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Effects of Weed Removal Practices on Soil Organic Carbon in Apple Orchards Fields †

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Abstract: The accelerated climate crisis has exacerbated the existing water and soil management challenges in the Mediterranean region, which are usually attributed to the combination of both irrational irrigation and unsustainable farming practices. The current conditions and future projections indicate that water-related risks are expected to intensify during the coming decades. Moreover, farmers often do not possess high environmental awareness; they adopt non-sustainable farming practices such as the extensive use of herbicides instead of mowing/mulching for the weeds, thus affecting soil hydraulic characteristics and fertility. To investigate the effects of different weed-management practices on soil organic carbon and thus on soil water holding capacity and infiltrability, an extensive soil-sampling campaign was performed in the semi-arid Mediterranean agricultural pilot basin of Agia—Greece. The pilot is located in the Pinios river basin, which constitutes the most highly productive agricultural plain in the country. The Agia basin was selected since it presents the uneven spatiotemporal distribution of groundwater resources and the wide application of herbicides, while an urgent need exists to sustain and improve agricultural production, with the main crops being apples and cherries. Moreover, the Agia basin constitutes a highly instrumented area where the Pinios Hydrologic Observatory belonging to the International Long Term Ecological Research network has been developed, and thus additional field measurements could contribute to the overall data-collection framework. Soil sampling was conducted in apple orchards in April 2022, just before the beginning of the growing season. Ninety six soil samples in total were collected from eight different fields; half of them applied systematic herbicides treatment, and others mulching. For the upper soil profile (0–10 cm depth), the results indicate that soil organic carbon in the fields applying mowing was found to be higher by more than 30% compared to the fields applying herbicides. The corresponding difference for soil depth of 10–30 cm was 7%, thus demonstrating the effectiveness of mulching in increasing soil organic carbon. The results of the current study could be upscaled at a larger scale in the context of adapting agricultural water-stressed regions to climate change, whilst contributing significantly to the production cost and the preservation of the ecosystemic values of the regional nexus.

Keywords: pinios basin; Mediterranean area; nature-based solutions; soil organic carbon; soil sampling; mulching; sustainable agriculture; environmental protection; soil protection; vegetation

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1. Introduction

Soil is considered the largest carbon pool, accounting for about 2500 Gt, followed by the atmospheric (760 Gt) and biotic (560 Gt) pools [1]. Soil organic carbon (SOC) includes plants, roots, fungi, and microbial residues and accounts for more than 60% of global total soil carbon [1]. The understanding of weed-removal practices, including herbicides application and mulching, which affect soil carbon balance dynamics, is crucial for yield-potential preservation, terrestrial ecosystem conservation, and food security [2,3]. Sustainable weed management constitutes a challenge for ensuring agricultural productivity since in the case of improper management, infestations of grass and broadleaf weeds could reduce crops yield and quality. The level of weed and crop competition depends on soil and environmental conditions, weed density, and agricultural practices, including crop row spacing, planting density, and the presence of competitive cultivars [4].

Herbicides constitute the primary tactic to address weed control and are widely used, mainly because they are easily applied and improve the cost/benefit ratio of the agronomic business. However, their repeated use may evolve weed resistance to multiple mechanisms of herbicide action [5] and result in herbicide-resistant weed growth in the case of some cultivations [6]. Moreover, their systematic use may adversely affect soil hydraulic properties. Nowadays, attempts are being made to eliminate the use of herbicides in favor of environmental protection and the appearance of herbicide-resistant weed population avoidance.

