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Performance of green bean(*Phaseolus vulgaris L.*) under different types of degradable mulch *

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Abstract

The research examined the impact of degradable mulch on soil characteristics and development of green bean.Three types of degradable mulches:biodegradable, oxo-degradable, and paper degradable mulchwere comparedwithblack polyethylene mulch andexposed soil. The results showed a significant increasedin soil temperature, with polyethylene and oxo-degradable mulch, while biodegradable mulch exhibited lower temperatures compared to other mulchingtretments. Application different mulching treatments increased soil moisture content significantly compared to the exposed soil. Organic carbon content, soil nutrient content, electrical conductivity and pH, were not significantly affected among different mulch treatments. However, differences in soil microbial populations were observed, with biodegradable mulch promoting higher fungal counts compared to othertretments. Bean growth measurements revealed no significant differences in plant height, but leaf area and shoot fresh and dry weights were influenced by the type of mulch used. Oxo-degradable and paper degradable mulch resulted in larger leaf areas, and biodegradable mulch positively impacted shoot weights. The results also demonstrated that polyethylene ,oxo-degradable mulch and paper degradable mulch treatments significantly increased bean yield compared to exposed soil and biodegradable mulch treatments. Visual mulch degradation evaluation indicated that biodegradable and paper degradable mulches had higher degradation percentages compared with polyethylene and oxo-degradable mulches. These findings emphasize the importance of using environmentally friendly mulching materials, such as biodegradable and paper degradable mulches, in horticulture to reduce environmental impact and promote sustainable food systems.

Key words:Phaseolus vulgaris L., Plastic mulch, Biodegradable mulch,Oxo-degradable mulch, Paper degradable mulch.

1. Introduction:

Beans, (*Phaseolus vulgaris* L.), are a type of legume that belongs to the Fabaceae family. Beans are an important vegetable crop due to their high nutritional value, appealing taste, and versatility in various cuisines. Bean, is a widely consumed grain legume appreciated for its edible seeds and pods by people worldwide (Heuzé et al., 2013). Mulching is a common agricultural practice that entails covering the soil around plants with either organic or synthetic material.This technique is employed to improve crop yield and create optimal conditions for plant development (Chakraborty et al., 2008; Kader et al., 2017). Mulching helps reduce soil compaction, increase aeration, promote soil microbial activity, and improve the overall rooting environment (Tindall et al. 1991). Additionally, it creates a physical barrier that reduces soil water evaporation, controls weed growth, and protects crops from soil contamination (Tindall et al. 1991). Moreover, mulching can reduce the amount of used fertilizers (Jones et al., 1977) and heat soil (Singh et al., 1988). In some cases, mulching can even sterilize the soil, as in the Jordan Valley, where farmers practice soil solarization by intensively heating the polyethylene-mulched soil (Katan et al. 1976).

Plastic mulch is a widely adopted technique in agriculture. Polyethylene (PE) the main materials employed in producing plastic mulches. Plastic mulch is cost-effective, easy to handle and manufacture, and offers numerous benefits to fruit and vegetable production (Martín-Closas et al., 2017). However, plastic mulch films pose a significant environmental problem due to their hydrophobic properties (Hussain et al., 2022; He et al., 2014; Steinmetz et al., 2016). Polyethylene waste has a low biodegradability rate, and due to limited recycling alternatives, it usually finds its way into landfills or is incinerated, which can further exacerbate the environmental impact of plastic mulches (Shogren and Hochmuth, 2004; Ingman et al., 2015; Shah, 2020).

