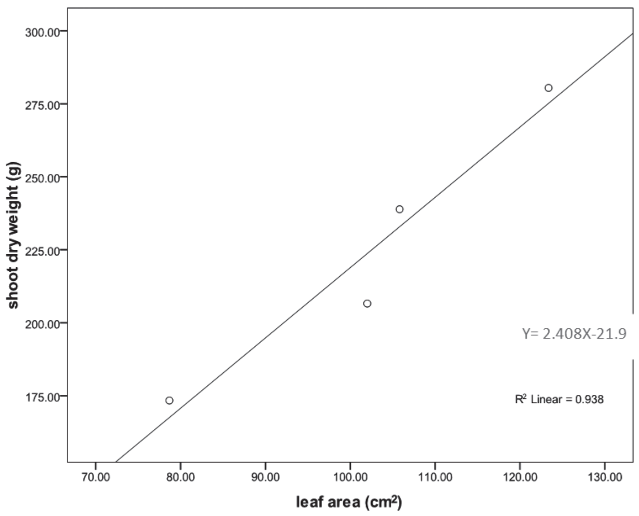

Fig. 2. The relationship between leaf area and shoot dry weight of '956'tomato

previous result in Martin-Closas et al. (2008) who found that total dry weight of tomato was similar for the biodegradable and polyethylene mulch. The significant difference between polyethylene and oxo-degradable mulch in the measured shoot fresh and dry weight was not being noticed. Also, Lopez-Tolentino et al. (2017) indicated that mean shoot dry weight of cucumber was similar for oxo-degradable mulch and polyethylene mulch. The improvement of tomato shoot dry weight under biodegradable mulch treatment could be associated with enhancement of tomato leaf area (Figure 2).

Leaf chlorophyll content

Chlorophyll content in the leaves of tomato plant under oxo-degradable and biodegradable treatments increased significantly compared to those planted in bare soil. Whereas no significant difference was found between polyethylene, oxo-degradable and biodegradable mulches. The mean value of chlorophyll content under oxo-degradable mulch treatment was 55.2 SPAD units, while under biodegradable mulch and polyethylene mulch treatments were 54.1 and 53.9 SPAD units, respectively. The lowest mean value of SPAD unit was recorded in bare soil treatment (51.7).

These findings, support the conclusion of Choudhary et al. (2012) who indicated that chlorophyll content was higher because of the availability of water under biodegradable, oxo degradable, and polyethylene mulch treatments than bare soil that enhances the synthesis of chlorophyll constitutes.

Leaf mineral content

There were no differences were detected in leaf mineral content including nitrogen, phosphorus, and potassium between the all mulch treatments. To our knowledge, there were no studies illustrated the variation that occurs in the leaf mineral content in response to the degradable mulch. Therefore, we limited to the studies that assessed the effect of polyethylene mulch on leaf mineral content. Wien et al. (1993) found no significant difference in nitrogen, phosphorus, and potassium content in leaf tissue of tomato plants under polyethylene mulch treatment than bare soil as well as Min-Li et al. (2004) found that there was no significant difference in nitrogen accumulation between polyethylene and bare soil in the second growing season of wheat, which consistent with present results.

Yield components

The present data illustrated that total yield of tomato (7.4 kg/m^2) under biodegradable mulch treatment was significantly higher compared with other treatments (Figure 3). The oxo-degradable mulch exhibited similar total yield of tomato (5.4 kg/m^2) to the polyethylene mulch treatment (5.0 kg/m^2). It was observed that bare soil treatment recorded a lower total yield of tomato (3.5 kg/m^2) compared with other treatments. A similar conclusion was pointed by Cirujeda et al. (2012) as well as Moreno et al. (2013) who indicated that yield of 'Perfect Peel' a processing tomato was similar under oxo-degradable and polyethylene mulch treatments. Whereas, Filippi et al. (2011); Saraiva et al. (2012); Benincasa et al. (2014); reported that there was no significant difference in a total yield of melon between the polyethylene and biodegradable mulch.

