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Shifting Long-Term Tillage to Geotextile Mulching for Weed Control Improves Soil Quality and Yield of Orange Orchards

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Abstract: Weed control in urban and peri-urban orange orchards is challenging due to operational and legislative restrictions. Tillage, besides from negatively affecting soil fertility and microorganisms, is demanding for humans. On the other hand, herbicides are advised against due to the possibility to reach waterbodies from the soil surface. Therefore, in urban and peri-urban areas, instead of tillage and herbicides, mulching with black plastic geotextile fabric is often used. This study aimed at assessing the impact of long-term soil mulching with black plastic geotextile fabric on soil fertility, microbial community and yield of an orange orchard in comparison to conventional tillage. To this aim, four soil management systems were set up: rotary tillage for the last 15 years, mulching with black plastic geotextiles for the last 15 years, rotary tillage for 7 years followed by mulching for the last 8 years, mulching for 7 years followed by rotary tillage for the last 8 years. Soil samples were analyzed to determine the chemical and biochemical parameters related to soil fertility. In addition, the abundances of the main microbial groups were investigated. Mulching increased soil total organic C at least by 65%. The greater soil organic C in mulched soil in turn contributed to increase the cation exchange capacity (+62% on average) and microbial biomass C (+120% on average). Additionally, the microbial quotient exhibited higher values in mulched soils compared to tilled ones, suggesting a greater soil organic matter accessibility by soil microorganisms. Moreover, mulching favored fungi over bacteria, and Gram-positive bacteria over Gram-negative bacteria, thus contributing to the establishment of a microbial community more efficient in utilizing C sources. The latter result was confirmed by the lower values of the metabolic quotient in mulched soil compared to tilled one. Overall, the black plastic geotextile fabric improved chemical and biochemical soil fertility that, in turn, lead to a higher orange yield in mulched soil.

Keywords: soil fertility; soil bioindicators; Washington navel; weed management; tillage

