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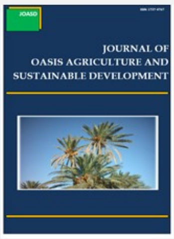

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Effect of reduced tillage under various mulch types on soil fertility and yield of an organic pepper crop

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Abstract

The effects of mulching on soil characteristics and plant development for pepper crops conducted in organic farming were studied in the Sahel coast of Tunisia. The types of mulching used for tests are straw mulching, compost mulching, and plastic mulching which were compared with bare soil without mulching (control). The soil characteristics under these different mulching systems were evaluated by soil physical and biological parameters such as penetration resistance at 0-60 cm layer, microbial biomass, organic matter, and water content at 0-20 cm layer. Measurements were performed every week for 50 days. The obtained results showed that compost mulching led to a better growth rate and improved the structural and water state of cultivated soil by decreasing its resistance to penetration and increasing its organic matter content. It can be concluded that the "*Beldi*" organic pepper crop under conservation tillage and compost mulching has presented the best combination thus leading to motivating results such as the positive effects of soil physical properties and microbial biomass on the final crop yield.

1. INTRODUCTION

Despite the progress noted in recent years, African agriculture has a low production due to the low productivity of current agricultural production systems. Thus, the major challenge will be to increase productivity while preserving natural resources. To meet this challenge, many technical practices and technical innovations will be implemented by agricultural actors, such as organic farming and conservation agriculture (Djamen et al. 2005). Tunisia has systematically reformed its agricultural sector to meet the growing demand for organic products. In the last years, the organic sector was characterized by higher crop diversification with a strong area and farmers increase (GIZ, 2020). Organic farming is a solution to the various problems associated with the excessive use of chemicals in agriculture, while conservation farming allows a reasoned application of farming practices (Dinesh et al. 2018). In Tunisia peppers is one of the most popular fruits, show a wide variation related to the size, flavor, and pungency, and known to be consumed fresh, dried, preserved or in spicy sauces are (Dabbou et al. 2017; Bogusz Junior, 2015; Pino et al. 2007). In fact, the areas of organic agriculture reached about 326 thousand hectares in 2019 against 18.600 hectares in 2002 and the number of operators rose from 481 in 2002 to 7.190 in 2019. Organic vegetable crops in Tunisia, present 211 ha from the total area (CTAB, 2021). Depending on the pepper varieties and the purpose of production, the harvest period may vary. Peppers are usually harvested green, manually, with their peduncle when the fruits have not yet reached full maturity. It is recommended to harvest between 50 and 55 days after flowering for green fruits or 60 to 80 days transplanting. In this case, the risk of rot, insect attack or sunburn is limited. The harvest may last three months or longer as long as disease levels are controllable, or production becomes insignificant. Fresh fruit yields are in the range of 10 to 20 tons per hectare but theoretically yields of 40 tons are possible whereas grain yields are in the range of 120 kg/ha (ITCMI, 2010). Conservation agriculture aims to improve the natural functions of ecosystems and thus an intensification of the soil biological activity. Mulching is an innovative technique to achieve the objectives of conservation agriculture (Li et al. 2018). This technique is highly recommended due to its effects on weed control and soil moisture conservation, and thus ultimately, the reduction of tillage. Thus, mulching has an economic and environmental impact on horticultural production systems (Torres-Olivar et al. 2017). Nachtergaele et al. (1998) and Kodešová et al. (2014) showed the effects of gravel mulch on soil temperature and on evaporation. De Vita et al. (2007) and Martínez et al. (2008) have demonstrated that reduced tillage under straw mulch, could improve the soil structure, enhance the soil water conservation, and promote root growth. Govaerts et al. (2007) showed that soil with straw mulch has higher water content than non-straw mulch during major growth stages under no-till conditions. In this context, it is evident that information on the use of different mulching materials is still incipient. Thus, the study aimed to determine the effects of three types of mulching: a straw mulching, compost mulching, and plastic mulching on soil properties and the development of two pepper varieties grown organically.