It seems essential to note that, despite the soil under biodegradable mulch was less heated than in the case of polyethylene mulch and oxo-degradable mulch in the current assessment, the marketable yield of tomato plants under the biodegradable mulch treatment was significantly higher (6.5 kg/m^2) than other treatments (Figure 3). These results support our hypothesis that the lower soil temperature under biodegradable mulch can be beneficial in term of tomato growth and yield during the summer season. The effect of oxo-degradable mulch treatment on marketable yield of tomato in the current study (4.3 kg/m^2) was lower than biodegradable mulch, but similar to polyethylene mulch (3.0 kg/m^2) and higher than bare soil (2.3 kg/m^2). This result agrees with Cirujeda et al. (2012) who reported that the marketable yield of processing tomatoes under oxo-degradable mulch treatment was similar to polyethylene mulch. The unmarketable yield of tomato plants was found to be significantly highest under polyethylene mulch treatment (2.0 kg /m^2), followed by bare soil treatment (1.2 kg/m^2).The significantly lowest unmarketable yield of tomato plants was recorded under biodegradable (0.9 kg/m^2) and oxo-degradable (1.1 kg/ m^2) treatments (Figure 3). The positive effect of biodegradable mulch on the total and marketable yield of tomato plant might be as a result of the improvement in the shoot dry weight. The tomato shoot dry weight is good predictor of yield, there was a strong relationship between shoot dry weight and marketable yield of tomato ($R^2 = 0.97$; $p = 0.01$) as shown in Figure 4.

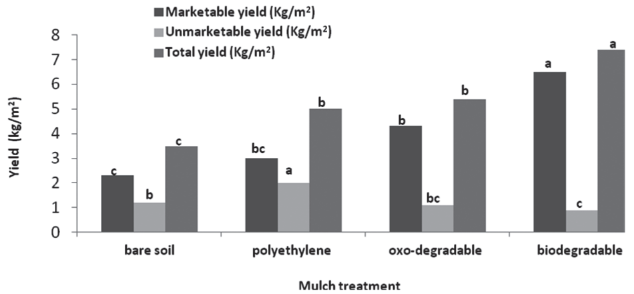

Fig. 3. Effect of degradable mulch on tomato yield kg/m^2

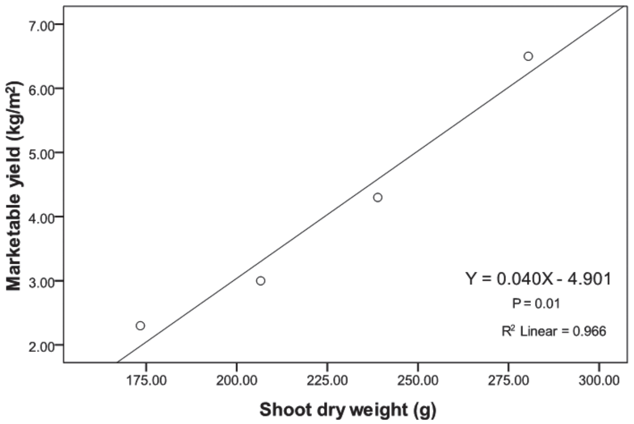

Fig. 4. The relationship between shoot dry weight and marketable yield of '956' tomato

The positive impact of biodegradable mulch on fruit number was clear as compared to the other treatments (74 fruit/m^2).Whereas, the oxo-degradable mulch exhibited similar effect without any significant difference (56 fruit/ m^2) compared to polyethylene mulch treatment (59 fruit/m^2). The lowest significantly fruit number was found in the bare soil (42 fruit/m^2) (Figure 5). A similar trend was observed by Devetter et al. (2017) who found that strawberry fruit number was higher under biodegradable mulch treatments than bare soil. No significant difference was detected in data collected for the average weight of tomato fruit. The biodegradable mulch showed a slight increase in the average weight of tomato fruit (101 g) followed by oxo-degradable mulch (96 g) compared to polyethylene mulch (85 g) and bare soil treatment (84 g). Similar observation were obtained by Candido et al. (2006); Martin-Closas et al. (2008); Moreno et al. (2009) who found insignificant difference in average fruit weight of tomato between polyethylene and biodegradable mulch. In addition, Hannan (2012) observed that there were no significant differences in fruit weight of tomato between the biodegradable, oxo-degradable and polyethylene mulch.