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1. Introduction

Weed control is crucial for agricultural production as well as landscape and environment management, as it plays an important and a determinant role to meet future food production requirements [1]. In farming (crop reinforcement against weeds), physical (tillage, burning, hand-removing), biological (organisms, pasture), genetic (herbicide tolerant or resistant crops) and chemical (herbicides) approaches are adopted for weed management [2–4]. Conventional practices for weed control in citrus orchards usually include tillage in the inter-rows and mowing or use of herbicides (mainly glyphosate) in the tree rows [5]. Tillage either destroys weeds or makes the soil environment less suitable for seed germination and weed growth. However, continuous tillage adoption, three-to-four times yearly, in the long term may exert detrimental effects on soil properties such as compaction [6,7], water-stable aggregation [8], nutrient availability, microbial biomass and activity [9,10], as well as the enhancement of erosion hazard [11,12]. The worsening of the aforementioned soil properties entails a decline in soil quality [13]. Badagliacca et al. [10] found, in a semiarid Mediterranean environment, that no tillage compared to continuous tillage increased soil total organic C (TOC), microbial biomass, in particular Gram-negative bacteria, and increased the percentage of organic C of microbial origin (the microbial quotient). Chemical management, based on the use of synthetic herbicides, is usually preferred by farmers because it is easy to apply and may imply different lasting effects. However, chemical herbicides may exert side-effects on the ecosystem's functioning, as they comprise pollutants able to damage the living components of soil–water–air compartments, and, lastly, human and animal health [14,15]. The excessive use of synthetic herbicides favors the selection of herbicide-resistant weeds, [16] which can affect the soil's microbial community structure and, consequently, the turnover of soil organic carbon [17,18]. Moreover, according to the need to reduce the dependence of agriculture on pesticides [19], developments in weed management should increase the efficiency of herbicides or integrate them with other single strategies such as mechanical control [20]. Moreover, drawbacks caused by tillage in urban and peri-urban areas negatively impact humans [21], whereas herbicides, such as glyphosate, are advised against due to the possibility of them reaching waterbodies from the soil's surface [22]. In addition, some countries (e.g., Italy) have already prohibited glyphosate in urban and peri-urban areas [23]. Therefore, there is a need to identify alternative and sustainable methods to control or to manage weeds, especially in urban and peri-urban areas. Mulching is one of the most advantageous practices that can be used in citrus orchards for weed control [24,25]. It consists of covering the soil surface with a protective layer of a material that may be organic, inorganic or synthetic. Plastic film mulching is extensively used to control weeds in a broad range of orchard and horticultural crops [25]. It is generally associated with yield increases for many field crops [26–28]. Måge [24] reported that the black plastic film used for soil mulching in young apple trees improved growth and yield, whereas trees in permanent grass sod had the lowest growth and yield. Plastic film mulching is effective in avoiding the germination of weeds and limiting soil water loss by evaporation, thus increasing water uptake, water use efficiency and plant growth. On the other hand, plastic film mulching does not allow for the addition of organic matter and nutrients to the soil and, overall, rainfall infiltration. Some of such drawbacks may be overcome by using geotextile mulch films. These are fabrics used in geotechnical applications, such as road and railway embankments, earth dikes and coastal protection structures, designed to perform one or more basic functions such as separation of layers, drainage, filtration, stabilization or reinforcement [29]. Geotextiles are generically made by plastic materials, mostly polypropylenes and polyesters. They let air and water pass through but withstand cracking and trampling, so they can last for a long time [29]. However, they inevitably increase soil moisture and temperature, thus affecting the biological characteristics of the soil, but some negative impacts on soil quality and sustainability cannot be excluded. Therefore, there is a need to critically examine the impact of geotextile mulching on soil microbial community and soil fertility, so as to predict the changes in soil quality and identify a sustainable management strategy for agro-ecosystems. Microbial biomass and activity, as well as the abundance of the main microbial groups, are reliable indicators of soil management because they reflect microbial ability for both synthesizing cellular compounds and decaying organic substrates; indeed, any of their changes relate to nutrients and carbon cycling [30]. Total organic C and microbial biomass C (MBC) are greatly affected by tillage and other crop management practices [13]. Thus, changes in soil microbial biomass and activity are fundamental to understand soil ecosystem functioning and how it is affected by different agro-techniques.

This study aimed at assessing the effects on soil quality of long-term geotextile mulching in comparison to long-term conventional tillage for weed management in an urban citrus orchard. We hypothesized that mulched soil is of higher quality than tilled soil and that the longer the mulching duration, the better the soil quality. Such a hypothesis relies on the fact that mulched soil is less disturbed, i.e., less aerobic, than the tilled one, and that the soil organic matter mineralization process is slowed down, thus leading to its accumulation that, in turn, increases microbial biomass and activities, i.e., indirectly affecting the soil ecosystem functions.

2. Materials and Methods

2.1. Study Area and Experimental Design

This study was carried out in a peri-urban area (Sicily, Italy; 37°42′22.60″ N; 12°30′20.32″ E) where citrus orchards are generally cultivated near the inhabited center. Washington navel orange plants were planted in 1982 with a layout of 5 × 5 m, thus having 400 plants per hectare (Figure 1).

Figure 1. Orange orchard (**A**) un-mulched and (**B**) mulched with black plastic geotextile fabric.