Mulching is widely recognized as one of the most efficient weed and soil management techniques in terms of soil structure improvement, soil moisture evapotranspiration reduction, soil water holding, and soil erosion mitigation, all of which support plant growth [7,8]. The effectiveness of mulching depends on the selected technique, the soil characteristics, and the type of crops residue, while the benefits are usually developing slowly and observed after a long period, which may exceed six or more growing seasons [9]. Mowing and mulching techniques seem to increase SOC content and carbon (C) storage, thus reducing greenhouse gas emissions [10], although relevant studies regarding mulching effects on SOC concentration present contradictory results [8,11,12]. This uncertainty relies on complex and labile soil carbon fractions, including light organic carbon, dissolved organic carbon, particulate organic carbon, and easily oxidizable organic carbon, which present a high spatiotemporal distribution based on local climate, soil texture, and soil-management conditions, as well as a large effect on soil biochemical processes, nutrients, and carbon cycling [7].

The purpose of this study is to evaluate the effects of herbicides and mulching technique application on soil organic carbon in low sloping apple orchard fields.

2. Materials and Methods

2.1. Study Area and Soil Analysis

The Agia basin in central Greece, where the Pinios Hydrologic Observatory was established in 2015, covers an area of 52.5 km^2 [13]. Based on the Digital Elevation Model produced by the Hellenic Cadastre S.A. at 5 m resolution, the Agia basin spans altitudes varying from 94 to 1520 m a.s.l. (Figure 1). Land use includes forested, agricultural, and urbanized areas. Agriculture, which is characterized by land fragmentation leading to small land parcels in the order of 1–1.5 ha on average, is the dominant socio-economic activity. Apple and cherries orchards form the key cultivations, the irrigation needs of which are covered by groundwater. Considerable spatio-temporal differentiation of groundwater distribution results in seasonal availability deficiency at specific high productivity zones. During such periods, groundwater abstraction depths are considerable, which, along with the increased energy costs, make irrigation management and water saving essential.

2.2. Field Experiment

Soil texture in the study area is classified as loam (68.38%), sandy loam (24.86%), silt loam (5.00%), silty clay loam (1.15%), sandy clay loam (0.42%), and clay loam (0.18%). Soil also presents a pH of 6.94, 7.05, and 7.06; 42.66%, 42.97%, and 41.09% sand; 38.42%, 38.14%, and 37.16% silt; and 18.88%, 18.85%, and 21.70% clay, at 0–5 cm, 5–15 cm, and 15–30 cm depth, respectively, based on field measurements conducted in July 2020 along with data derived from the SoilGrids system [14].

Field studies were conducted at the beginning of the previous growing season, i.e., April 2022 in the Agia water basin. In particular, soil samples were collected at 12 points in 8 different orchard parcels; half of them by applying herbicides and the rest by implementing the mulching technique (Figure 1). The area of parcels ranges from 1.8 to 19.1 ha with an average value of 7.2 ha. Samples were collected at 2 different depths, i.e., 0–10 cm and 10–30 cm, and thus 96 soil samples in total were collected and analyzed.

Organic carbon content was determined using a wet combustion technique, according to the Wakley–Black method [15]. Soil samples were air-dried, and the fraction of fine earth (<2 mm) was used for the analysis. In total, 1 g of soil was transferred into a 500-mL wide-mouth Erlenmeyer flask; 10 mL of 1 N $K_2Cr_2O_7$ and 20 mL of concentrated H_2SO_4 were added, and the flask was swirled until soil and reagents were mixed. After 30′ standing, 200 mL of deionized water was added to the flask, while 3–4 drops of diphenylamine were used as an indicator for the titration with 0.5 N $FeSO_4$.