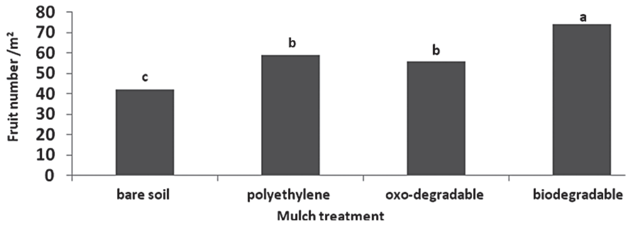

Fig. 5. Effect of degradable mulches on fruit number/m^2

Evaluation of visual mulch degradation

Another purpose of this study was to assess the ability of degradation of degradable mulch (oxo-degradable and biodegradable) under local environmental conditions. Since one of the main benefits associated with the use of degradable mulch is to overcome the removal and disposal problems of polyethylene mulch. The results of the assessment indicated that degradation of biodegradable mulch began early in the growing seasons. The first signs of degradation were found 17 days after transplanting (Figure 6).

Fig. 6. The first signs of degradation in the biodegradable mulch 17 days after transplanting

The oxo-degradable and polyethylene mulch did not show any signs of degradation on the same date. Also, Moreno et al. (2009) observed that first signs of mulch degradation appeared in the biodegradable mulch only seven days after tomato transplanting. A similar observation in the previous study conducted by Cowan et al. (2013) who mentioned that first signs of visual mulch degradation appeared within 2 weeks in biodegradable mulch treatment. Field observations, depended on percent scale of mulch degradation (0% = intact mulch, 100% = completely degradation) showed significant differences between mulch treatments. These differences persist to the end of growing season. The biodegradable mulch had the highest percent of visual degradation among mulch treatments (80), followed by oxo-degradable treatment (40). The degradation of polyethylene mulch treatment, as expected, was less evident, remained practically intact and had the lowest percent of visual mulch degradation at the end of the growing season (3.17) (Figure 7).

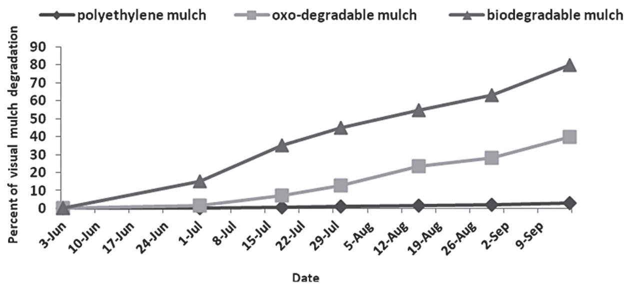

Fig. 7. Evaluation of visual mulch degradation according to the percent scale of mulch degradation (0% = intact mulch, 100% = completely degradation)

From current results, it appears that the polymer composition can contribute to the difference in degradation between the biodegradable and oxo-degradable mulch treatments. The conclusions obtained by Kale et al. (2007); Lopez-Tolentino et al. (2017) supported our hypothesis. They stated that biodegradation depends on various factors included the polymer characteristics as chain flexibility, molecular weight, and polymer composition. The current results consistent with DeVetter et al. (2017) who mentioned that biodegradable mulch showed the highest degradation and only 3% degradation in polyethylene mulch. Similar results was attained by Sabatino et al. (2018) as they found that the degradation was higher for biodegradable mulch compared to polyethylene mulch which recorded only 7.7% of mulch degradation. It appears that polyethylene mulch did not exhibit any significant visual evidence of degradation throughout present study.

Despite the high performance of the oxo-degradable mulch on tomato growth and yield, its degradation during the growing season was not satisfying due to the low percent visual degradation compared to the biodegradable mulch. Secondly, due to the experimental site pollution with plastic particles resulted from the oxo-degradable fragmentation. While the biodegradable mulch was significantly degradation compared to polyethylene and oxo-degradable mulch. Since the biodegradable mulch is considered a suitable carbon source for microorganisms, this feature might be helpful in the consume of biodegradable mulch by microorganism and consequently accelerated the degradation rate. The present results support the hypothesis that biodegradable mulch is a beneficial alternative to polyethylene, while the hypothesis that oxo-degradable mulch as an environmentally friendly alternative to polyethylene mulch is questionable.