The soil of the study area was an Eutric Cambisol [31]. The main characteristics of the 0–20 cm soil layer determined at the beginning of the experiment (2005) were as follows: 325 g kg^{-1} clay, 225 g kg^{-1} silt, 450 g kg^{-1} sand (sandy clay loam texture), pH 7.8 (1:2.5 H_2O, w/v), 12.1 g kg^{-1} organic C and 18.2 $cmol_{(+)}$ kg^{-1} cation exchange capacity. According to Köppen–Geiger’s classification, the climate of the study area is classified as Mediterranean hot summer (Csa), with mild and wet winters, and from warm to hot and dry summers [32]. Climatic data recorded from 1998 to 2020 showed a mean annual air temperature of 17.8 °C and a mean annual rainfall of 603 mm [33]. Since 2005, four different weed management systems were established in a citrus orchard obtaining twelve plots of 10 m in length and 20 m in width. In order to discriminate between the effects of the geotextile and rotary tillage, taken both alone and combined, four soil treatments were set up: no mulching—rotary tillage for the last 15 years (M0T15), no tillage—mulching with black plastic geotextiles (130 g m^{-2}) for the last 15 years (T0M15), rotary tillage for 7 years followed by mulching for the last 8 years (T7M8) and mulching for 7 years followed by rotary tillage for the last 8 years (M7T8). Each weed management was replicated three times in the field. In the tilled plots, rotary tillage was applied two-to-three times per year in March or April, June and October down to the first 15/20 cm of soil. Rotary tillage is a tillage management commonly used in orchards to incorporate organic residues and fertilizers in the topsoil. The tillage device is constituted of milling cutter blades that mix and crumble the topsoil operating perpendicularly to the soil surface. In April 2020, three soil samples at 0–20 and 20–40 cm depth per management were taken (4 weed management × 3 soil samples × 2 soil depths), thus obtaining 24 samples in total (each sample about 1 kg). All plots were biannually organically fertilized, by removing temporarily the geotextile mulch, with 4-month-aged solid cow manure, to supply 190, 50 and 100 kg ha^{-1} of NPK, respectively.

2.2. Chemical and Biochemical Soil Analyses

Soil chemical analyses were carried out on samples which were air-dried and sieved at 2 mm. Cation exchange capacity (CEC) was determined with ammonium acetate solution buffered at pH 7.0 [34] and TOC on pulverized soil samples by dichromate digestion [35]. Previously air-dried and sieved soils, immediately before biochemical analyses, were pre-incubated at 50% of water holding capacity (WHC) and 25 °C for 7 days, in order to restore the microbial activity. Microbial biomass C was determined by the fumigation–extraction (FE) method [36] following the procedure reported by Badagliacca et al. [10]. Microbial biomass C was calculated as EC/k_{EC}, where EC is the organic C extracted from fumigated soil minus that extracted from non-fumigated soil and k_{EC} is 0.38 [37]. The concentration of K_2SO_4-extractable C from non-fumigated soil was assumed as a proxy of available C [38]. The microbial quotient was calculated as the percentage of TOC present as MBC. Microbial respiration was determined by measuring the CO_2 evolved from soil during incubation. Briefly, 20 g of soil at 50% of WHC was placed in a 250 mL glass bottle, and the CO_2 cumulated during 3 days of incubation at 25 °C was determined by a gas chromatograph (Trace GC, Thermo Electron) equipped with a thermal conductivity detector. The metabolic quotient (qCO_2) was calculated as mg CO_2-C g^{-1} MBC h^{-1}.

The composition of main soil microbial groups was quantified by the direct extraction of ester-linked fatty acids (ELFAs), following the method proposed by Schutter and Dick [39]. A Thermo Scientific FOCUS™ gas chromatograph equipped with a flame ionization detector and a fused-silica capillary column Mega-10 (50 m × 0.32 mm I.D.; film thickness 0.25 µm) was used for ELFA detection and quantification. The gas chromatograph temperature was set as follows: initial isotherm at 140 °C for 5 min, increase at a rate of 1.5 °C per minute from 140 to 230 °C and final isotherm at 230 °C for 2 min. The identification of FAME peaks was based on comparing retention times with known standards (Supelco Bacterial Acid Methyl Esters mix cat no. 47080-U and Supelco 37 Component FAME mix cat no. 47885-U). FAMEs were expressed as nmol kg^{-1} dry soil. FAs with less than 14 carbon atoms or more than 19 carbon atoms were excluded as originating from non-microbial sources [40,41]. The FAs i15:0, a15:0, 15:0, i16:0, i17:0, 17:0, cy17:0, 18:1 ϖ7 and cy19:0 were used to represent bacterial biomass, while 18:2 ϖ6,9 was used for fungal biomass. Gram-positive bacteria (bacG+) were quantified by summing the FAs i15:0, a15:0, i16:0 and i17:0, while for Gram-negative bacteria (bac−) the FAs summed were 18:1 ϖ7, cy17:0 and cy19:0.