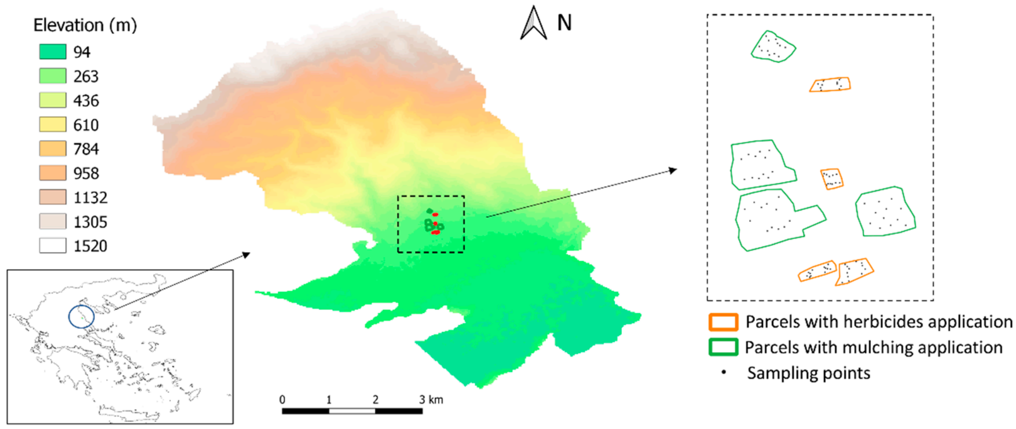

Figure 1. Study area and location of field parcels under study.

3. Results and Discussion

Figure 2 presents high in-field variability of soil organic carbon in terms of both weed removal practice and soil depth. The difference between the mean SOC in fields applying herbicides and mulching was also found to be statistically significant, as indicated using the student's *t*-test method. SOC was found to be 31% and 7% higher for the fields applying mulching compared to those applying herbicides for depths 0–10 cm and 10–30 cm, respectively. The results confirm the importance of mulching application in SOC fractions, particularly in the upper soil layers [7,16].

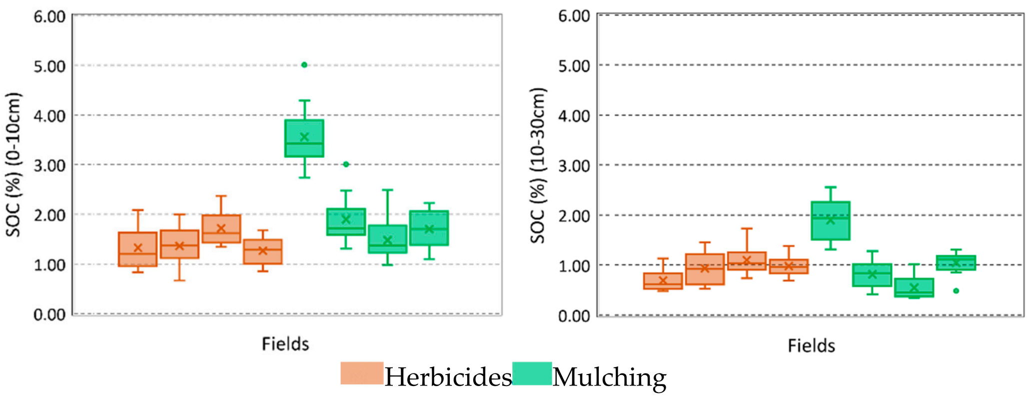

Figure 2. Soil organic carbon (%) for the two different weed removal practices at two different soil depths.

Increased SOC documented in the fields where mulching was applied provides multiple assets to the farmers that have adopted it. Soil fertility significantly improves, especially when SOC increase relates to crop residue retention [17]. Soil water holding capacity is also positively affected, despite the fact that the latest literature suggests that actual improvement is rather limited [18]. Precision agriculture and environmentally friendly pest and weed management are adopted techniques in the framework of the Green Deal and the Farm to Fork policies that call for a 50% reduction in agrochemicals used in the European Union Member States by the year 2030. Hence, compliance with these regulations and the environmental targets set to call for the systematic adoption of techniques such as mulching is necessary. Additionally, the progressive increase in agrochemicals as a result of the energy crisis and the declining number of licensed drastic compounds for use in the member states is a strong incentive to convert to nature-based solutions such as mulching.

4. Conclusions

This research provides a scientific basis and confirms the value of mulching as a sustainable although time-consuming agricultural method to improve soil organic carbon sequestration. Long-term effects of mulching have to be tracked to identify whether SOC improvement reaches a steady state related to the saturation of SOC pools. Future studies are also needed to quantify associated economic benefits and agricultural sustainability related to carbon-transformation processes.

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