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# Long term changes in soil properties and enzyme activities after almond shell mulching in avocado organic production

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ABSTRACT

The recycling of almond shell as mulch would allow avocado orchards to be managed organically, maintaining plant yield and improving soil conditions simultaneously. This study aims to analyze the long term effects of successive applications of almond shell as mulching for organically grown avocado. Effects on soil properties, enzyme activities and soil carbon storage as well as avocado yield and growth were studied in comparison to no-tillage conventionally managed (using mineral fertilizers and herbicides) avocado. In 2002, 2007 and 2012 almond shells were applied in a 7 cm thick layer (26.0 kg dry matter $m^{-2}$) covering 4 m × 8 m per tree. After a 10-year period a new soil organic horizon was established in the organic treatment, and the upper mineral soil layer (0–25 cm) enhanced its C content from 43 g $kg^{-1}$ in F to 91 in g $kg^{-1}$, and proportionally P and N contents. The high lignin content of almond shells, 362 g $kg^{-1}$, led to low organic matter degradation, 37% for the 10-year period. Nevertheless, this reduced rate of organic matter mineralization was sufficient to supply the needed nutrients and to maintain or even increase fruit yield in the organic treatment. Urease, β-glucosidase, dehydrogenase, protease and phophomonoesterase showed high microbiological activity in the organic layer decreasing in mineral layers. Enzyme activities were significantly correlated to soil OC (organic C) content and site specific soil moisture. Reduced mineralization and high surface microbiological activity make almond shell an ideal mulch for avocado trees combining increased soil organic C content and agricultural benefits.



## 1. Introduction

Food quality and environmental concerns have increased the general interest for organic agriculture over the last decades. From an environmental standpoint, there is wide agreement that organic farming is linked to lower pesticide and energy consumption, better soil conservation and higher biodiversity than conventional farming (Kristiansen, 2006). Moreover, in the current climate change scenario, organic production systems are likely to be more resilient to the impacts of climate change on temperature and rainfall, due to the ability of the organic matter to counteract drought conditions (Metzger et al., 2006). Increasing periods of water shortages will probably be part of the new climate under Mediterranean conditions, driving to an agricultural change characterized by a reduction in the available land for cultivation and reduced yields. In addition, organic agriculture, especially when organic mulches are used, has a great potential as carbon sink and could become an interesting strategy to offset carbon emissions.

Appropriate mulching is a key tool in organic management of most woody perennial crops and it provides several environmental and agronomical advantages such as preventing weed growth (Verdú and Mas, 2007), controlling diurnal/seasonal fluctuations in soil temperature, protecting soil from erosion (Jafari et al., 2012) or increasing water use efficiency by reducing evaporation (Grundy and Bond, 2007). Unlike synthetic mulches, that need to be removed after a period of time, organic mulches decompose and they need to be re-applied, increasing soil organic matter and water holding capacity, releasing nutrients and enhancing soil aggregation (Haynes, 1980). Organic mulches also promote favorable soil biotic activities, such as soil respiration and

*Abbreviations:* OM, organic matter; SOC, soil organic carbon.

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microbial biomass (Grundy and Bond, 2007), and improve overall soil productivity (Siczek and Frąc, 2012).

From a sustainable perspective, residual organic materials from nearby crops or agro-industrial activities would be the best option as sources of mulch or soil amendments, increasing soil C storage and reducing the carbon footprint of the whole production. In recent years, environmental issues related to global climate change have demonstrated the need to assess soil organic matter dynamics and soil storage capacities more precisely (Vidal-Beaudet et al., 2012). One of the main factors involved in controlling the C budget is the microbial decomposition of organic mulches. Nevertheless, the extent of $CO_2$ balance due to mulching will also depend on the kind of organic substances used, particularly its richness in lignin and phenolic compounds, because these compounds significantly influence the soil microbial enzyme activity (Theuerl and Buscot, 2010). Soil enzyme activities may respond to changes in soil management faster than other soil variables and, therefore, they might be useful as early indicators of biological changes. Enzyme activities have been studied to evaluate the response of soil functions to changing environmental conditions or management practices (e.g., tillage, type of crop, fertilization, etc.) (Nannipieri et al., 2012). Several studies have focused specifically on compost and crop residues, such as straw, used as mulch or soil amendment (Siczek and Frąc, 2012; TerAvest et al., 2011). In spite of this and with the exception of plant litter in natural forests and wood chips, very few of these studies address lignocellulosic residues such as those present in almond shells.