2.3. Statistical Analyses

The reported results are the arithmetic means of three field soil samples (one for each replicated plot per soil management) and are expressed on soil oven-dry weight basis (105 °C). Before performing parametric statistical analyses, normal distribution and variance homogeneity of the data were verified by Kolmogorov–Smirnoff goodness-of-fit and Levene's tests, respectively. One-way analysis of variance (ANOVA) was performed with soil management as a factor for each sampling depth. The significant effects of soil management and sampling depth were separately tested by one-way analysis of variance, with the least significant difference test ($p < 0.05$) used for means comparison either among management at the same depth or between depths within the same management. Washington navel orange orchards yield was analyzed by one-way ANOVA with soil management as a factor, followed by the least significant difference test ($p < 0.05$) used for means comparison among management within the same year. SPSS 13.0 was used for statistical analyses.

3. Results

Soil mulching with black plastic geotextile fabric avoided the germination of weed for the whole duration of the experiment. This is because it let air and water pass through, but not light. Therefore, weed seeds did not germinate.

3.1. Tillage and Mulching Effects on Soil Properties

The cation exchange capacity ranged from 27.1 to 16.6 $\mathrm{cmol_{(+)}\ kg^{-1}}$ in the 0–20 cm soil layer and from 23.6 to 14.6 $\mathrm{cmol_{(+)}\ kg^{-1}}$ in the 20–40 cm layer, displaying lower values in tilled soil compared to the mulched one, while intermediate values were found soils tilled for less than 15 years, regardless of whether the tillage period preceded the mulching period (Table 1).

Table 1. Main chemical and biochemical properties of soil under four soil management systems since 2005 (M0T15, rotary tillage; T0M15, mulching with black plastic geotextiles during the last 15 years; T7M8, tillage for 7 years followed by mulching during the last 8 years; M7T8, mulching for 7 years followed by tillage during the last 8 years).

Soil Management	CEC[1] $\mathrm{cmol_{(+)}\ kg^{-1}}$	TOC[2] $\mathrm{g\ kg^{-1}}$	EOC[3] $\mathrm{g\ kg^{-1}}$	MBC[4] $\mathrm{mg\ kg^{-1}}$	Microbial Respiration $\mathrm{g\ kg^{-1}\ d^{-1}}$	Microbial Quotient %	Metabolic Quotient $\mathrm{mg\ CO_2\text{-}C\ MBC\ g^{-1}\ h^{-1}}$
0–20 cm soil layer							
T0M15	27.1 Aa	22.2 Aa	213 Aa	631 Aa	14.4 BCa	2.9 Aa	0.9 Ca
M7T8	20.1 Ba	15.3 Ba	111 Ca	314 Ca	15.9 ABa	2.1 Ba	2.1 Ba
T7M8	20.6 Ba	17.5 Ba	147 Ba	499 Ba	13.4 Ca	2.8 Aa	1.1 Ca
M0T15	16.6 Ca	12.8 Ca	101 Ca	215 Da	16.1 Aa	1.7 Ca	3.1 Aa
20–40 cm soil layer							
T0M15	23.6 Ab	16.8 Ab	144 Ab	411 Ab	12.3 Ab	2.4 Ab	1.0 Ca
M7T8	17.7 Bb	10.1 Cb	72 Bb	230 Bb	9.9 Cb	2.3 Aa	2.1 Ba
T7M8	17.2 Bb	14.4 Bb	74 Bb	363 Ab	11.4 ABa	2.5 Aa	1.1 Ca
M0T15	14.6 Ca	10.2 Ca	59 Bb	171 Ca	9.4 BCb	1.7 Ba	3.0 Aa

[1] CEC, cation exchange capacity; [2] TOC, total organic carbon; [3] EOC, extractable organic carbon;.[4] MBC, microbial biomass carbon. Different upper-case letters indicate significant differences ($p < 0.05$) among management (T0M15, M7T8, T7M8 and M0T15) within the same layer (0–20 cm and 20–40 cm). Different lower-case letters indicate significant differences ($p < 0.05$) between depths (0–20 cm vs. 20–40 cm) within the same management system (T0M15, M7T8, T7M8 and M0T15).