Conversely, biodegradable mulch decomposes as a result of the microorganisms, including bacteria, fungi, and algae(Mooney,2009). Starch-based mulch films have gained popularity in recent research due to their cost-effectiveness and abundance as natural polymers, which enable them to form a film structure. Halley et al. (2001) have combined biodegradable polyester polymers with starch-based polymers to create a high-performance blend, and the starch enhances the film's degradation to micro debris on the soil. Biodegradable substances can be easily incorporated with soil into,biomasswater,carbon dioxideand methane. Unlike materials such as polyethylene and non-biodegradable mulches that require disposal, biodegradable materials offer a sustainable and environmentally friendly alternative in terms of waste generation. Oxo-degradable polymers are a group of degradable pro-oxidant substances. These substances, such as transition metal salts like manganese, cobalt, or iron salts, act as catalysts for the oxidative degradation process. The presence of pro-oxidant substances allows these materials to undergo oxidative degradation, leading to form oxygenated groups that can be more easily metabolized by microorganisms (Ojada et al., 2009). Oxo-degradable plastics degrade as a result of both oxidative and cell-mediated processes.in commercial vegetable production,the use ofpaper mulch was limited due to its short lifespan and high labor and materials cost, as Hopen and Oebker noted in 1976. However, recent developments in biodegradable paper mulch have made it a viable alternative to polyethylene mulch, as it naturally degrades and adds organic matter to the soil, according to (Saglam et al., 2017).

Paper mulch has been around since the early 1920s. Nevertheless, its brief lifespan and exorbitant expenses in terms of materials and labor prevented its utilization in the realm of commercial vegetable cultivation. However, recent technological advancements have led to the development of biodegradable paper mulch, made from cellulosic hydrocarbons and naturally degrade, adding valuable organic matter to the soil. Research has shown that paper mulch can be a valuable alternative to traditional PE mulch, with unique properties that allow it to conform comfortably to the soil surface. According to a study by Saglam et al., (2017), biodegradable paper mulch has a unique texture that gives it some flexibility, allowing it to conform to the soil surface. Paper mulch has a positive impact on the environment. Unlike PE mulch, paper mulch is biodegradable, so it does not contribute to plastic pollution in the soil. Additionally, paper mulch can reduce the amount of plastic waste generated by agricultural activities. Abbate et al., (2023) noted that covering soil surface with paper mulch has been found to increase soil temperature similarly to PE mulch while reducing plastic waste. The aim of this study is to explores biodegradable, oxo-degradable, and biodegradable paper mulch alternatives to polyethylene plastic mulch, to assess their impact on bean yield.

2. Material and methods

The experiment was carried on facultyof agriculture, Mutah University at, Al-Karak Governorate (Latitude 31°16′N, Longitude 35°45′E; Elevation 920 m above sea level).The experiment was conducted during the summer growing season from May to August 2022.

Seeds of bush bean hybrid (*Phaseolus vulgaris* L., Momentum cv.) were sown on the last week of May with 5 cm deep halls on the center of the row (bed) at 30 cm spacing. Each row was at 1.5 m spacing (0.8m as footpaths), 4 meter in length, and 70 cm in width. Thirteen bean seeds were planted in each bed. Agricultural practices were conducted in the open field, seeds were sown simultaneously, and an additional row on each side of the experiment was assigned to protect it from edge effects and pests.The application of mulch was carried out at planting time, with drip lines being laid at the center of each row. The five mulching treatments used in each block were as follows: exposed soil (no mulch) as a control, polyethylene mulch(black), biodegradable mulch(black), oxodegradable mulch(black), and white paper degradable mulch with three replicates for each treatments. The location was designed using a randomized complete block design (RCBD). Soil samples were gathered at a depth of 10 cm in three subsamples from each plot order to assess the impact of treatments on various soil properties, including,total nitrogen content (N), available phosphorus content (P), available potassium content (K), electrical conductivity,pH and organic carbon content. Plant growth measurements such as leaf area, leaf chlorophyll content, plant height, shoot fresh weight, and shoot dry weight were measured as will as yield and yield component. Leaf mineral content (N, P and K), were measured at the end of growing season. The appearance of the mulch was evaluated weekly throughout the growing season by determining the percentage of visual degradation in a 1m² area of each mulch treatment. The evaluation was conducted using the method described byAlamro et al., (2019) and Lopez-Tolentino et al. (2017) with some modifications, and the percentage ranged from 0% (intact mulch) to 100% (completely degraded mulch).