Almond shells are the woody endocarps of the fruits produced by the almond tree (*Prunus amygdalus* Batsch), a woody perennial crop originated in Southwest Asia and currently cultivated worldwide in regions with a Mediterranean climate. The almond shells are obtained as a residue when the fruit is processed to obtain the edible seeds (kernels). Its ligneous character makes this waste suitable to obtain activated C or biomass fuel (Fernández et al., 2012). Almond shells are normally incinerated or dumped without control due to logistic problems (seasonal production in small scale factories, transport costs, lack of energetic plants). Some alternative uses, near the productions sites of almond shells and, therefore, more advantageous to $CO_2$ savings, have been proposed and evaluated. Urrestarazu et al. (2005) indicated that almond shells seem to be an acceptable growing medium (100% pure) for soil-less cultures and they could be a viable and ecologically friendly alternative to widely used rockwool. Lao and Jiménez (2004) also obtained good results when using almond shells as a growing media component. Rigane et al. (2011) studied almond shell co-composting with other agricultural wastes and indicated that the resulting composts are compatible for use as constituents in growing media for horticultural soil-less cultures. Vargas-García et al. (2005) tested the capability to obtain inocula for composting from ligno-cellulolytic fungi growth on these shells. In a recent paper, Esfahlan et al. (2010) reviewed the possible uses of the almond by-products. Long lasting, availability, low cost and resistance against wind made this waste highly recommended as mulch. Nevertheless, the information about the use of almond shells as mulch is still scarce and usually only plant response has been evaluated. Jafari et al. (2012) recommended the use of almond shells as a mulch in fig orchards and its possible use in orange trees for weed control has been also tested (Verdú and Mas, 2007).

Almond shell is an easily available residue in southern mainland Spain, the only region in continental Europe with a significant production of subtropical fruits such as avocado or mango. Avocado (*Persea americana* Miller, Lauraceae), in particular, is a crop with low nutrient requirements and weed pressure that shows relatively easy natural pest and disease control in Mediterranean climates and, consequently, it is particularly suitable for organic production in areas such as continental Spain. One of the ways to enhance avocado organic production is through the use of organic mulching. The benefits of organic mulches in increasing root health, ameliorating stress, and increasing yield and fruit size in avocado are well known (Moore-Gordon et al., 1997). However, except for a recent paper (Bonilla et al., 2012) studying the effects of almond shells and other organic amendments on soil bacterial community composition, there is a lack of information about the long term effects of this organic residue on chemical and biochemical properties of soil under organic farming practices.

Supposedly, mulching with almond shell would allow avocado growth under organic farming practices maintaining plant yield and improving soil conditions. This study aims to analyze the long term effects of successive applications of almond shell as mulching for organically grown avocado. Effects on soil properties, enzyme activities and soil C storage as well as avocado yield and growth were studied in comparison to no-tillage conventionally managed (using mineral fertilizers and herbicides) avocado. The combination almond shell-avocado would give both sides high added value in an environmentally sound way.

## 2. Materials and methods

### 2.1. Experimental site and design

The trial was carried out in a cv. Hass, grafted onto cv. Topa-Topa seedling rootstocks, avocado orchard located at the experimental station 'La Mayora', on the coast of Malaga province (SE Spain). The trees, planted at $8 \times 8$ m, were 29-year-old at the starting of the trial (2002) when almond shell mulching was applied for the first time. Previously the plot was cultivated in the usual way for avocado, under no-tillage receiving standard applications of N, K and B fertilizers, and herbicides through the microsprinkler irrigation system. Each tree had 2 microsprinklers that wet a 5 m wide strip along the tree row. Weed cover in the inter-row areas, maintained under rainfed conditions, was cut 2–3 times per year. Irrigation water was of good quality for avocado (electrical conductivity 0.5–0 to 0.6 $dS\,m^{-1}$, nitrate-N $<2\,mg\,L^{-1}$).

Before tree planting in 1973, the land in the experimental farm was terraced, forming benches 30–80 m wide and on the average about 50 cm deep, by adding topsoil from a nearby site. A heavy organic amendment (100 $tonnes\,ha^{-1}$ of manure) was also incorporated at that time. The resulting soil was derived from shale, having 41% of gravel. It presented a homogeneous sandy loam texture (sand 60.6%, silt 31.4%, clay 8.0%) and was well drained, without Ca and Mg carbonates.

Two no-tillage treatments, organic (O) and conventional with the application of inorganic fertilizers (F), were started in this orchard in May 2002. At that date no significant differences were found in soil matric potentials (measured by tensiometers) and leaf N content between the trees selected for both treatments. The O treatment consisted in a massive application of coarse almond shell as mulching. The almond shell was produced by Almendras Forclamar (Trapiche, Vélez-Málaga, Málaga, Spain) located near (10.7 km) the experimental orchard. The main physico-chemical characteristics of the applied almond shells are shown in Table 1. After this initial application, the almond shell application was repeated twice, in December 2007 and February 2012. Each time, the almond shell was applied as a 7 cm thick layer (30 $kg\,m^{-2}$, 26.0 kg dry matter $m^{-2}$) covering a surface of $4 \times 8$ m per tree. No fertilizer was applied since the first application of almond shells in 2002; except Fe-EDDHA (3.1 $kg\,ha^{-1}$ in 2002), $ZnSO_4$ (10.2 kg Zn $ha^{-1}$ in 2002 and 2012) and natural phosphate rock (47 kg $P_2O_5\,ha^{-1}$ in 2010).

The F treatment continued receiving mineral fertilizers, according to leaf analysis, at the following yearly doses: 50–60 kg N $ha^{-1}$, using mainly $NH_4NO_3$, $KNO_3$ and $Ca(NO_3)_2$, every year, 11 kg P $ha^{-1}$ as