More precisely, shifting weed management systems from tillage to geotextile mulching increased CEC, on average, by 62% at the 0–40 cm depth after 15 years. The CEC increase was less marked for shorter periods of mulching. Similarly, both total and extractable C pools increased by shifting weed management systems from tillage to geotextile mulching (Table 1). Indeed, with the former they increased by 73% and 65% and with the latter by 110% and 144%, in the topsoil and subsoil, respectively. Additionally, in the two treatments where mulching and tillage were carried out for a shorter time, both total and extractable C pools increased, although less remarkably compared to 15 years of mulching (Table 1). TOC was positively correlated with CEC ($R^2 = 0.766$; n = 24, $p < 0.01$, data not shown).

Microbial biomass C ranged from 631 to 214 mg C $\mathrm{kg^{-1}}$ in the topsoil, while it ranged from 411 to 171 mg C $\mathrm{kg^{-1}}$ in the subsoil (Table 1). In 15 years of mulched soil, compared to 15 years of tilled soil, it was 2.9 and 2.4 times higher at the topsoil and subsoil, respectively. At intermediate mulching periods, the MBC increase was lower but, remarkably, MBC was higher when the mulching period followed the tillage period than the other way around (Table 1). Microbial respiration was rather higher in the topsoil compared to the subsoil at the same treatment (Table 1). At both depths, microbial respiration was lower in soil mulched for 15 years compared to soils tilled for 15 years, whereas no differences were observed between T0M15 and T7M8 mulched soils, indicating that subsequent 8 years of mulching were able to offset the negative impact of the previous 7 years of tillage. The microbial quotient ranged from 1.7% to 2.9% and in the topsoil resembled the pattern of MBC (Table 1), with again the positive effects of the last 8 years of mulching after the previous 7 years of tillage. Moreover, in the subsoil the lowest value occurred in soil only tilled for 15 years, with about 40% higher values in the three mulched treatments. The qCO_2 ranged between 0.9 and 3.1 mg CO_2-C g^{-1} MBC h^{-1} and generally displayed an opposite pattern compared to the microbial quotient (Table 1). The total amount of ELFAs (nmol FA g^{-1}) of microbial origin followed the same pattern of the MBC content, these two bioindicators being positively correlated ($R^2 = 0.791$; $p < 0.01$; $n = 24$; data not shown). Total bacteria ranged from 293 to 112 nmol FAs g^{-1} in the topsoil and from 150 to 65 nmol FAs g^{-1} in the subsoil (Table 2).

Table 2. Abundance of the main microbial groups (nmol g^{-1}) assessed on soil samples under four soil management systems since 2005 (M0T15, rotary tillage; T0M15, mulching with black plastic geotextiles during the last 15 years; T7M8, tillage for 7 years followed by mulching during the last 8 years; M7T8, mulching for 7 years followed by tillage during the last 8 years).

Soil Management	ELFAs	Bacteria	Bacteria G+	Bacteria G−	Fungi
0–20 cm soil layer					
M15	391 Aa	293 Aa	163 Aa	95 Aa	75 Aa
M7T8	220 Ca	181 Ca	106 Ba	57 Ca	22 Ba
T7M8	262 Ba	221 Ba	109 Ba	76 Ba	27 Ba
T15	132 Da	112 Da	63 Ca	31 Da	12 Ca
20–40 cm soil layer					
M15	191 Ab	150 Ab	87 Ab	45 Ab	30 Ab
M7T8	106 Bb	87 Bb	55 Bb	22 BCb	13 BCb
T7M8	115 Bb	93 Bb	52 Bb	28 Bb	16 Bb
T15	78 Cb	65 Cb	37 Cb	16 Cb	9 Ca

Different upper-case letters indicate significant differences ($p < 0.05$) among management (T0M15, M7T8, T7M8 and M0T15) within the same layer (0–20 cm and 20–40 cm). Different lower-case letters indicate significant differences ($p < 0.05$) between depths (0–20 cm vs. 20–40 cm) within the same management (T0M15, M7T8, T7M8 and M0T15).