2. MATERIAL AND METHODS

2.1 Experimental description

Experiments were carried out under field conditions in the Technical Center of Organic Agriculture in Sousse governorate, Tunisia (35◦54′53′′ N, 10◦34′16′′ E, and 12 m of altitude) during the spring-summer season (from April to July 2020), in a sandy clay loam soil (26 % clay, 68 % sand, and 6 % silt) under reduced tillage system with four treatments and five replications (Fig. 1).The treatments consisted of different materials for soil mulches: straw mulch SM (10 cm thickness), compost mulch CM (5 cm thickness), black plastic film produced from polyethylene films PF, and without mulches with weed hoeing NM (Fig. 2). The pepper local variety "*Beldi*" was grown in twenty beds, spaced 0.8 m between rows and 0.4 m between plants. The distance between the treatment beds was 1.00 m, totaling 60 thousand plants per hectare. Irrigation was carried out considering the water requirement of the pepper crop of approximately 700 mm throughout the cycle. In spring-summer, the plants were grown for 90 days.

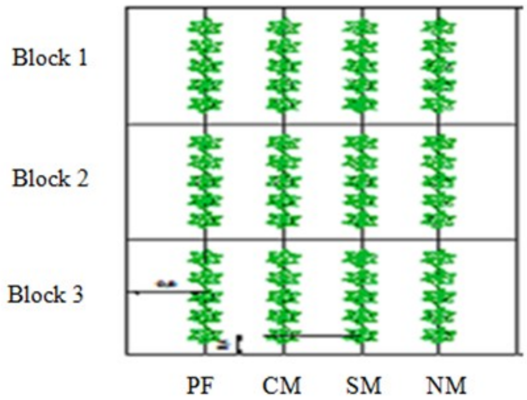

Fig. 1. Experimental layout
(SM: straw mulch of 10 cm thickness, CM: compost mulch of 5 cm thickness, PF: black plastic film produced from polyethylene films, NM: control without mulches and with weed hoeing).

Fig. 2. Different types of Mulch

2.2 Soil penetration resistance

Measurements were performed at 10-day intervals from the beginning of the transplant until 50 days after transplanting (DAT) using an electronic penetrologger (Eijkelkamp, Giesbeek, The Netherlands) to a depth of 60 cm. It measures the mean vertical stress required for penetration of a steel cone of 11.28 mm. It is the resistance of soil to the force of penetration per unit area expressed in [Nm^{-2}] or in [MPa]. The penetration depth is measured continuously as the cone is pressed within the soil. The resistance was then calculated based on the surface area of the cone (manometer reading, kN/base area of cone, cm^2), and finally the values were converted to MPa. The penetration resistance is greatly influenced by soil mulching, water content, soil texture, organic matter content, speed of penetration, and the length and tip angle of the cone. Soil water content was measured jointly at 0-10 and 10-20 cm layers by drying the soil samples at 105°C for 24 hours (Keller et al., 2007).

2.3. Soil temperature

Ten measurements of soil temperature were performed, at 10-day intervals, from the beginning of the transplant until 50 DAT. The data collection was performed with a digital thermometer with a probe 115 mm long stainless steel. Measurements were taken at 8 a.m. and 2 pm in two depths, at 5 and 15 cm below the soil surface.

2.4. Soil microbial biomass

Microbiological analyzes consisting in counting mesophilic and thermophilic bacteria and fungi with the typical techniques. These analyzes were carried out at 0-10, 10-20 cm soil layers. Microbial biomass was determined by colony counting using the enumeration method after inserting into agar. Soil organic matter (SOM) was measured by Walkley and Black method.

2.5. Statistical analysis

Analysis of variance was performed to evaluate the treatments effects on the soil and crop yield. The effect of the treatments under reduced tillage system was evaluated by analysis of variance when significant effects of evaluated factor were observed (F test, $P \leq 0.05$), the Tukey test was used to compare the means at 5% probability. All analyses were performed using SAS statistical software.