Conclusions

Based on present results, the lower soil temperature under biodegradable mulch during the summer season might be attributed to the enhancement of tomato vegetative growth. This enhancement positively revealed a significant effect on total, marketable yield and fruit number of tomato. The results of the visual degradation assessment indicated that biodegradable mulch had the highest percent of visual degradation followed by oxo-degradable mulch. The degradation of polyethylene mulch, as expected, was less evident, remained practically intact and had the lowest percent of visual mulch degradation at the end of the growing season. We can conclude that biodegradable mulch might be a suitable alternative to polyethylene mulch for tomato production under field conditions as it may offer the benefits of polyethylene mulch for crop production with the added benefit of environmental protection. Despite the positive effect of oxo-degradable mulch on tomato growth and yield, it might be not a suitable option to be alternative to polyethylene mulch, if environmental pollution with plastic mulch residues taken into account. Further studies are needed to test these types of mulch in the long term and in different locations.

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References

Benincasa, P., Massoli, A., Polegri, L., Concezzi, L., Onofri, A. & Francesco, T. (2014). Optimizing the use of plastic protective covers in field grown melon on a farm scale. *Italian Journal of Agronomy, 9*, 556-564.

Briassoulis, D. (2004). An overview on the mechanical behavior of biodegradable agricultural films. *Polymers and the Environment, 12*, 65-85.

Briassoulis, D., Babou, E., Hiskakis, M. &Kyrikou, I. (2015a). Degradation in soil behavior of artificially aged polyethylene films with pro-oxidants. *Applied Polymer Science*, *42289*, 1-19.

Briassoulis, D., Babou, E., Hiskakis, M. &Kyrikou, I. (2015b). Analysis of long-term degradation behavior of polyethylene mulching films with pro-oxidants under real cultivation and soil burial conditions. *Environment Science Pollution Research, 22*, 2584-2598.

Brouwer, R. (1962). Influence of temperature of the root medium on the growth of seedlings of various crop plants. Jaarboek Institute for Organic and Chemical Agricultural Crops.Wageningen.11-18.

Candido, V., Miccolis, V., Castronuovo, D., Manera, C. & Margiotta, S. (2006). Mulching studies in greenhouse by using eco-compatible plastic films on fresh tomato crop. *ActaHorticulturae*, *710*, 415-420.

Choudhary, V. K., Bhambri, M. C., Pandey, N. & Sharma, H. G. (2012). Effect of drip irrigation and mulches on physiological parameters, soil temperature, picking patterns and yield in capsicum (*Capsicum annuum* L.). *Archives of Agronomy and Soil Science, 58*, 277-292.

Cirujeda, A., Aibar, J., Anzalone, A., Martin-Closas, L., Meco, R., Moreno, M. M., Pardo, A., Pelacho, A.M., Rojo, F., Royo-Esnal, A., Suso, M.L. & Zaragoza, C. (2012). Biodegradable mulch instead of polyethylene for weed control of processing tomato production. Agronomy for Sustainable Development, *32,* 889-897.

Cowan, J. S., Inglis, D. A. & Miles, C. A. (2013). Deterioration of three potentially biodegradable plastic mulches before and after soil incorporation in a broccoli field production system in northwestern Washington. *HortTechnology, 23*, 849-858.

Cox, E. F. (1972). A photoelectric digital scanner for measuring leaf area. *New Phytologist, 71*, 819-823.

DeVetter, L. W., Zhang, H., Ghimire, S., Watkinson, S. & Miles, C. A. (2017). Plastic biodegradable mulches reduce weeds and promote crop growth in day-neutral strawberries. *Hort. Science, 52*, 1700-1706.

Domagala-Swiatkiewicz, I. & Siwek, P. (2013). The effect of direct covering with biodegradable nonwoven film on the physical and chemical properties of soil. *Polish Journal of Environmental Studies, 22*, 667-674.

English, M., Schaeffer, S., DeBruyn, J., Flury, M., Miles, C., Hayes, D. & Bandopadhyay, S. (2016). Soil Carbon and biodegradable mulches. Washington State University Extension Fact Sheet SE-2016-01.

Filippi, F., Magnani, G., Guerrini, S. &anghino, F. (2011). Agronomic evaluation of green biodegradable mulch on melon crop. *Italian Journal of Agronomy, 6*, 111-116.