In the topsoil, similarly to previous bioindicators, they were more abundant in soil only mulched for 15 years, followed by that mulched for the last 8 years, whereas the lowest value was found in soil only tilled for 15 years. The same pattern was found in the subsoil, except for no difference between M7T8 and T7M8. Additionally, fungi for any treatment were more abundant in the topsoil compared to the subsoil (Table 2). At both depths, soil only mulched for 15 years exhibited values of fungi at least triple compared to the soil only tilled for 15 years, with the other two treatments (M7T8 and T7M8) exhibiting intermediate values. However, at both depths no difference was found between these two treatments (Table 2). Within bacteria, the bac+ predominated over bac- and displayed the same pattern among treatments: both groups were more abundant in soil only mulched for 15 years and the lowest in the only tilled one (Table 2). However, by increasing the time during which the soils are tilled at both depths, the fungi decreased and the bacteria increased, whereas the opposite, evidently, occurred by increasing the time during which the soils are mulched (fungi increased and bacteria decreased) (Figure 2). Additionally, bac- and bac+ displayed a pattern linked to soil management: by increasing the time during which the soils are tilled, bac- increased, whereas bac+ decreased. On the other hand, as expected, by increasing the time during which the soils area is mulched, bac+ decreased and bac- increased (Figure 3).

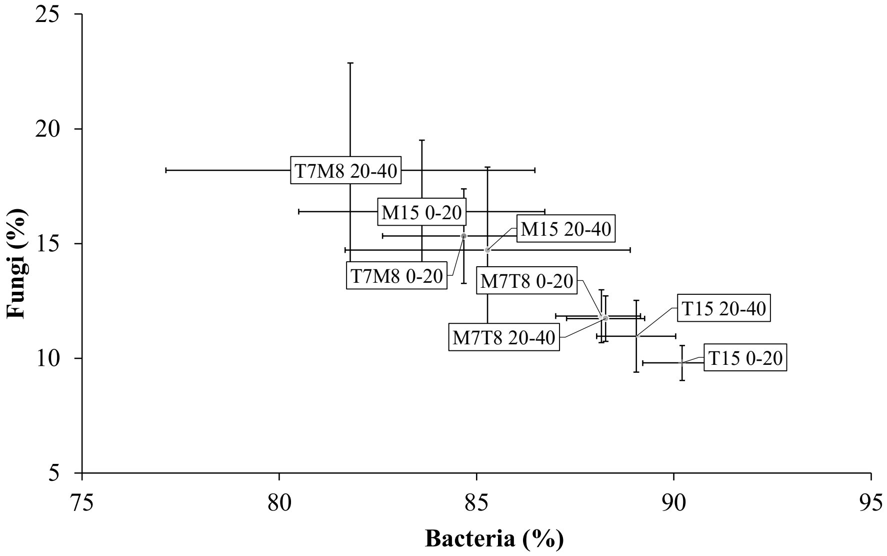

Figure 2. Relationships between relative abundance of total bacteria and fungi at both soil depths of the four soil management systems: M0T15, rotary tillage; T0M15, mulching with black plastic geotextiles during the last 15 years; T7M8, tillage for 7 years followed by mulching during the last 8 years; M7T8, mulching for 7 years followed by tillage during the last 8 years.

