Pak. J. Agri. Sci., Vol. 56(4), 857-866; 2019
ISSN (Print) 0552-9034, ISSN (Online) 2076-0906
DOI:*10.21162/PAKJAS/19.7451*
http://www.pakjas.com.pk

WEED CONTROL IN TOMATO (Solanum lycopersicum Mill.) BY NEW BIODEGRADABLE POLYPROPYLENE SHEETS AND OTHER SOIL MULCHING MATERIALS

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Field experiments were carried out to evaluate the effects of different soil mulch materials and herbicides on growth and yield of tomato and weed control at two locations in Jordan during the 2016 and 2017 growing seasons. Treatments included different new nonwoven biodegradable UV-treated polypropylene fabrics, paper, black plastic, animal manure, straw mulches, five soil-applied herbicides, and weed-free and weed-infested controls. On average, weed competition with tomato for the entire growing season reduced marketable fruit yield by 58.6% of the weed-free control. Animal manure, black/white mulch/double face 45 g/m^2 (GSM) density (B/WMD45) and paper mulches resulted highest tomato growth and fruit yield at the University of Jordan Campus. Other polypropylene treatments gave similar yield to that of plastic mulch while all mulch treatments gave higher yield than herbicides. Of the herbicides, metribuzin and trifluralin treated plots produced the lowest fruit yield. Similar trends for tomato yield and weed growth were also obtained at the Jordan Valley Research Station except for black plastic that gave the highest fruit yield but not significantly different from that of B/WMD45, paper and weed-free control. Among herbicides, oxyfluorfen resulted highest yield but differences between herbicide treatments were not significant. The highest tomato growth and fruit yield were from paper, black plastic, B/WMD45, and animal manure treatments and the lowest for herbicides and weed-infested treatments. B/WMD45 may be considered as a suitable substitute for black plastic in tomato fields.
Keywords: Vegetable production, weed management, soil solarization, soil mulches, nonwoven biodegradable polypropylene, herbicides

INTRODUCTION

Tomato is the main vegetable crop grown under irrigation and rainfed conditions in Jordan. Different weed species interfere with this crop under field conditions (Qasem, 1992) and their control is necessary for high growth and yield.

Methods of weed control in tomato are many and varied and range from hand weeding to herbicides. Hand weeding is time consuming, coasty and tedious while persistence and toxicity on rotated crops, lack of trained labors and/or extension on herbicides application, limited weed control spectrum, and environmental hazards necessitate search for alternative weed control methods.

Different soil mulching materials are used for weeds control in vegetables including tomato (Anderson *et al*., 1995; Orzolek and Lamont Jr, 2000). Some of these are white and black polyethylene, animal manure, bark and composted municipal green waste, straw, newspaper, carton, saw dust, wood chips, foam, hydramulch (Masiuras *et al*., 2003; Warnick *et al*., 2006; Bakht and Khan, 2014) and living mulches (Boydston, 2008; Geddes *et al*., 2015). Covering soil surface with suitable opaque and infrared-transmitting (IRT) materials can reduce weed seed germination, provide shade and physically hinder emerging weeds. It also enhances crop growth and competitiveness since conserving soil moisture and sometimes modifying soil temperature hence promote soil warming, and enhance early crop growth (Schonbeck and Evalylo, 1998; Schonbeck, 2015).

In the open field, tomato suffers heavy weed infestation; certain weed species are dominant in different parts of Jordan and cause great yield losses (Qasem, 1992). However, weed competition effects depend on weed density, growing conditions and agricultural practices employed (Zimdahl, 1980; Qasem, 1992). One of the most widely adopted agricultural practices by local farmers is the use of polyethlene black plastic mulch before crop transplanting. This practice is usually used during soil solarization treatment in the Jordan Valley and aim at soil covering for effective pest control through soil heating and raise in temperature up to the lethal degree. After soil solarization, growers usually keep the same black plastic sheets, make holes or slits cut into the mulch at planting distance and transplant their crops and thus avoid extra cost and work of plastic exchange or removal. Black plastic thus became widely used in vegetable fields as a soil cover of different purposes including the help in pest control and prevention of weed growth through denying light required for seed germination of certain weed species and through the prevention of photosynthesis of emerged weeds.

Mulching can reduce weed competition against vegetable crops, and lowers cost of weed control. Although plastic mulch greatly reduces weed growth, including *Orobanche* spp., and substantially increases yield and earliness of warm season vegetables including tomato (Riley *et al*., 2007) but it has several drawbacks, among which are the coast, and the susceptibility to penetration by nutsedge (*Cyperus* spp.) (Webster, 2005; Warnick*et al*., 2006). It can't or hardly controls perennial weeds and causes serious problems associated with environmental pollution (Masiuras *et al*., 2003; Espí *et al*., 2006; Grossman, 2015). Plastic is a none-degradable material, persists for a long period and even when turned into the soil it takes years before decayed. Tattered plastic pieces are the main cause of environmental pollution. These are liable to wind-drift over a large area in fields and their surroundings, swallowed by cattle, clog digestive tract and cause death to ruminants.