Soil microbial (bacteria and fungi) enumeration was conducted by obtaining soil samples from all experimental treatments 90 days subsequent to the burial of mulch residues into the soil at the end of the growing season. The quantification of bacteria and fungi was determined by assessing the number of colony forming units (CFU) per gram of fresh soil on culture media. This was achieved through the preparation of serial dilutions using 10 grams of dry soil mixed with distilled sterilized water.Latterly, 100 microliters were applied onto nutrient agar in thepetri dishes, which were incubated at 37 °C for a duration of 24 hours to grease bacterial growth. For fungal culturing, dextrose agar with 1 milliliter periodical dilutions was employed and incubated at 25 °C for a period of 72 hours. The total count of colonies present on each plate was enumerated, and the issues were expressed as colony- forming units per gram of fresh soil.(CFU/g).The experimental data were analysis of variance (ANOVA) using MSTATC software.

3. Result and Discussion

There was a noticeable difference in soil temperature among mulch treatments and the exposed soil throughout the study period (Table 1). The highest temperature in the soil was observed under polyethylene mulch during the growing season.In general, differentmulch treatmentsexhibited higher soil temperatures compared to the exposed soil treatment.

This observation aligns with the findings of Alamro et al. (2019), which demonstrated that covering the soil with polyethylene, biodegradable, and oxo-degradable mulch led to higher soil temperatures thanexposed soil.In the same vein, Huo et al. (2023) reported that different types of mulching techniques, such as polyethylene, biodegradable, and oxo-degradable mulch, resulted in elevated soil

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temperature when compared to the absence of mulching. However, a contrasting result was reported by Mu et al. (2023), who found that soil temperature decreased when biodegradable mulch was compared to exposed soil.The present results suggest that paper mulch and biodegradable mulch have lower heat preservation than oxo-degradable and polyethylene mulch..Runham et al. (1998) reported that soil temperature beneath paper mulch is lower compared to polyethylene mulch. It appears that paper mulch and biodegradable mulch tend to radiate heat more efficiently than other mulch types.

Soil moisture content in exposed soil plots was significantly lower compared to the different mulch treatments, but there were no significant differences between the different mulch treatments.The results from table (1) indicate a notable higher soil moisture under polyethylene mulch and oxo-degradable mulchcompared with other mulcing treatments. This finding aligns with the findings of Snyder et al. (2015), who reported a negative correlation between mulching effects and soil moisture levels in exposed soil. Similarly, Alamro et al. (2019) demonstrated that soil covered with oxo-degradable mulch, polyethylene mulch, and biodegradable mulch exhibited higher soil water content compared to exposed soil. Manna et al. (2018) reported that mulching helps preserve soil moisture content by increasing water retention, reducing evaporation, and minimizing weed population density.

Table 1: Impact on soil properties of different mulches

Treatment	soil temperature	Soil moisture	Soil pH	Soil EC (µS/cm)	Soil organic carbon content g/Kg
Exposed soil	36.9c	10.9b	8.30 a	227.0 a	122.8 a
Polyethylene mulch	42.6a	20.0a	8.25 a	307.0 a	128.6 a
Biodegradable mulch	38.3b	13.9a	8.48 a	256.5 a	132.1 a
Oxo-degradable mulch	41.4a	19.9a	8.26 a	220.0 a	130.4 a
Paper degradable mulch	40.3ab	15.8a	8.44 a	206.5 a	135.6 a

*Mean values marked with the same letter in each column indicate no significant difference at a significance level of $p \leq 0.05$.

There were no significant diferencesesin soil organic carbon content,soil electrical conductivity (EC) and soil pH(table 1) among the various mulch treatments. These findings are consistent with the results reported by Zhang et al. (2019), and Alamro et al. (2019), who also found no significant variation between the different mulch treatments. The study also investigated the effects of degradable mulch on soil electrical conductivity (EC) and soil organic carbon.These findings agreed with the results reported by Alamro et al. (2019) who found mulching had no significant effect on electrical conductivity. Additionally, Zhang et al. (2019) noted that polyethylene and biodegradable mulch increased EC, whereas paper mulch reduced soil EC.

Table 2:Impact on thesoilmineral contentof differentmulches

Treatment	N %	P %	K %
Exposed soil	0.12a	27.97 c	0.039 ab
Polyethylene mulch	0.12 a	28.00 c	0.038 b
Biodegradable mulch	0.10 a	34.53 bc	0.043 ab
Oxo-degradable mulch	0.11 a	38.10 ab	0.044 ab
Paper degradable mulch	0.10 a	43.43 a	0.045 a

*Mean values marked with the same letter in each column indicate no significant difference at a significance level of $p \leq 0.05$.