Fleige, H. B., Meyer, B. &Scholz, H. (1971). Fractionation of soil nitrogen for N-Hushalts-Bilanz. *Goettinger Bodenkundl Ber.*, *18:* 1-37.

Goldberger, J. R., Jones, R. E., Miles, C. A., Wallace, R. W. & Inglis, D. A. (2013). Barriers and bridges to the adoption of biodegradable plastic mulches for US specialty crop production. *Renewable Agriculture and Food Systems, 30*, 143–153.

Hakkarainen, M. & Albertsson, C. (2004). Environmental degradation of polyethylene. *Advances in Polymer Science, 169*, 177-200.

Hannan, J. M. (2012). Black degradable plastic mulch evaluation. Iowa State Research Farm Progress Reports. http://lib.dr.iastate.edu/farms-reports/30.

Jiang, X. J., Liu, W., Wang, E., Zhou, T. & Xin, P. (2017). Residual plastic mulch fragments effects on soil physical properties and water flow behavior in the Minqin Oasis, northwestern China. *Soil and Tillage Research, 166*, 100-107.

Kale, G., Auras, R., Singh. S. P. & Narayan, R. (2007). Biodegradability of polylactide bottles in real and simulated composting conditions. *Polymer Testing, 26*, 1049-1061.

Kaseem, M., Hamad, K. & Deri, F. (2012). Thermoplastic starch blends: A review of recent works. *Polymer Science, 54*, 165-176.

Kasirajan, S. & Ngouajio, M. (2012). Polyethylene and biodegradable mulches for agricultural applications: a review. *Agronomy for Sustainable Development, 32*, 501–529.

Lee, J. H., Kim, M. J., Kim, H. L., Kwack, Y. B., Kwon, J. K., Park, K. S., Choi, H. G. & Khoshimkhujaev, B. (2015). Effects of biodegradable mulching film application on cultivation of garlic. *Protected Horticulture and Plant Factory, 24*, 326-332.

Li, C., Moore-Kucera, J., Miles, C., Leonas, K., Lee, J., Corbin, A. & Inglis, D. (2014). Degradation of potentially biodegradable plastic mulch films at three diverse U.S. locations. *Agroecology and Sustainable Food Systems, 38*, 861-889.

Lopez-Tolentino, G., Ibarra-Jimenez, L. & Mendez-Prieto, A. (2017). Photosynthesis, growth, and fruit yield of cucumber in response to oxo-degradable plastic mulches. *Acta Agriculture Scandinavica, section b- soil and plant science, 67*, 77-84.

Manna, K., Kundu, M. C., Saha, B. & Ghosh, G. K. (2018). Effect of nonwoven jute agrotextile mulch on soil health and productivity of broccoli (*Brassica oleracea* L.) in lateritic soil. *Environmental Monitoring and Assessment, 190*, 82-92.

Martin-Closas, L., Bach, M. A. & Pelacho, A. M. (2008). Biodegradable mulching in an organic tomato production system. *Acta Horticulturae, 767*, 267-274.

Meiwes, K. L., Hauhs, M., Gerke, H., Asche, N., Matzner, E. & Lammersdorf, N. (1984). The evaluation of matter cycling in forest ecosystem: concept and method. Ber. Research Center Forest Ecosystems Forest Death. *7,* 68-142.

Min-Li, F., Wang, J., Zhang-Xu, J. & Lian-Xu, H. (2004). Productivity and soil response to plastic film mulching durations for spring wheat on entisols in the semiarid Loess Plateau of China. *Soil and Tillage Research, 78*, 9-20.

Moreno, M. M. & Moreno, A. (2008). Effect of different biodegradable and polyethylene mulches on soil properties and production in a tomato crop. *Scientia Horticulturae, 116*, 256-263.

Moreno, M. M., Moreno, A. & Mancebo, I. (2009).Comparison of different mulch materials in a tomato (*Solanum lycopersicum* L.) crop. *Spanish Journal of Agricultural Research, 7*, 454-464.

Moreno, M., Moreno, C. &Tarquis, A. (2013). Mulch materials in processing tomato: a multivariate approach. *Scientia Agricola, 70*, 250-256.