Gathering or abandoning plastic in the fields and its disposal by burning is coasty, tedious and emitting smug with toxic substances causing more pollution and may leads to health problems. These issues and may be others necessitate search for eco-friendly alternatives to plastic mulch. Among measures employed are hand weeding, herbicides, mechanical cultivation, and the use of different soil mulching materials. Each however, has associated problems that hinder its effectiveness. For example, animal manure must be treated for weed seeds and propagules disinfection but can't prevent growth of tall growing weeds. Wood chips and straw mulch may yield allelochemicals that inhibit crop plants plus other problems.

The objectives of this work were to evaluate the effects of different soil mulching materials including some recently produced UV polypropylene fabrics and recommended herbicides on growth and yield of tomato and on weed growth. Measuring the effect of different mulching materials on soil moisture and temperature after crop transplanting and determine any differences in the two factors under the new fabrics and plastic mulches and their influence on weed control and crop growth and yield.

MATERIALS AND METHODS

A field experiment was conducted to study the effects of different soil mulching materials (including newly developed biodegradable fabrics) and herbicides on tomato growth and yield and effectiveness in weed control. The experiment was first conducted at the University of Jordan Campus Research Station, Al-Jubeiha during the 2016 growing season. The area is located at an elevation of 980 m a.s.l with an average annual rainfall of about 450 mm. The soil is clay loam with 62.3% clay, 36.7% silt, 1.1% sand, 0.71% organic matter and pH approximately 7.6. Average day/night temperature was 29.7/19.4°C, relative humidity (RH) 40.5% and sunrise was for 15.1 hrs throughout the whole growing period. The experiment was repeated at the Jordan Valley Agricultural Research Station, University of Jordan (about 255m b.s.l.) for the 2017 growing season. The soil is sandy loam with 50% sand, 25% silt and 25% clay of 1.3% organic matter content and a pH of 7.5. Average day/night temperature was 27.9/16.4°C, relative humidity 34.7%, and sunrise was for 16.3 hrs.

In both sites, the soil was tilled twice, leveled, and planting beds were prepared. Treatments in both experiments included the use of black polyethylene plastic mulch, fermented animal manure, wheat straw, paper and nonwoven polypropylene fabrics of different densities and colors namely; Agri. protect-Saudi- German Nonwoven (SGN) Black Mulch of 25 (BM25), 35 (BM35), and 45 (BM45) g/m^2 (GSM) densities, Agri protect-Saudi-German Nonwoven (SGN) White Mulch of 30 g/m^2 (GSM) density (WM30), and Agri protect-Saudi-German Nonwoven (SGN) Black and White Mulch/double face of 67 (B/WMD67), and 45 (B/WMD45) g/m^2 (GSM) densities. All materials were supplied by the Saudi-German Co. for Nonwoven Products, 2nd industrial city, Dammam, Saudi Arabia. In addition, treatments also included selected widely used soil-applied herbicides in tomato fields including; metribuzin (70% a.i.) at 0.5 kgha^{-1}, oxadiazon (25% a.i.) at 4lha^{-1}, oxyflourfen (24% a.i.) at 4lha^{-1}, pendimethalin (33% a.i.) at a rate of 5lha^{-1} and trifluralin (48% a.i.) at 2.5 lha^{-1}. All were used as pre-transplant, soil-applied treatments. Weed-free (maintained through continuous hand-weeding) and weed-infested (left unweeded) plots for the whole growing season were included as controls. Herbicides were applied as an aqueous spray at a constant pressure in the morning in both years in absence of wind currents, using a Knapsack sprayer with a single nozzle at a volume of 1250 lha^{-1} and directly before tomato transplanting. However, in the first experiment (at Campus site), tomato transplanting and irrigation were followed directly after herbicides application; while in the second experiment (Jordan Valley site), herbicides application was immediately followed by rain. In both sites, a half wheat straw bale (12.5 kg weight) and 50L of fermented animal (sheep, cow and chicken) manure mixture were applied per plot bed of straw and animal manure mulch treatments, receptively. Animal manure consists 70% organic matter, 2-2.5% N, 2.5% P, 2.5% K, 1-1.5% P_2O_5, < 0.9% Cl, < 0.01% Na, C: N ratio 1.4:1-18.1, and of pH 7-7.5 (Registration No. 6475, Ministry of Agriculture).

Four-week old seedlings of tomato (*Solanum lycopersicum* Mill cv. Margo 956), TYLCV virus resistant, were used in both experiments. Plot size was 2.5*1.5 m of one planting bed consisting a single row. Plants were spaced 30 cm apart within a row and each bed consists seven tomato plants. In both experiments, the plots were drip-irrigated and each dripper delivered 4lh^{-1} of water. Plots were irrigated 2-3 h twice a week. Other required agricultural operations were done like local farmer practices including pesticides and fertilizer applications. The first experiment was started on 5 June 2016 and harvested on 23 August 2016, and the second experiment on 12 February 2017 and harvested on 20 May 2017. Experiments were terminated by first hand- removal of the weeds from the above soil level in the whole plot area. Weed species were identified, separated and number of plants of each per plot was recorded. Tomato fruits were harvested from all plants in each plot, plants were cut-removed from the above soil level and in the whole plot area. Weeds and tomato shoots were piled separately in each plot, left to air-dry in the field and were frequently turned upside down and exposed to sunlight for 3 weeks after harvest in the summer until completely dried. Data on shoot dry weight of tomato plants, total fruit yield and marketable yield and numbers, weight per fruit, and weed shoot dry weight were determined. Weeds found growing below black plastic and polypropylene mulch sheets in different treatments were identified and their growth was visually estimated using a scale of 0-10 at which zero denotes no weed growth and 10 means that weeds were fully growing. Soil moisture and temperature in all treatments were recorded at harvest time and 2 weeks later in both locations using a portable tensiometer (Hydra Probe, Stevens Company).

