Soil & Tillage Research 180 (2018) 250–258

Contents lists available at ScienceDirect

Soil & Tillage Research

journal homepage: www.elsevier.com/locate/still

Soil quality and tree status in a twelve-year-old apple orchard under three mulch-based floor management systems

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ARTICLE INFO

Keywords:
Living mulches
Yield
Compositional data analysis

ABSTRACT

Interest in abandoning herbicide fallow as the standard in-the-row orchard floor management system continues unabated. Despite research efforts, available relevant data remain insufficient to formulate reliable recommendations for individual site conditions. A long-term experiment was therefore initiated in a temperate climate area in south-western Poland. 'Ligol' and 'Pinova' cultivar apple trees were planted in an unirrigated orchard in 2004, with treatment plot tree-rows mulched and control plots maintained with herbicide fallow. In 2016, black woven polypropylene fabric and *Agrostis vulgaris* With. and *Festuca ovina* L. living mulches were compared with the herbicide fallow in terms of their effect on soil properties, tree nutrient status and yields. While the living mulches had a positive influence on soil porosity, humus content and pH, there were substantial yield reductions; arguably due to competition for water. It is therefore important that more intensive methods of understory vegetation suppression are explored and more competition-resilient rootstocks sought to counteract yield loss. The polypropylene cover was primarily associated with a decreased leaf K:Ca + Mg ratio. A synthetic mulch is a viable choice for certain rain-fed orchards.

1. Introduction

The current standard orchard floor management system in temperate climates comprises vegetation-free herbicide strips in tree rows and periodically mown grass cover in drive alleys (Merwin, 2003). While the approach proved both effective and inexpensive (Lipecki and Berbeć, 1997), the widespread trend of reducing synthetic pesticides in plant crops has triggered interest in alternative systems (Hogue et al., 2010; Yao et al., 2005). One of the promising alternatives is replacing herbicide strips with various mulches to control weeds in fruit tree rows. In addition to addressing consumer concerns, mulch-based orchard floor management systems may contribute to soil conservation by protecting soil from erosion and improving its biological activity and water regime (Granatstein and Sánchez, 2009; Lisek, 2014; Tahir et al., 2015).

Living mulch, i.e. mulch with living plants, has the potential to reduce nutrient leaching and sequester carbon and nitrogen. However, the plants can compete with fruit trees for water and nutrients, thus impairing growth and yield (Granatstein and Sánchez, 2009; Tahir et al., 2015). Hammermeister (2016) recommended the use of living mulches only at sites with fertile soils, sufficient water supply and lacking perennial weed species.

Although the competition issue does not arise in mulching with dead material, this option involves substantial purchase and labor costs, which are particularly high for covers requiring frequent renewal (Lisek, 2014; Tahir et al., 2015). While this problem can be reduced with a durable synthetic mulch which provides satisfactory weed control, they also have limitations, including low water permeability, increased summer soil temperatures beyond tree-root tolerance and lack of sustainability (Granatstein and Sánchez, 2009; Lipecki and Berbeć, 1997).

The published literature on orchard mulch application is sparse and insufficient to guide satisfactory synthesis. Despite the availability of recent reviews (Hammermeister, 2016; Lisek, 2014), research still lags continual progress in fruit-growing technology. Simultaneously, applicability of early experimental results, such as those employing less than 400 trees planted per hectare and control treatments using currently dismissed herbicides (e.g. Glenn et al., 1987; Miller, 1983; Sanchez et al., 2003), becomes questionable.

Another problem has been insufficient number of long-term studies (Atucha et al., 2011a). The following two exceptions can be noted: (1) 556 apple trees per hectare planted in the Pacific Northwest (Atucha et al., 2011a,b; Oliveira and Merwin, 2001; Yao et al., 2005, 2009) and (2) a Midwestern United States experiment (Sanchez et al., 2003).

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https://doi.org/10.1016/j.still.2018.03.010
Received 1 August 2017; Received in revised form 12 March 2018; Accepted 14 March 2018

However, the latter was conducted in a tart cherry orchard and employed simazine in the control treatment, thus hindering comparison with other published experiments, based on apple trees and glyphosate.

Mulches are a major research subject at the Wrocław University of Environmental and Life Sciences (Poland); where the longest running experiment has been conducted in rain-fed rather than irrigated apple trees. We present the results which describe the orchard state after 12 years of continuous mulching. Our paper provides new primary data investigating the validity of theories on the long-term influence of mulches on apple orchard soil properties and estimates of living mulch effects on mature trees in the absence of irrigation.

2. Material and methods

2.1. Site description and experimental design

The study was set up at the Fruit Experimental Station in Samotwór (51°6′ N, 16°50′ E), managed by the Wrocław University of Environmental and Life Sciences (Poland). The orchard lies in a temperate climatic zone on Haplic Luvisol with light loam texture. According to the Agri4cast Resources Portal (Biavetti et al., 2014), for the duration of the experiment annual mean temperature in the area ranged from 8.1 to 11.0 °C and annual precipitation sum amounted to 392–738 mm (Table 1).