In general, nitrogen percentage in soil was not affected by different mulching treatments (table 2). Thehighest value soil P percentage was obtainedbycovering soil plots with paper degradable mulch, while the lowest value was obtained in exposed soil and polyethylene mulch plots. Thehighest K soil contentwas obtained with mulching the soil with paper degradable mulch, while covering with polyethylene plastic mulch reduced soil K value. This finding is consistent with Liu et al. (2020) and Thompson et al. (2019), which reported that paper degradable mulch enhances nutrient availability and uptake in the soil. While, Alamro et al. (2019), detailed no significant differences in soil N, P, and K contents among the different mulch treatments. This discrepancy could be attributed to variations in experimental conditions, such as soil conditions, climate, and plant species, which may influence the effectiveness of different types of mulch.

Soil microbial activity play a vital role in soil healthiness and nutrient cycling. Data presented in table (3), show the impact of different types of mulching treatments on soil microbial counting. It appears that no significant variations in fungi count were observed among different mulching treatments (table 3). The biodegradable mulch treatment exhibited the highest fungi count, followed by polyethylene mulch and exposed soil. On the other hand, the lowest count was recorded under oxo-degradable and paper mulch treatments. These findings agreed with Tan et al., (2016), who reported a higher population of bacteria under biodegradable mulch compared to polyethylene. Also, Alamro et al. (2019) indicating that the highest fungal and bacterial populations were found under biodegradable mulch compared to oxo-degradable mulch, polyethylene, and exposed soil. Yang et al. (2003) reported that mulching plotsresulted in a more significant population of bacteria and fungi thanunmulched plots.

Table 3: Impact on soil microbial count($CFUg^{-1}$)of differnet mulches

	Fungi	Bacteria ($\times 10^4$)
Before seeding		
Treatment	2845	57
Exposed soil	4575 a	189 a
Polyethylene mulch	4792 a	91 a

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Biodegradable mulch	5419 a	238 a
Oxo-degradable mulch	4254 a	219 a
Paper degradable mulch	3844 a	219 a

*Mean values marked with the same letter in each column indicate no significant difference at a significance level of $p \leq 0.05$.

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

Bandopadhayy et al. (2019) found no significant effect of degradable mulches on the soil microbiome compared to polyethylene. It's might be due tovarious factors, including soil conditions, climate, and mulch incorporation techniques can influence the response of soil microbial communities to different mulch types.

Leaf area, shoot fresh weight, and shoot dry weight parameters provide insights into the growth and productivity of plants under various mulching techniques . In general, table (4), vegetative growth parameters (plant height, leaf area, shoot fresh weight and shoot dry weight) of green beans (*Phaseolus vulgaris L.*) showed a significant difference among different mulch treatments. Plots covered with polyethylene plastic mulch and oxo-degradable mulch gave the highest plant height, followed by biodegradable mulch, while the lowest plant height was obtained with exposed soil treatment.Oxo-degradable mulch had the highest leaf area (90.04), followed by paper degradable mulch (81.62), biodegradable mulch (80.66), and polyethylene mulch (78.32), while exposed soil had the lowest leaf area (69.85).The highest fresh weight was observed for the polyethylene mulch treatment (122.2gm.), followed by the oxo-degradable mulch treatment (116.6gm.). In comparison, the lowest fresh weight was recorded for the exposed soil treatment (89.7gm.). Dryweight of green beens had similar trend. Moreno et al. (2008) found that high dry weight of tomatoe plants under biodegradable and polyethylene mulch treatments. Additionally, there were no significant differences in shoot fresh and dry weight between polyethylene and oxo-degradable mulch treatments, aligning with the findings of Lopez-Tolentino et al. (2017) for cucumber plants.