3. RESULTS AND DISCUSSION

3.1. Soil penetration resistance

Compost mulching showed the lowest soil resistance of 100 daN at 10 cm depth while plastic mulching showed the highest value of 172 daN at the same depth (Table 1). At a depth of 30 cm under straw mulching, we noted a lower soil penetration resistance of 152.57 daN. Thus, the highest value was recorded under plastic mulching with 225 daN. The positive effect of the mulching system occurs mainly in the first centimeters of the soil and can be as much as 30

Table 1. Average cone resistance to penetration (daN) under different mulch types for the Beldi variety.

Depth	NM	SM	CM	PF
0	97.67	63.67	67.67	94.33
1	99.67	73.33	67.00	102.33
2	109.00	83.67	98.33	128.67
3	112.00	95.67	105.67	142.67
4	144.00	100.00	112.00	152.00
5	138.00	101.00	103.33	175.33
6	135.00	110.00	100.33	157.33
7	133.67	112.33	102.33	166.33
8	132.67	108.33	98.33	168.00
9	127.33	101.00	83.33	174.00
10	126.00	116.00	100.33	172.00
11	124.00	118.33	104.33	174.67
12	126.33	119.67	116.00	162.67
13	126.67	120.00	116.67	149.33
14	127.00	119.67	113.67	157.67
15	134.33	113.33	114.67	150.67
16	138.00	115.33	113.33	151.33
17	130.67	109.00	113.00	175.33
18	142.67	115.00	120.67	185.00
19	146.00	108.00	146.00	181.33
20	144.33	129.33	151.33	184.67
21	142.67	153.33	148.67	198.33
22	127.33	159.00	148.67	224.67
23	127.67	154.33	126.00	222.00
24	129.00	143.67	112.33	216.67
25	115.00	147.67	140.67	177.00
26	122.67	142.67	142.00	178.33
27	130.33	147.00	146.00	201.33
28	136.33	148.67	156.00	209.67
29	136.67	141.33	156.00	220.33
30	143.33	152.67	161.33	225.33
31	226.33	174.00	154.33	231.33
32	228.67	189.33	152.00	198.67
33	267.00	216.67	159.00	235.00
34	247.33	211.00	171.67	225.67
35	240.00	219.33	165.00	128.33
36	238.33	194.33	191.67	227.33
37	235.33	208.00	202.67	199.00
38	233.33	225.33	199.00	208.67
39	253.67	248.33	183.67	313.00
40	263.67	244.00	184.67	321.67
41	276.67	242.00	184.67	345.33
42	270.00	233.00	208.00	352.67
43	279.67	246.33	207.67	356.67
44	281.33	273.33	145.67	230.67
45	284.00	286.33	214.67	322.33
46	299.00	296.33	184.67	332.67
47	310.67	309.00	192.33	270.00
48	320.00	321.00	230.00	331.67
49	365.00	332.33	260.33	324.00
50	268.33	342.00	291.33	337.33
51	336.67	365.67	316.00	341.00
52	237.67	375.00	338.33	299.33
53	255.33	380.00	358.00	261.33
54	276.33	316.33	363.33	306.67
55	238.00	328.67	361.00	311.00
56	336.33	333.33	391.67	315.00
57	366.67	338.67	410.67	279.33
58	379.00	293.00	311.67	349.00
59	385.00	301.67	345.67	377.33
60	391.00	339.33	360.67	316.00

NM: no mulching; SM: straw mulching; CM: compost mulching; PF: plastic film mulching

Table 2. Comparison of soil penetration resistance (daN) for different mulching systems under reduced tillage.