The orchard was established in spring 2004 with modified split-plot design. The main-plot factor was an orchard floor management system, and rootstock supplied the subplot level. The design included two blocks (replications) divided into four pseudo-replication sections (Fig. 1). These contained alternating planted 'Ligol' and 'Pinova' apple tree cultivars separated by 'Idared' pollinator lines. Planting was from one-year-old whip-quality nursery stock with 2380 trees per hectare (3.5 × 1.2 m).

In spring 2004, floor management systems were incorporated in 1 m wide strips in the tree rows. Treatments included: control herbicide fallow maintained with two or three annual applications of mixed glyphosate (4 L ha^{-1}) and 2-methyl-4-chlorophenoxyacetic acid (2 L ha^{-1}), black woven polypropylene fabric (AGRO 84F-170 TKANINA PP, 94 g m^{-1}; hereafter, PP) and *Tropaeolum majus* L. and *Agrostis vulgaris* With. living mulches. *Tropaeolum majus* L. was replaced by *Festuca ovina* L. (hereafter, Festuca) in the second year because of poor performance. The living mulches were maintained by mowing with a string trimmer. Although the original design also included *Tagetes patula* L. and *Trifolium repens* L. living mulches, these produced retarded tree growth and weed infested covers, so the study focused solely on the herbicide, PP, Festuca and Agrostis floor management systems.

Each main plot was divided into three subplots with five trees and allocated to different rootstocks. The study was eventually limited to the P 2 rootstock because it was the only one sufficiently vigorous to enable trees to compete with the living mulches. Like all rootstocks in the P-series, P 2 has been bred in Poland. It is a high-yielding rootstock related to M.9, exhibiting similar vigour, but better adapted to the Polish climate (Mantinger, 1996). In comparison, the excluded rootstocks, P 16 and P 22, provide a more dwarfing effect and are deficient in terms of, respectively, cold-hardiness and soil requirements (Mantinger, 1996; Szczygieł and Czynczyk, 2002).

The trees were trained into a slender spindle and the orchard was fertilised with an average dose of 50 kg N ha^{-1} yr^{-1} as ammonium nitrate or urea. Tree protection followed current recommendations for commercial growers. Periodically mown sod was maintained in the drive alleys. The orchard was unirrigated.

Table 1
Weather descriptors characterizing each year of the experiment. Based on the data from the Agri4cast Resources Portal (Biavetti et al., 2014), cell 103128 (51°5′ N, 16°40′ E).

Year	Mean temperature (°C)	Precipitation sum (mm)
2004	9.3	449
2005	9.1	552
2006	9.6	622
2007	10.2	569
2008	10.2	470
2009	9.4	738
2010	8.1	702
2011	10.0	524
2012	9.5	522
2013	9.3	658
2014	11.0	580
2015	10.9	392
2016	10.2	617

2.2. Data collection

At the end of April 2016, 'A horizon' topsoil samples were collected from alternate pseudo-replications (Fig. 1). From each plot, four core samples were randomly collected close to where the three internal tree trunks stood. Herbaceous vegetation including main root biomass was removed from the sampling points, and top 5 cm of exposed soil was collected. This provided a total of 64 core samples.

The sample water content, water content after full saturation (hereafter, WCAFS) and bulk density were determined at the Crop Research Institute, Czech Republic, where all laboratory analysis was performed. The bulk density values were converted to porosity with uniform 2.583 Mg m^{-3} particle density assumed because of low soil organic content. This value was obtained using the liquid pycnometer method after combining the soil from all samples. The volume of non-saturable pores (hereafter, VnSP) was calculated as the difference between porosity and WCAFS. Some cores were damaged in transportation and subsequent handling, thus reducing the final number of observations to 58.

A composite loose soil sample was also collected from each plot by combining six single samples from beside the internal tree bases. Approximately 20 cm exposed soil was collected by soil auger after removing plant biomass, but slightly shallower sampling was occasionally necessary to avoid subsoil portions. The total number of samples was 32, with half collected in April 2016 and the remainder at the beginning of August.

Mehlich-3 extractable P, K, Ca and Mg contents; humus, organic C and total N contents; as well as pH in water and 1 mol KCl L^{-1} were determined after drying samples and sieving them through 2-mm mesh, The C:N ratios were calculated from their relative contents, and four runs of herbicide and Festuca aggregate stability assessment (Kemper and Koch, 1966) were performed. These provided percentages of stable aggregates (SAS).

Two internal trees per experimental plot were randomly chosen for leaf chlorophyll content measurement and leaf sample collection in August 2016. Three trees were missing in one pseudo-replication and additional two in the Festuca treatment, so the pseudo-replication and the treatment were excluded from analysis. Chlorophyll concentration was determined by CCM-300 device (ADC BioScientific Ltd., Hoddesdon, United Kingdom). This device exploits the relationship between chlorophyll content per unit leaf surface area and fluorescence response ratio of 735 and 700–710 nm bands. Conversion is then based on linear regression (Gitelson et al., 1999). Measurements were taken on two or four large, undamaged leaves found in middle sections of