Statistical analysis: Treatments in both experiments were laid out in a randomized complete block design with four replicates. All data were subjected to the analysis of variance (ANOVA) using SAS software version SAS (r) 9.1 (SAS Institute Inc., 2004) and treatments means were compared using the least significant differences (LSD) at 5% level of probability.

RESULTS

***Weed species and densities in the experimental sites*:** Weed species and their densities in both experiments are shown in Table 1. All weeds were broad-leaved except two narrow-leaved perennials; *Cyperus rotundus* and *Cynodon dactylon* found in both sites and *Setaria verticellata* at the University Campus site. However, densities of both weed species were not more than 2 plants m^{-2}. The dominating weed species were *Amaranthus retroflexus* (23 plant m^{-2}) at Campus site and *Chenopodium murale* (12 plant m^{-2}) at the Jordan Valley.

***Experiment 1 (University Campus, 2016)*:**

***Tomato growth and yield*:** The highest tomato shoot dry weight was obtained from animal manure and B/WMD45 treatments followed by paper mulch which was not significantly different from black plastic and weed-free control (Table 2). The lowest tomato growth was in weed-infested control.

Marketable tomato yield was highest in animal manure mulched plots which was not significantly different from that of B/WMD45, paper, WM30 and weed-free control. Straw, BM25, BM35 and black plastic mulches resulted in the lowest fruit yield among all mulch treatments. However, all mulch treatments gave significantly higher yields than herbicides treatments.

The highest number of tomato fruits was in animal manure and B/WMD45 mulched plots. Considering weight per fruit

Table 1. Weed species and their average densities found at the experimental sites during the 2016 and 2017 growing seasons in both locations.

University Campus, Al-Jubeiha		Jordan Valley	
Weed species	**Density (plant m^{-2})**	**Weed species**	**Density (plant m^{-2})**
Amaranthus blitoides S. Wats.	1	*Amaranthus gracilis* Desf.ex Poir.	3
Amaranthus retroflexus L.	23	*Amaranthus retroflexus* L.	1
Chenopodium album L.	1	*Ammi majus* L.	1
Convolvulus arvensis L.	2	*Atriplex halimus* L.	1
Cynodon dactylon(L.) Pers.	1	*Beta vulgaris* L.	1
Cyperus rotundus L.	1	*Chenopodium murale* L.	12
Eruca sativa Mill	1	*Convolvulus arvensis* L.	1
Heliotropium europeum L.	1	*Conyza bonariensis* (L.) Cronquist	2
Malva sylvestris L.	1	*Chrozophora tinctoria* (L.) Raf.	2
Orobanche ramosa L.	3	*Cynodon dactylon* (L.) Pers.	2
Portulaca oleracea L.	1	*Cyperus rotundus* L.	2
Setaria verticillata (L.) P. Beauv.	1	*Heliotropeum europium* L.	3
Sinapis arvensis L.	1	*Lactuca serriola*L.	2
Sisymbrium bilobum (C. Koch) Grossh.	1	*Malva sylvestris* L.	1
Tribulus terrestris L.	3	*Prosopis farcta* (Banks et Sol.) Macbride	1
-	-	*Sisymbrium irio* L.	2
-	-	*Sonchus oleraceous*L.	3
-	-	*Tribulus terrestris* L.	2

as an indicator on fruit quality, the highest was in animal manure followed by BM35 treatments.

Unmarketable fruit yield was highest in paper covered plots followed by WM30 and animal manure mulches and lowest in BM35 plots. The highest number of unmarketable fruits was in paper mulched plots followed by WM30, B/WMD45, and animal manure although differences between these treatments and the weed-free control were not significant. The lowest unmarketable fruit number was in BM35 treatment,

Among herbicides, pendimethalin and trifluralin resulted in lowest crop growth similar to that of the weed-infested control. Marketable fruit yield was lowest in metribuzin treated plots. Oxyfluorfen gave the highest fruit yield but differences from the weed-infested control were not significant. In all treatments, the lowest fruit quality was in trifluralin treated plots followed by oxadiazon and weed-infested control plots. The highest number of unmarketable fruits was in oxyflourfen treatment and the lowest in metribuzin treated plots. ***Weed growth*****:** Weed dry weight was highest with black plastic mulch although differences from other mulch treatments (except straw and B/WMD67 gave the lowest growth) were not significant (Table 2). Visual estimation of weed growth below polypropylene, black plastic and paper mulch showed that the highest growth was under WM30 sheets followed by paper mulch (Table 4) and the lowest below BM25 and BM35 which was not significantly different from that found below black plastic and BM45 sheets.

Soil moisture and temperature**:** At harvest, the highest temperature recorded was below B/WMD67 which was not significantly different from that measured below BM45, B/WMD45 and paper mulches (Fig. 1). The lowest temperature however, was in weed-infested control and below straw mulch. Soil moisture percentage was highest below WM30 sheets followed by BM35, straw and B/WMD45 mulches but the lowest under animal manure and in the weed-free control.