Ngouajio, M., Auras, R., Fernandez, R. T., Rubino, M., Counts, J. W. & Kijchavengkul, T. (2008). Field performance of aliphaticaromatic copolyester biodegradable mulch films in a fresh market tomato production system. *Hort. Technology, 18*, 605–610.

Sabatino, L., Iapichino, G., Vetrano, F., Moncada, A., Miceli, A., Pasquale, C. D., Anna, F. D. & Giurgiulescu, L. (2018). Effects of polyethylene and biodegradable starch- based mulching films on eggplant production in a Mediterranean area. *Carpathian Journal of Food Science and Technology, 10*, 81-89.

Saglam, M., Sintim, H. Y., Bary, A. I., Miles, C. I., Ghimire, S., Inglis, D. A. & Flury, M. (2017). Modeling the effect of biodegradable paper and plastic mulch on soil moisture dynamics. *Agricultural Water Management, 193*, 240-250.

Saraiva, A., Costa, R. & Carvalho, L. (2012). The use of biodegradable mulch films in muskmelon crop production. *Basic Research Journal of Agricultural Science and Review, 1*, 88-95.

Schirmel, J., Albert, J., Kurtz, M. P. & Munoz, K. (2018). Plasticulture changes soil invertebrate assemblages of strawberry fields and decreases diversity and soil microbial activity. *Applied Soil Ecology, 124*, 379-393.

Shu-Min, Z., Tang-Yuan, N., Zhen, L., Bin, W., Tao, S., Xue-Peng, Z. Zhen-Kun, H., Yan, Y. & Qing-Hua, M. (2017). Weed infestation, soil moisture, and temperature under mulching cultivation with different films and the effects on yield and quality of Potato. *Acta Agronomica Sinica, 43*, 571-580.

Sintim, H. Y., Bandopadhyay, S., English, M. E., Bary, A. I., DeBruyn, J. M., Schaeffer, S. M., Miles, C. A., Reganold, J. P. & Flury, M. (2019). Impacts of biodegradable plastic mulches on soil health. *Agriculture, Ecosystems and Environment, 273*, 36-49.

Siwek, P., Libik, A., Kalisz, A. & Zawiska, I. (2013).The effect of biodegradable nonwoven direct covers on yield and quality of winter leek. *Folia Horticulture, 25*, 61-65.

Siwek, P., Domagala-Swiatkiewicz, I. & Kalisz, A. (2015).The influence of degradable polymer mulches on soil properties and cucumber yield. *Agrochimica, 59*, 108-123.

Subrahmaniyan, K. & Zhou, W. (2008). Soil temperature associated with degradable, non-degradable plastic and organic mulches and their effect on biomass production, enzyme activities and seed yield of winter rapeseed. *Sustainable Agriculture, 32*, 611-627.

Tan, Z. , Yi, Y., Wang, H., Zhou, W., Yang, Y. & Wang, C. (2016). Physical and degradable properties of mulching films prepared from natural fibers and biodegradable polymers. *Applied Sciences, 6*, 147-158.

Walkley, A. J. & Black, I. A. (1934). Estimation of soil organic carbon by the chromic acid titration method. *Soil Science Journal, 37*, 29-38.

Wang, Q. & Nomura, C. T. (2010). A survey of biodegradable plastics in the U.S. *Bioplastic, 36*, 18-23.

Wang, Y. P., Li, X. G., Hai, L., Siddique, K. H. M., Gan, Y. & Li, F. M. (2014). Film fully-mulched ridge-furrow cropping affects soil biochemical properties and maize nutrient uptake in a rain fed semi-arid environment. *Soil Science and Plant Nutrition, 60*, 486–98.

Watanabe, F. S. & Olsen, S. R. (1965). Test of an ascorbic acid method for determining phosphorus in water and $NaHCO_3$ Extracts from the soil. *Soil Science Society of American Journal, 29*, 677-678.

Waterer, D. (2010). Evaluation of biodegradable mulches for production of warm-season vegetable crops. *Canadian Journal of Plant Science, 90*, 737-743.

Wien, H. C., Minotti, P. L. & Grubinger, V. P. (1993). Polyethylene mulch stimulates early root growth and nutrient uptake of transplanted tomatoes. *Journal of the American Society for Horticultural Science, 118*, 207-211.

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