Depth	Control	SM	CM	PF
0	97.66±42.19	63.66±14.15	67.66±21.22	94.33±22.94
10	126±14.73	116±31.79	100.33±17.38	172±41.56
20	144.33±50.74	129.33±68.42	151.33±34.02	184.66±68.97
30	143.33±64.05	152.66±20.5	161.33±17.21	225.33±124.6
40	263.66±7.51	244±54.06	184.66±35.92	321.66±19.86
50	268.33±190.62	342±45.18	291.33±32.02	337.33±69.66
60	391±129.32	339.33±57.59	360.66±61.01	316±233.67
LSD *(P=0.05)*	ns	ns	ns	ns

±: standard deviation; ns means no significant. SM: straw mulching; CM: compost mulching; PF: plastic film mulching

cm of depth (Table 2). The effect on soil aeration and the improvement of biological life subsequently has an impact on the improvement of root development conditions. This effect is no longer significant beyond 30 cm of depth. Compost mulching ensures the best conditions for plant development (Zhang et al., 2020). With the PF treatment, the average soil penetration resistance was highest at 0-10 cm and lower (316 daN) at 50-60 cm depth with no significant differences between the treatments. The occurrence of lower soil resistance under CM under reduced tillage could be related to an increase of soil water. The mulching system had a significant effect on the soil moisture (Adekiya et al., 2017). CM showed the highest value at the 0-10 cm layer with an average water content of 18.8%, followed by SM with 17.4%, NM with 15.6% and PF with 13.2% content (Fig. 3). Compost mulching maintains sufficient soil moisture ensuring the best conditions for the plant development (Kundi et al., 2019). Abrougui et al., (2019) showed that stability of soil structure in surface is usually larger under shallow tillage, direct seeding, and ridges than in plowing. In effect, conventional tillage reduced the surface organic matter amount after plowing and biological activity still lower in surface. In addition, minimum tillage required fewer passages of the machinery in wetter conditions and avoided plow pans formation. Under minimum tillage, aggregates stability is often similar to that under conventional tillage when the tillage action causes the destruction of aggregates though this system upgrades the organic matter accumulation in surface for reduced tillage. There was a significant negative correlation between soil resistance and soil water content (SWC). Soil resistance increased with decreasing SWC, and about 62% of the variation in soil resistance could be explained by SWC. The cause of the higher soil penetration resistance with the no mulching treatment was mainly related to decreased soil water content. In agreement with our results, several previous studies have showed that using mulch on bare soil can reduce soil resistance to penetration by improving soil water, enhancing soil porosity, and improving microbial activities (Ourgholami et al., 2020; Liu et al., 2018). Furthermore, mulch has been observed to enhance the mineralization

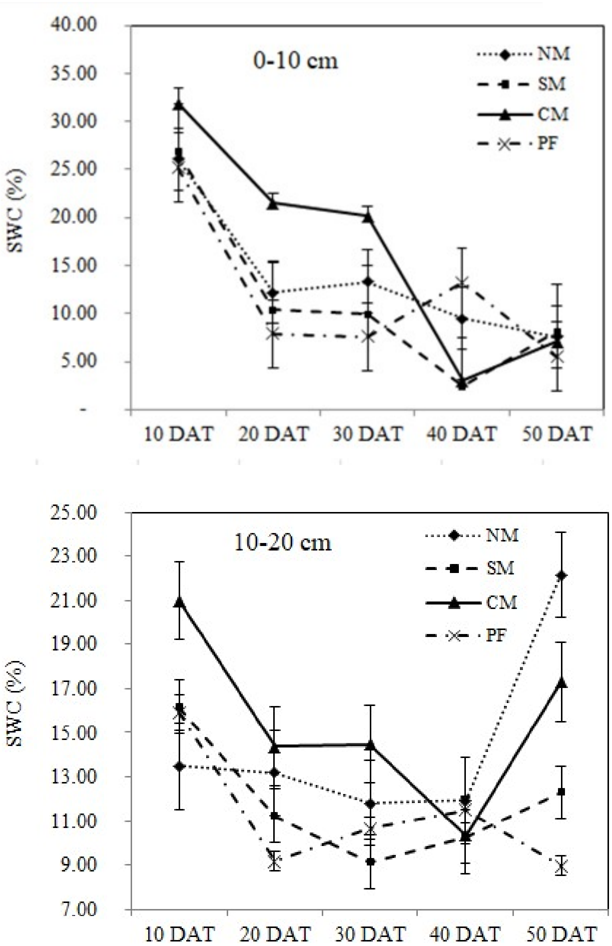

Fig. 3. Average soil water content at 0-10 and 0-20 cm layers under different mulch types, NM: no mulching; SM: straw mulching; CM: compost mulching; PF: plastic film mulching