Two weeks after harvest, the highest temperature recorded was from below paper mulch and the lowest in straw-mulched plots although differences between treatments were not significant (Fig. 1). The highest moisture was recorded below black plastic, followed by BM35, B/WMD45, B/WMD67, BM45, paper, WM30, BM25, straw and animal manure mulches, in order. The lowest soil moisture was in weed-infested control.

In herbicides treated plots, the highest temperature was in metribuzin and oxyflourfen treatments and the lowest in trifluralin and pendimethalin treated plots. Soil moisture percentage was highest in oxadiazon treated plots. Two weeks

Table 2. Effects of different soil mulching treatments and herbicides on tomato growth and fruit yield and weed growth at al-Jubeiha location during 2016 growing season.

Treatments	Tomato					Weeds shoot dry weight ($MTha^{-1}$)
	Shoot dry weight ($MTha^{-1}$)	Fruit				
		Marketable		Unmarketable		
		Weight ($MTha^{-1}$)	No. ha^{-1} ($X10^3$)	Weight ($MTha^{-1}$)	No. ha^{-1} ($X10^3$)	
Weed- free	1.53	9.66	164	1.97	52	0.00
Weed-infested	0.29	3.81	83	1.85	66	5.28
Polypropylene fabrics mulch treatments						
Agri.protect- SGN White Mulch 30 GSM (WM30)	0.94	3.98	149	2.55	67	3.74
Agri protect -SGN Black Mulch 25 GSM (BM25)	0.99	6.94	138	1.39	41	4.80
Agri protect -SGN Black Mulch 35 GSM (BM35)	0.67	6.10	97	0.92	26	4.80
Agri protect -SGN Black and white Mulch/double face 67 GSM (B/WMD67)	0.95	7.21	134	1.64	56	3.04
Agri protect -SGN Black Mulch 45 GSM (BM45)	0.94	7.08	126	1.65	49	4.52
Agri protect -SGN Black and white Mulch/double face 45 GSM (B/WMD45)	1.33	9.94	183	1.75	63	3.82
Other mulch treatments						
Animal manure	1.65	11.66	183	2.51	63	5.22
Black plastic mulch	0.67	7.04	134	1.16	38	5.32
Paper mulch	1.33	9.77	171	2.97	78	4.02
Straw mulch	0.57	5.12	97	1.64	45	3.36
Herbicides						
Metribuzin	0.53	2.97	56	0.94	26	5.18
Oxadiazon	0.67	4.97	105	1.50	52	4.94
Oxyflourfen	0.77	5.39	112	2.14	56	4.16
Pendimethalin	0.39	3.78	78	1.60	40	3.54
Trifluralin	0.49	3.64	179	0.99	29	4.50
LSD $p = 0.05$	0.57	4.89	75	1.46	39	2.55

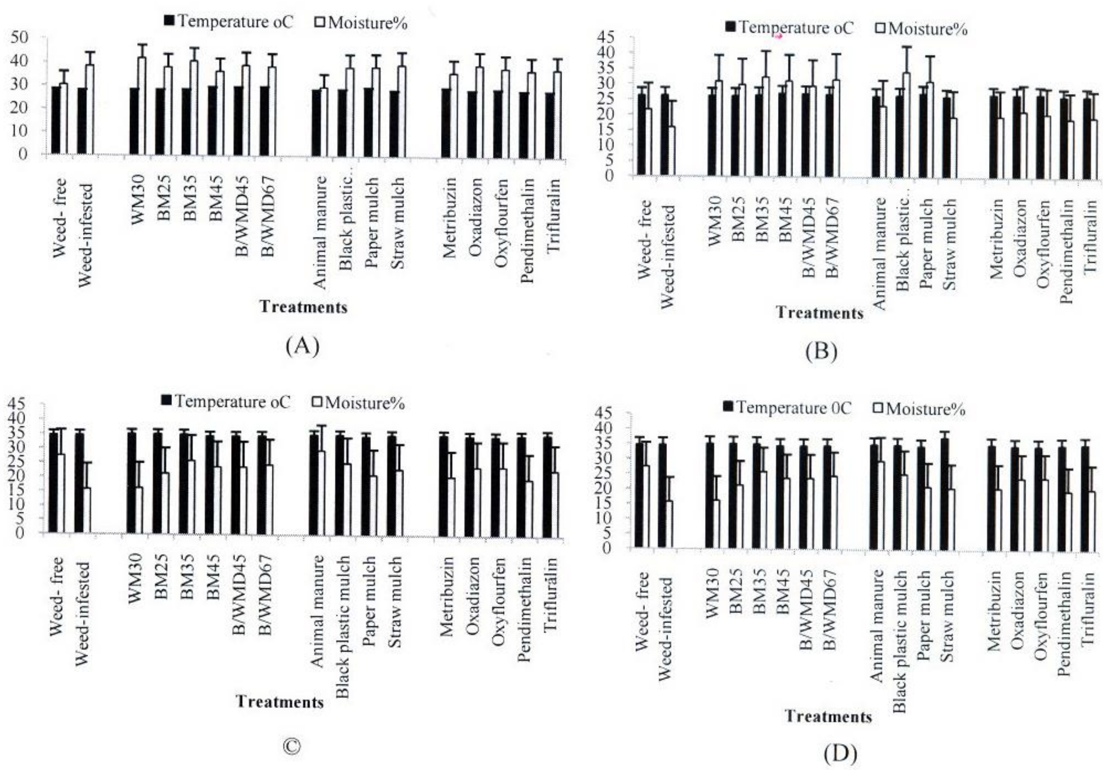

Figure 1. Soil moisture and temperature at University Campus at harvest (A) and two weeks later (B) and at Jordan Valley at harvest (C) and two weeks later (D). I = LSD (*p*=0.05).

after harvest, the lowest moisture was in pendimethalin and metribuzin treated plots.