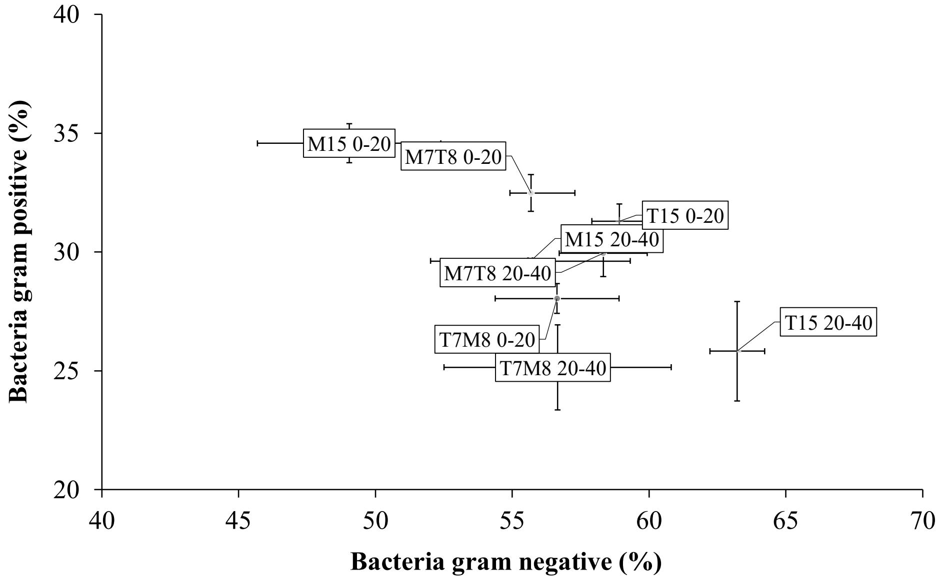

Figure 3. Relationships between relative abundance of bac+ and bac- at both soil depths of the four soil management systems: M0T15, rotary tillage; T0M15, mulching with black plastic geotextiles during the last 15 years; T7M8, tillage for 7 years followed by mulching during the last 8 years; M7T8, mulching for 7 years followed by tillage during the last 8 years.

3.2. Tillage and Mulching Effect on Citrus Yield

Both tillage and mulching affected citrus yield during the last three years of the experiment. At each year of observation, orange yield was higher in only mulched soils compared to only tilled ones (Table 3). Moreover, it is worth noting that orange yield increased during the three years of observation in only mulched soils, whereas it remained constant or slightly decreased in only tilled ones. Moreover, generally the yield was always higher when, within the 15 years, the mulching followed the tillage rather than the other way around.

Table 3. Washington navel orange orchards yield (Mg ha^{-1}) during last three years (2018, 2019 and 2020) since the study was undertaken (2005). Soil management systems were as follows: M0T15, rotary tillage; T0M15, mulching with black plastic geotextiles during the last 15 years; T7M8, tillage for 7 years followed by mulching during the last 8 years; M7T8, mulching for 7 years followed by tillage during the last 8 years.

Soil Management	2018	2019	2020	Average
T0M15	13.4 A	13.7 A	14.9 A	14.0 A
M7T8	12.8 AB	11.1 B	11.9 C	11.9 B
T7M8	12.6 B	13.9 A	13.9 B	13.5 A
M0T15	11.0 C	10.9 B	11.8 C	11.2 B

Different upper-case letters indicate significant differences ($p < 0.05$).