of soil organic carbon and nitrogen, which leads to the stabilization of soil aggregates and the improving of cone soil penetration resistance (Lenka et al., 2021; Sara et al., 2021). Soil penetration resistance throughout the research study period was not affected by the increase of the mulch level from 5 t ha^{-1} to 10 t ha^{-1} and the volume of irrigation water required to the above field capacity.

3.2. Soil temperature

The soil mulch had a direct influence on soil temperature in the 0-10 and 10-20 cm layers (Fig. 4). The average highest soil temperatures were recorded under PF (20.7ºC) for the comparing to other mulching materials. Similar results were showed by Zhang et al. (2020), an increase in soil temperature with plastic

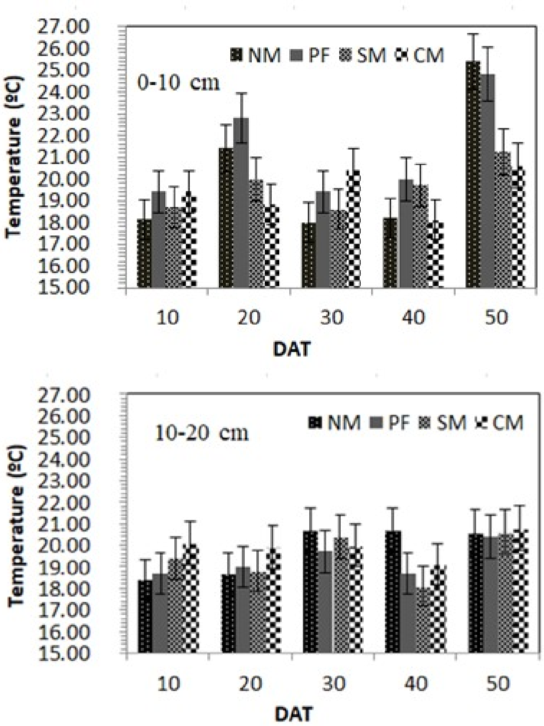

Fig. 4. Average soil temperature under different mulch types and days after transplanting, NM: no mulching; SM: straw mulching; CM: compost mulching; PF: plastic film mulching

coverings occurred in all growing seasons, especially in the summer. The results showed that dark-colored plastic mulches films allowed a higher increase in soil temperature compared to the bare soil. Job et al. (2016) also demonstrated that the behavior of the radiant energy and its influence on the microclimate is determined by the color of the plastic mulch film affecting soil temperature. Pepper plants demonstrated better development in spring-summer season characterized by a higher incidence of sunlight and higher temperatures than in winter. According to Karvatte et al. (2020) and He et al. (2019), among the environmental factors, air and soil temperature present a principal role in the growth of tomato plants.

3.3. Soil microbial biomass and organic matter

The measured microbial biomass MB (Fig. 5) is higher with compost mulching (58.8*10^3 UFC/g) under reduced tillage, but the differences between the treatments remain significant 45.1*10^3UFC/g; 51.5*10^3UFC/g and 36.6*10^3UFC/g for NM, SM and PF treatments respectively. The increase of soil organic matter