***Experiment 2 (Jordan Valley, 2017)*:**

***Tomato growth and yield*:** Mulching with B/WMD45 gave the highest tomato growth, followed by black plastic mulch but differences were not significant (Table 3). All other polypropylene mulches treatments resulted in tomato growth greater than the weed-free control and comparable to that of animal manure and paper mulch treatments. The effect of different mulches on marketable fruit yield showed similar trend. Paper, black plastic and B/WMD45 mulched plots produced the highest yield and differences between these treatments were not significant. The lowest tomato yield was in weed-infested plots followed by straw mulch. Mulching with WM30 and BM45 produced higher tomato yield than the weed-free control but differences were not significant. Fruit number per plot was highest in black plastic and paper mulches followed by B/WMD45. The lowest fruit number was in straw mulch and weed-infested control. Weight per fruit was highest in straw and BM35 mulches. The unmarketable fruit yield and number were highest in black plastic, B/WMD45 and paper mulch treatments and lowest in animal manure treated plots.

Among herbicides treatments, the lowest tomato growth was in trifluralin treated plots, but differences between all herbicides and weed-infested control were not significant. Yield, number and quality of marketable fruits were lowest in trifluralin and oxyflourfen treated plots but unmarketable fruit yield (weight and number) was lowest in oxyfluorfen treated plots.

***Weed growth*:** Weeds shoot dry weight in different treatments is shown in Table 3. Among mulches, the highest growth was in animal manure treatment and the lowest in B/WMD67 followed by paper, BM45 and B/WMD45 mulches.

In herbicides treated plots, the highest weed dry weight was in oxyflourfen and trifluralin treated plots and the lowest in pendimethalin treatment.

Visual estimation on weed growth found below different synthetic mulch materials showed highest growth below WM30 sheets. Differences between other mulch treatments

Table 3. Effects of different soil mulching treatments and herbicides on tomato growth and fruit yield and weed growth at Jordan Valley location during 2017 growing season.

Treatments	Tomato					Weed shoot dry weight ($MTha^{-1}$)
	Shoot dry weight ($MTha^{-1}$)	Fruit				
		Marketable		Unmarketable		
		Weight ($MTha^{-1}$)	No. ha^{-1} ($X10^3$)	Weight ($MTha^{-1}$)	No. ha^{-1} ($X10^3$)	
Weed- free	3.19	7.17	86	2.45	45	0.00
Weed-infested	1.86	3.19	45	1.92	49	3.12
Polypropylene mulch treatments						
Agri.protect- SGN White Mulch 30 GSM (WM30)	2.81	7.85	93	2.88	71	2.77
Agri protect -SGN Black Mulch 25 GSM (BM25)	2.70	7.66	93	1.86	34	2.97
Agri protect -SGN Black Mulch 35 GSM (BM35)	3.30	5.28	60	2.03	37	3.01
Agri protect -SGN Black and white Mulch/double face 67 GSM (B/WMD67)	3.08	5.95	75	1.39	49	1.83
Agri protect -SGN Black Mulch 45 GSM (BM45)	3.37	7.77	93	3.12	67	2.45
Agri protect -SGN Black and white Mulch/double face 45 GSM (B/WMD45)	4.00	9.04	108	3.82	78	2.48
Other mulch treatments						
Animal manure	2.48	5.03	64	1.13	22	3.89
Black plastic mulch	3.92	11.89	161	4.89	93	2.69
Paper mulch	3.29	10.56	134	3.35	75	2.27
Straw mulch	1.90	4.80	41	1.64	34	2.86
Herbicides						
Metribuzin	2.20	5.07	37	1.82	41	3.30
Oxadiazon	2.00	5.05	60	1.58	37	3.58
Oxyflourfen	1.61	2.98	60	0.88	19	4.16
Pendimethalin	1.71	5.36	60	2.51	56	2..34
Trifluralin	1.30	2.84	55	2.07	45	3.82
LSD p = 0.05	1.04	3.85	80	1.29	26	2.34

were not significant although weed growth below B/WMD67and paper was relatively high (Table 4).

Table 4. Visual estimation of weed growth under different mulching treatments at two locations.

Treatment	Campus experiment	Jordan Valley experiment
	Score out of 10 †	Score out of 10
WM30	10.00	4.75
BM25	1.13	0.00
BM35	2.13	1.25
B/WMD67	3.63	1.60
BM45	2.38	0.13
B/WMD45	3.75	0.25
Black plastic	2.13	0.13
Paper mulch	4.63	1.50
LSD p = 0.05	2.06	2.20

† Scale 0-10, at which 0 denotes no weed growth under the mulch, while 10 score means that weed growth is full under the mulch material.