Table 4: Impacton plant height, leaf area, fresh weight and dry weightof green bean plant of different mulches

Treatment	Plant height (cm)	Leaf Area (cm^2)	Fresh weight (gm.)	Dry weight (gm.)
Exposed soil	38.56 c	69.85 a	89.74 c	14.25 c
Polyethylene mulch	48.56 a	78.32 a	122.2 a	21.00 a
Biodegradable mulch	46.89 b	80.66 a	105.9 b	17.67 b
Oxo-degradable mulch	48.47 a	90.04 a	116.6 a	18.23 b
Paper degradable mulch	47.45 b	81.62 a	104.7 b	18.50 b

* Mean values marked with the same letter in each column indicate no significant difference at a significance level of $p \leq 0.05$.

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Leafchlorophyll content of green beans was insignificantly affected by different mulching treatments(table 5). The highest chlorophyll content of beanleaves was recorded grown under polyethylene mulch, followed by beans grown with biodegradable mulch.Ashrafuzzamanet al. (2011), reported thatcovering the soil with plastic mulch significantly increased the chlorophyll content of beans compared to the exposed soil treatment.

Table 5: Impact on beans leaf chlorophyll content and macronutrient elementsof different mulch

Treatment	Chlorophyll content	N %	P %	K %
Exposed soil	44.23 a	2.400 a	0.513 c	2.400 ab
Polyethylene mulch	47.49 a	2.300 a	0.590 b	2.167 b
Biodegradable mulch	47.13 a	2.520 a	0.683 a	2.583 a
Oxo-degradable mulch	46.16 a	2.400 a	0.673 a	2.390 ab
Paper degradable mulch	46.49 a	2.360 a	0.656 a	2.44 ab

*Mean values marked with the same letter in each column indicate no significant difference at a significance level of $p \leq 0.05$.

Data presented in table (5) showed no significant differences in leaf N content at all mulching treatments,which agreed withLi et al. 2014 andChen et al. (2020), who found no significant difference in nitrogen content between exposed soil and biodegradable mulch treatments. Regarding phosphorus content (P %) (Table 5), the highest value was recorded in the biodegradable mulch treatment (0.6833), which is consistent with the findings of Zang et al. (2022), who observed an increase in phosphorus uptake in plants grown with biodegradable mulch. On the other hand, Wang et al. (2019) found no significant difference in phosphorus content between exposed soil and biodegradable mulch treatments, suggesting that the impact of mulch on phosphorus content may depend on various factors.Thehighest value of leaf K content (table 5) was obtained in the biodegradable mulch treatment (2.583). Chen et al. (2022), reported an increase in K % content in plant leaves with the use of degradable mulch. In contrast, Zang et al. (2019), observed no significant difference in leaf K content between exposed soil and degradable mulch treatments.

Overall, present results indicate that using degradable mulch, particularly biodegradable mulch, can potentially increase the nutrient content in bean leaves compared to exposed soil, as reported by several studies. However, the variability of results reported in the literature, which could be attributed to factors such as crop type, soil conditions, mulch composition, and specific experimental setups.

Data presented in table (6)shows yield and yield components of green been under different mulching treatments Pod lengthandpod diameter were not significantly affected by different mulching treatments. In conclusion, pod measurements such as length and diameter can be influenced by multiple factors, including the type of mulch, environmental conditions, and agricultural practices. Mulching treatments significantly affected green bean yield per hectare and yield per plantin similar trend.Thehighest yield was obtained with the oxo-degradable mulch (5775.0 kg/ha), paper degradable mulch (5652.0 kg/ha), and polyethylene mulch (5598.0 kg/ha), then the biodegradable mulch (5146.0 kg/ha), While the lowest yield was obtained from the exposed soil (1064.0 kg/ha).

Table 6: Impact ongreen bean yield and yield components of different mulch

Treatment	Pod length (cm)	Pod diameter (cm)	Yield/ plant (g)	Yield/ ha (kg)
Exposed soil	12.74 b	0.627 a	47.90 c	1064.0 c
Polyethylene mulch	14.17 a	0.857 a	251.9 a	5598.0 a
Biodegradable mulch	14.22 a	0.855 a	228.6 b	5146.0 b
Oxo-degradable mulch	14.26 a	0.843 a	259.9 a	5775.0 a
Paper degradable mulch	14.22 a	0.833 a	254.3 a	5652.0 a

*Mean values marked with the same letter in each column indicate no significant difference at a significance level of $p \leq 0.05$.