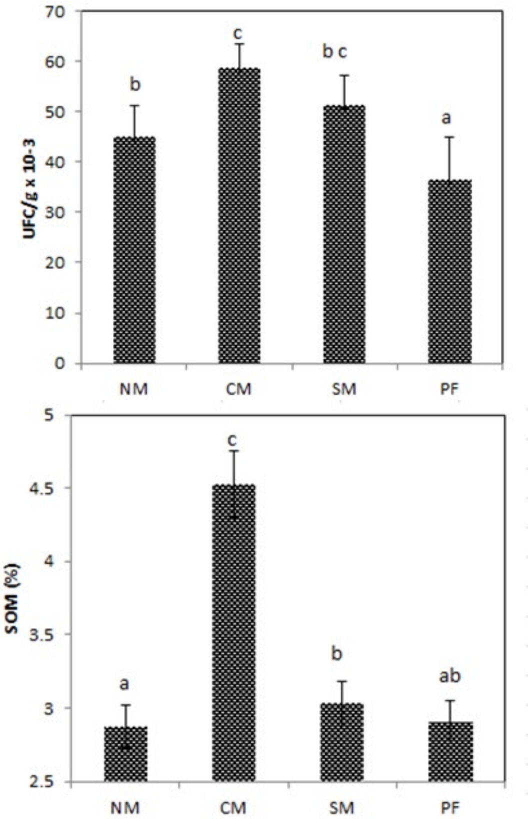

Fig 5. Average soil microbial biomass and organic matter at 0-20 cm layer under different mulch types; NM: no mulching; SM: straw mulching; CM: compost mulching; PF: plastic film mulching; the numbers followed by a common letter are not statistically different (P <0.05).

in surface layer under minimum tillage with compost mulching (4.5%) under reduced tillage, promotes microbial biomass and microbial diversity in the upper soil layer but the differences between the treatments remain significant 2.8%; 3% and 2.9% for NM, SM and PF treatments respectively. Mulching is widely used to increase organic crop yield in semiarid regions in Tunisia, but little is known about the effect of different mulching systems on the microbial properties of the soil, which play an important role in agroecosystemic functioning and nutrient cycling (An et al. 2015). Compost mulching modifies the physical and chemical environment of the soil and thus globally influences the growth and activity of microorganisms. These changes play an important role in crop growth and agroecosystemic function and sustainability in dryland farming. The level of soil moisture has been associated with microbial biomass, but Zhang et al. (2020) reported that plastic-film mulching reduced MB during crop growth, which confirm our results. The reason for the higher values in our study might attribute to the higher soil organic matter under compost mulching. Indeed, Gong et al. (2009) reported that manure could provide abundant organic matter for the growth of microorganisms, with positive effects on microbial activity and biomass, and thus enzymatic activities (Wei et al. 2015). In our study, the increase of soil moisture and topsoil temperature under mulching technologies was closely related to soil microbial biomass.

3.4. Pepper crop yield

In the present study, plastic film mulching significantly increased pepper yield. Higher averages were found under plastic film mulch (3.8 t/ha) followed by CM (3 t/ha) and SM (2.4 t/ha). These results confirmed those of Liu et al. (2018), who reported that film mulching promoted maize growth and development. Mulching may reduce evaporation, reradiation of solar energy and losses of latent and sensible heat and thus increase soil temperature and moisture, promoting earlier germination and plant establishment. The effect of PF mulch on pepper yield was not statistically significant compared to the compost mulch. Optimizing soil management in organic pepper production is necessary in arid and semiarid areas where wind erosion is common. Differences in soil microbial and enzymatic activities from technics should be investigated when modifying farming practices, although monitoring the long-term effects of mulching on soil microbes may be needed for a better understanding and management of microbial processes for optimizing crop productivity while maintaining and improving soil quality in this semiarid agroecosystem.

4. CONCLUSION

Plastic film mulches affect soil temperature in spring-summer growing season, with higher temperatures which may have compromised pepper growth. In the other side, compost mulches also affect soil properties precisely its cone penetration resistance and maintains sufficient soil moisture ensuring the best conditions for the plant development. The increase of soil moisture and topsoil temperature under compost mulching system was closely related to higher soil microbial biomass in the upper 0-10 cm layer. The effects of organic farming on soil microbes were complex. Monitoring the long-term effects of mulches and fertilizers on microbial diversity is thus needed in future studies. Black plastic film mulches resulted in a 23% increase in pepper yield compared to straw mulch and an 11% increase compared to compost mulch. However, ulterior research would be needed to assess soil chemical and biological properties and yield under different mulching and growing seasons.

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