***Soil moisture and temperature levels*:** At harvest, the highest soil moisture percentage was recorded from the below animal manure mulch, followed by weed-free control and BM35 cover. In contrast, the lowest moisture level was in the weed-infested control followed by WM30 mulch. However, differences in temperature were not significant between all treatments and ranged between 35.3 to 34.6°C. Temperature was higher in certain treatments than from below black plastic (Fig. 1). Two weeks after harvest, moisture percentage below animal manure, black plastic and paper mulch was highest, but the lowest in weed-infested plots followed by straw and WM30 mulch treatments. Temperature was not significantly varied among all treatments, but highest below paper mulch and lowest in weed-infested control.

Considering the effects of different mulch treatments on average tomato growth and fruit yield and on weed control at two locations, tomato shoot dry weight was highest in B/WMD45 mulched plots followed by black plastic, paper, animal manure and BM35 treatments (Fig. 2). Fruit yield was highest in paper, black plastic, B/WMD45, weed-free control and animal manure treatments. The lowest yield was recorded in the weed-infested control.

Generally, all polypropylene mulch materials produced higher tomato growth and fruit yield than that of herbicides treated and straw mulched plots. Weight per fruit was highest in BM35, followed by metribuzin and straw mulch, and lowest in trifluralin and oxyflourfen treated plots. Unmarketable fruit yield showed similar trend to marketable

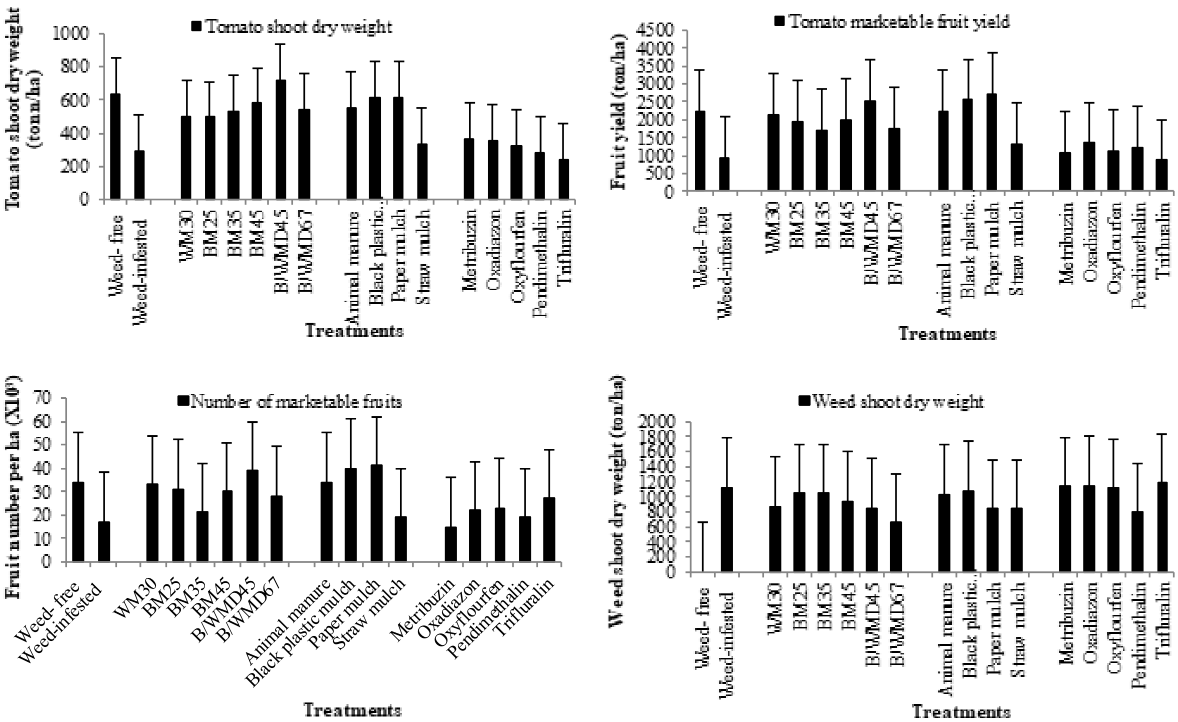

Figure 2. Effect of different soil mulch materials and herbicides on average tomato growth and yield and on weed growth. Data are average of two experiments of two locations in two years. I = LSD (*p*=0.05).

yield. The lowest weed shoot dry weight was in B/WMD67, straw, paper, B/WMD45 and WM30 mulched plots (Tables 2 and 3).

Of the herbicide treatments, the lowest tomato yield was when trifluralin and metribuzin were used. Trifluralin, metribuzin and oxyfluorfen treated plots produced lowest tomato growth which was not significantly different from that of the weed-infested control. Weed dry weight was highest with trifluralin and lowest in pendimethalin treated plots (Tables 2 and 3).

DISCUSSION

In a new development, the Saudi-German Company for Nonwoven Products produced new soil cover materials as alternative to plastic mulch widely used in vegetables and fruit trees. These fabrics are nonwoven polypropylenes of different colours and thickness and UV treated. They are claimed as eco-friendly, biodegradable, and cost effective or even cheaper than the usually used polyethylene black plastic mulch.

Because black plastic is widely used in vegetable fields in the Jordan Valley as well as at high lands in different parts of the country, it was thought necessary testing the new developed materials under both environmental conditions and to compare with other mulching materials and recommended herbicides in tomato fields.