4. Discussion

Shifting from long-term tillage to geotextile mulching for weed control improved soil fertility by increasing soil cation exchange capacity and carbon pools (Table 1). Cation exchange capacity is a soil chemical parameter aimed at assessing changes in soil quality following the application of different agro-techniques and rarely investigated in studies, despite it providing useful information about potentially available cations for plant nutrition and, indirectly, holding water capacity [13]. Cation exchange capacity mainly depends on soil texture, and on the quantity and humification degree of soil organic matter [42]. Considering that soil texture did not change among treatments during the field trials (data not shown), it can be inferred that the high CEC in mulched soils, especially in those mulched for 15 years, was due to the concomitant increase in TOC. Since C input, by organic amendment, was the same in all plots during the experiment, the greater amount of organic C in mulched soil compared to tilled soil can be ascribed to a slower, and therefore smaller, biological decomposition of organic matter. Indeed, tillage, by increasing soil aeration and oxygen diffusion in soil [43], increases the degradation of organic matter due to the most effective aerobic catabolism, thus lowering soil C sequestration. Moreover, soil mixing by rotary tillage increases the accessibility of organic residues and amendment to soil microorganisms [44], thus speeding up their mineralization as well as contributing to aggregate disruption [45], thus exposing previously physically protected soil organic matter to microbial attacks [44]. In addition, the high MBC values in mulched soil can be attributed to the high amount of both total and available (extractable) soil organic C, the latter being the source of energy and nutrients for microorganisms [13,46]. Additionally, higher values of microbial quotient in mulched soil than in tilled soil suggested that mulching contributes not only to increasing soil organic C but also improves its quality, making it more accessible to soil microorganisms. Conversely, the lower values of microbial quotient in tilled soil indicate that MBC reduced faster than TOC, probably due to the lesser survival of soil microorganisms, consequent to both mechanical stress and drying induced by tillage [13,41].

The positive effect of mulching on MBC and microbial quotient was less evident at intermediate mulching periods, especially when tillage followed mulching (Table 1). Such results are in line with Alvaro-Fuentes et al. [47] and Heinze et al. [48], who reported that the increase in MBC was correlated with the duration of tillage reduction. Although tilled soils had a lower MBC, they exhibited higher values of microbial respiration. The higher CO_2 emission in tilled soils compared to the mulched ones, in turn, contributed to increase the qCO_2, which represents the quantity of organic C mineralized per unit of MBC and per unit of time. In general, in unsteady ecosystems the qCO_2 increases more than in stable ecosystems [46,49]. Higher values of qCO_2 in tilled soils agree with the findings of Kabiri et al. [50], who found values 37% higher in tilled than in not tilled soils. The concomitant increase in microbial respiration and qCO_2 may be ascribed to the input of fresh substrates C or to different abundances of the main microbial groups, which may have different carbon use strategies [51]. Considering that the C supply by organic amendment was similar across treatments and that the EOC values in tilled soils were lower than in mulched soils, the higher microbial respiration and qCO_2 in tilled soil can be ascribed to the different abundance of the main microbial groups (Table 2). Indeed, tilled soils exhibited a higher population of total bacteria and a lower population of fungi compared to mulched soils (Figure 2). Such results are in line with those of Badagliacca et al. [52], who reported a lower abundance of fungi in intensive tilled soils than in non-tilled ones. Physical stress by tillage clearly caused the disintegration of fungal hyphae, i.e., the decrease in fungal biomass. This, in turn, affected the qCO_2 as fungi are more efficient in utilizing C sources than bacteria [53]. In addition, bac-, which are characterized by high nutrient demand and, consequently, low efficiency in utilizing organic C [53–55] were more abundant in tilled soils than in mulched ones (Figure 3). Overall, these results suggest that mulching can have a positive effect on soil fertility, thus increasing the productivity of the orange orchard, but also on soil microbial metabolism as it favors those microbial groups more efficient in utilizing C substrates.

5. Conclusions

Weed control in urban and peri-urban areas is difficult to carry out due to operational and legislative restrictions. Soil mulching may be a valid alternative to chemical and physical methods for weed control. Mulching with black geotextile fabric materials impedes weed growth. The results of this study suggest that soil mulching with black geotextile fabric materials enhances soil fertility by increasing total and labile pools of organic C and allowing for a better utilization of C sources by the soil microorganism. In turn, the high soil fertility of mulched soil compared to tilled soil increased orange yield. However, geotextile fabrics are somewhat expensive; thus, to become cost-effective, they should remain in the field for more than 4 years [56]. Thus, mulching soil with geotextile fabric materials is an effective agro-technique for weed management in orange orchards of peri-urban areas.

6. Patents

This section is not mandatory but may be added if there are patents resulting from the work reported in this manuscript.

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