Polyethylene and oxo-degradable mulch treatments significantly increased the yield of bean crops compared to exposed soil and biodegradable mulch treatments. This finding agreed with Sinkeviciene et al. (2009), which emphasized the significant impact of mulching materials on crop yield.

Data presented in table (7), shows the evaluation of visual mulch degradation percentage for different types of mulch over several weeks after seeding. Itappears that polyethylene mulch did not degrade during the 10-week of evaluation period, while biodegradable, oxo-degradable, and paper degradable mulch showed varying degrees of degradation. Biodegradable and paper degradable mulch showed higher degradation percentages compared to oxo-degradable mulch. The comparison of treatments shows that the highest degradation percentage was observedat paper degradable mulch (92 %) followed bybiodegradable mulch (89 %), while the oxo-degradable mulch and polyethylene mulch have the lowest degredation percent by 12 and 12.5%, respectively.

This is supported by previous research that has shown that biodegradable and paper degradable mulches can provide a more environmentally friendly alternative to traditional mulching materials, as they break down more quickly in the soil and do not contribute to long-term pollution (Yang et al., 2020).

Table 7: The evaluation of visual mulch degradation.

	Degradation % weeks after seeding											
Treatment	1	2	3	4	5	6	7	8	9	10	20	25
Polyethylene mulch	0	0	0	0	0	0	0	0	3.6	3.6	6.2	12.5
Biodegradable mulch	0	0	0	0	2	6	8	18	24.3	34	41	89
Oxo-degradable mulch	0	0	0	0	0	0	0	2.2	3.8	5.5	7.4	12
Paper degradable mulch	0	0	0	0	1	3	8	15	23	29	45	92

This finding has important implications for sustainable agriculture and environmental protection. As mentioned by Yang et al. (2020), the use of biodegradable and paper degradable mulches can provide a more environmentally friendly alternative to traditional mulching materials, as they break down more easily in the soil and do not contribute to long-term pollution. Furthermore, the findings of this investigation propose that the degradation contrast between the biodegradable and oxo-degradable mulch treatments can be influenced by the polymer composition, as cited by Lopez-Tolentino et al. (2017); Martin et al. (2016); and Adhikari et al. (2016), who affirmed that biodegradation is contingent on several factors, including the polymer properties such as chain flexibility, molecular weight, and polymer composition.

Conclusion:

The study investigated the impact of degradable mulch on bean growth, yield, soil parameters growth. The results revealed significant variations among different mulch treatments and exposed soil.

In terms of crop yield, the use of polyethylene and oxo-degradable mulch and paper degradable mulch treatments significantly increased the yield of green bean compared to exposed soil and biodegradable mulch treatments.

The evaluation of visual mulch degradation showed that biodegradable and paper degradable mulches had higher degradation percentages than polyethylene and oxo-degradable mulches. This suggests that biodegradable and paper degradable mulches offer a more environmentally friendly alternative as they break down more quickly in the soil.

In terms of soil parameters, mulching had a significant effect on soil temperature and moisture content. Mulched plots generally exhibited higher soil temperatures, with polyethylene and oxo-degradable mulch resulting in the highest temperatures. Soil moisture content was significantly higher in mulched plots compared to exposed soil. However, the mulched plots and exposed soil had no significant differences in soil pH, electrical conductivity, organic carbon content, and nutrient content (N, P, and K). Variations in soil microbial counts were observed, with biodegradable mulch promoting higher fungi populations.

Regarding plant growth, mulching did not significantly affect the height of bean plants. However, mulching significantly affected leaf area, with oxo-degradable and paper degradable mulch resulting in larger leaf areas compared to other mulch types. Degradable mulches also positively influenced shoot fresh and dry weights, with biodegradable mulch showing the most pronounced effect.

The study highlights the potential benefits of using biodegradable and paper degradable mulches for sustainable agriculture and environmental protection. The choice of mulching materials should consider factors such as crop yield, soil temperature regulation, moisture retention, and microbial populations. The findings contribute to understanding the potential benefits and limitations of degradable mulches in agricultural practices, promoting more sustainable and environmentally friendly approaches to crop production.

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