Results showed that weed competition severely impaired growth and yield of tomato with an average yield loss of 58.6% compared with the weed-free crop for the entire growing season (Tables 2 and 3). The dominant weeds however, were *A. retroflexus* at the University Campus site and *C. murale* in the Jordan Valley while both are noxious annual summer weeds (Qasem, 1997), widely spread in the country. These results were to be expected since weeds compete with crop plants for different growth factors and can reduce yield quantity and quality under heavy infestation (Zimdahl, 1980). However, soil cover could effectively restrict weed growth and density. At Campus site, mulching with animal manure resulted the highest tomato shoot dry weight and fruit yield (Table 2). Mulching with B/WMD45 was the second, and followed by paper mulch. The effect of animal manure may be due to its fertilizer effects (in contrast to herbicides and other mulch materials). Manure provides nutrients, warm the soil, hold moisture and when thick enough it prevents weed emergence (Budd, 2017; Rosen and Bieman, 2017). Weed growth was completely prevented below opaque polypropylene and paper sheet mulches. Both prevent light from reaching weed seeds on/in soil surface, both are porous compared with plastic mulch and thus allow gas exchange. However, soil temperature under hydra mulch (newsprint, gypsum and cotton byproducts) was 1–4°C lower than that under polyethylene and in the absence of rain soil moisture levels were 1–4% lower than with polyethylene mulch (Warnick*et al*., 2006).

Polyethylene and paper mulches have been reported to produce the highest yield of processing tomato (Anzalone *et al*., 2010) and paper mulch effectively controlled purple nutsedge (*Cyperus esculentus* L.). In the present work, B/WMD45 sheet used is a double color fabric; the black face was positioned upper and white face lower. This layout allows sunlight interception, and soil warming through black face while white face allows light penetration into soil surface stimulating germination of light sensitive weed seeds. The whole mulch however, prevents physical weed puncture since thick (45g/m^2). In addition, it allows aeration and creates normal growing conditions. The same advantages may be also applied to paper mulch.

Other polypropylene sheets resulted in tomato growth and yield similar to that of the weed-free control. These results indicate that polypropylene mulch effectively controlled weeds and prevented their direct interference with crop plants (Table 2). However, in our treatments and in both locations total plot area was not entirely covered by mulch materials but only cultivated beds; hence weeds were growing in uncovered plot area. Therefore, integration of mulching with other weed control methods is necessary for complete weed prevention otherwise the whole plot area should be covered. Under Campus conditions, polypropylene mulches increased tomato yield to a higher or similar level of the weed-free control or of plastic-mulched plots (Table 2). Under such conditions, it seems that plastic mulch advantage in raising soil temperature more than other materials was not achieved and the recorded temperature under black plastic was not higher than that below other mulching materials (Fig. 1). Therefore, full benefits of plastic mulch including high soil temperature, pest control and crop earliness were denied. Moreover, soil moisture level under plastic was not higher than that in other treatments (Fig.1) indicating no additional advantages of plastic cover shown more than for other mulching materials or even may be lower.

Mulch controlled weeds grown on beds and prevented direct weed competition. However, in some cases certain mulching materials might have worsen weed problems. Organic mulches, such as hay may carry seeds of new weed species into the field. Thin shallow organic mulch layer may allow weed emergence and enhances weed growth by conserving soil moisture (Mohler and Teasdale, 1993). Legume residues have also been reported to release enough nitrate-N to trigger germination of nitrate-responsive weeds such as *A. retroflexus* and *Chenopodium* spp. (Qasem, 1997; Teasdale and Mohler, 2000). Aggressive perennial weeds can emerge through heavy (15 cm thickness) organic mulch layer, thrive, and exhaust moisture and nutrients intended for the crop. Weeds penetrating mulch are more difficult to control which is one of the problems encountered with straw and manure mulches and certain weeds emerged from mulch crop-transplanted holes or punctured plastic mulch. With continuous use of such materials, weed population increased and shifted toward more difficult to control because of selection pressure.

Among polypropylene fabrics, white mulch (WM30) allowed weed seed germination and growth but weeds were kept below sheets (Table 4). Other polypropylene sheets, plastic and paper mulch treatments prevented weed seed germination and/or their growth (Table 4) at varied levels at Campus site. This may be due to that WM30 sheets allowed sunlight interception on soil surface and promoted seed germination and growth of certain weed species. Light promotes seed germination of many agricultural weeds (Egley, 1996), however, low weed growth and better weed control were recorded below sheets in all mulched plots in the Jordan Valley compared with the Campus site. This may be due to the markedly higher soil temperature in the Jordan Valley (Fig. 1) and thus the effect of all mulching materials including black plastic on weeds was well demonstrated. Results indicated that the more the thickness of polypropylene sheets the better the weed control and the higher tomato shoot dry weight and fruit yield. Moreover, the double face colored fabrics were better than the single face whither black or white. Straw mulch effects on tomato growth and yield was not as that of other mulching materials. Straw is most effective on weeds emerging from seeds, and least effective on perennials such as *C. rotundus* and *P. farcta*. It may lower soil temperature and crop early development, but it conserves soil moisture and slow down evaporation (Schonbeck, 2015). Wheat straw however, is well documented to yield allelochemicals and its possible inhibitory effects on tomato plants was possible (Qasem, 2010).

The highest tomato fruit yield obtained in plastic mulch treatment in the Jordan Valley was associated with lower shoot dry weight compared with B/WM45 treatment, while the later resulted in higher tomato growth and yield at Campus site (Tables 2 and 3). Probably B/WM45 sheets encouraged and extended tomato vegetative growth and thus delayed fruiting while the opposite effect was true for plastic mulch. These results clearly demonstrate that black plastic advantages are best expressed in warm climate, warming soil, conserving moisture and probably raising temperature of water vapor underneath to a lethal level enough to kill soil pests and promote crop development and earliness. The effect of soil temperature under black plastic may not be the main cause of this effect since was not significantly different from that in other treatments and at two different readings. May be the combined effect of temperature and high moisture was more important. Bakht and Khan (2014) reported that polyethylene black plastic resulted in significantly highest fruit yield among other mulch and herbicide treatments while Warnick *et al*. (2006) documented high moisture level under plastic mulch. Opposite results in both sites were found using animal manure which may be due to the limited moisture level resulted from high evaporation and moisture loss slowed down the decay process in the Valley site. This might cause some burning on crop root system because of high wind and fermentation temperature. Organic mulches rarely block 100% weed emergence, they give best results when used in conjunction with good crop rotation and measures to prevent or limit weed propagation. Similarly, measures to reduce populations of *Cyperus esculentus* (nutsedge), *Ipomoea purpurea* (morning glory) and other aggressive weeds may be needed before synthetic mulches can be successfully used (Schonbeck, 2015). At the Campus site, animal manure was the best and resulted highest tomato growth and fruit yield but its effect in the Jordan Valley was much lower (Tables 2 and 3). The opposite effect however, was true for plastic mulch treatment in both sites.

All mulch materials resulted higher tomato growth and yield than any of the herbicides used. These results may be due to low or limited activity of the herbicides due to limited number of irrigation and thus un-evenly distributed moisture over the whole plot area. Plants were drip-irrigated and moisture was more available on planted plot beds while the rest of plot area was not moist enough to activate herbicides. In addition, herbicides phytotoxicity to crop plants was also possible. Certain chemicals reduced weed growth more than few mulch treatments but failed to give higher tomato growth or yield. This may be due to that herbicides provided no more benefits other than weed control. Instead, they might cause phytotoxicity to crop plants. In addition, certain herbicides used such as trifluralin are soil-applied labeled for use in tomato and other vegetables, but their immediate mechanical incorporation is necessary after application, otherwise inactivated through photooxidation or volatilization. In addition, these chemicals were not effective against perennial weeds including *C. rotundus, C. arvensis, C. dactylon* and *P. farcta* found in the experimental sites and on many large seeded broadleaf weeds. Crop injury is a concern when cool and wet conditions prevail after transplanting. Metribuzin is effective on annual broadleaf weeds in tomatoes as a soil applied in pre-transplanting treatment but temporary crop injury is possible when applied following several days of warm humid weather usually prevailing in the Jordan Valley and at high lands (Campus site) during the summer. This herbicide is of triazine group, therefore weeds resistant to atrazine and other herbicides of this group including *A. retroflexus* and may be *C. murale* were not controlled. Oxadiazon and oxyflourfen are usually used in a post-planting foliage application on emerged weeds at early growth stages although could be also used as soil-application but at higher rates. In the present work, all herbicides were soil applied and some level of adsorption on soil colloids might have occurred and thus hindered full activities. In addition, all herbicides used were of contact action, ineffective against perennials and their below soil regenerative organs.

In the present work, certain perennial weeds were present; these were not affected by the contact herbicides only effective on germinated seeds. Certain weed species may resist some used herbicides such as *Conyza bonariensis* that resists oxadiazon and oxyflourfen (Qasem, unpublished data) but effectively controlled by certain mulching materials. In addition, soil mulch adds more benefits to crop plants by improved growing conditions.

***Conclusions*:** Agri protect –SGN black and white mulch/double face 45 GSM (B/WMD45) was the best among all mulch treatments. This mulch produced highest tomato shoot dry weight in both locations and fruit yield was similar or higher than that of plastic mulch and weed-free control. Mulching with animal manure was best in producing the highest fruit yield at Campus (Mediterranean), while black plastic mulch was the best for marketable fruit yield in the Jordan Valley (tropical site). Other polypropylene and paper mulch treatments gave similar fruit yield to the weed-free control. All mulch treatments however, were better than herbicides in terms of crop growth and fruit yield and weed control. Results indicate that polypropylene fabrics could be suitable substitutes to black plastic mulch and more applicable for use in different regions grown by tomato crop in the country. These mulching materials are bio-degradable and of a reasonable cost to local farmers. Considering the average of two experiments at two locations, weed competition with tomato caused severe growth and yield reductions. Highest tomato growth was obtained in B/WMD45 mulch, weed-free control, paper mulch and plastic mulch, in order. The highest fruit yield was from paper, black plastic and B/WMD45 mulch treatments.

***Acknowledgements*:** The author thanks the University of Jordan for facilitating this work, the Saudi German Co. for Nonwoven Products, 2nd industrial city, Dammam, Saudi Arabia for providing the polypropylene fabrics, and its represintatives Eng. Yousif A. Naji, and Mrs. Madi Al-Abaddi and Luai Al-Batsh for field assistance.

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