Scientia Horticulturae 129 (2011) 9–17

Contents lists available at ScienceDirect

Scientia Horticulturae

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

Effects of different organic apple production systems on seasonal nutrient variations of soil and leaf

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ARTICLE INFO

Article history:
Received 1 November 2010
Accepted 14 February 2011

Keywords:
Compost
Organic apple
Seasonal nutrient
Shredded paper
Wood chips

ABSTRACT

An organic apple (*Malus* × *domestica* Borkh.) orchard was established to study the interaction effects of ground cover management systems (GMS) and nutrient sources (NS) on soil and tree nutrients in the Southern U.S.A. GMS mulches as follows: green compost (GC), wood chips (WC), shredded paper (SP), and mow-and-blow (MB). Across GMS, one of three NS treatments was applied: commercial organic fertilizer (CF), poultry litter (PL), and no fertilizer (NF). GC-treated plots had greater soil solution nitrate concentrations in year 3. GC plots also maintained greater seasonal soil organic matter and macronutrient concentrations during 3 years compared with the other GMS. Seasonal foliar nutrient concentrations grown under GMS in year 3 tended to follow nutrient concentration patterns similar to those observed in conventional apple orchards. GC and WC trees had overall greater leaf area, dry weight, and total foliar nutrient contents in year 3 than the SP and MB trees.

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1. Introduction

There are significant questions about nutrient availability and uptake in the permaculture of organic fruit production systems. Limited studies of organic orchard nutrition have been done in the arid Pacific Northwest in U.S.A. (Swezey et al., 1998; Andrews et al., 2001; Reganold et al., 2001; Neilsen et al., 2003; Peck et al., 2006) or the colder Northeast (Merwin and Stiles, 1994). Little or no research has been done in the lower Midwest or Southern U.S.A. Seasonal variations in soil and foliar nutrient concentrations are indicators of nutrient availability, limitations, and tree performance. However, those data were developed in conventional orchards using herbicide-treated weed-free strips and soluble synthetic fertilizers (Naraguma, 1994; Aichner and Stimpfl, 2002; Nachtigall and Dechen, 2006). Organic orchards with increased soil biological activity and slow-release nutrient sources may respond differently.

The aim of nutrition management in organic fruit production is to provide essential nutrients at the correct times and proper quantities in order to achieve good tree performance (Neilsen and Neilsen, 2003). Previous research demonstrated that apple trees required more readily available nitrogen (NO_3^- or NH_4^+) early in the growing season during active root growth, while the trees required less nitrogen in late season (Neilsen and Neilsen, 2003). However, if organic fertilizers have a lower nutrient level or do not contain readily soluble nitrogen, the amount and rate of release, and the rate of uptake may be slowed or altered. Minerals may be available either at inadequate levels or in a form trees may be unable to absorb. The seasonal nutrient status of an orchard depends on whether ground cover management systems (GMS) are combined with organic nutrient sources. Therefore, nutrition availability in organic apple orchards would be compounded due to the complicated biological diversity of the soil, which, in principal, should be increased in the organic systems (Rosen and Allan, 2007).

The objective of this project was to evaluate seasonal nutrient patterns in soils and leaves in organic apple production systems. This article is a follow-up to another report on estimated nitrogen use efficiency, surplus, and partitioning in young apple trees grown in varied organic production systems (Choi et al., unpublished manuscript): some data contained herein is cited from the above-mentioned unpublished manuscript. Interpretation of nutrient trends during the season is the first step in developing a reference for nutrition and fertility recommendations in organic apple farming systems in the Southern U.S.A.

2. Materials and methods

2.1. Plant materials and treatment applications

'Enterprise' apple (*Malus* × *domestica* Borkh.) trees on M.26 rootstocks were planted in an organically managed orchard at the

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0304-4238/$ – see front matter. Published by Elsevier B.V.
doi:10.1016/j.scienta.2011.02.009

Table 1
Estimated amount of nutrients applied of ground cover management systems (GMS) and nutrient source (NS) in year 3 (2008) in an organic apple orchard, Fayetteville, AR.

Treatment	Supplied nutrient content (g/tree/year)										
	C	N	P	K	Ca	Mg	Fe	Mn	Zn	Cu	B
GMS											
Green compost (GC)	4486	354	48	117	589	42	112	17.9	2.17	0.58	0.34
Wood chips (WC)	3782	104	11	38	174	15	26	5.2	0.49	0.24	0.15
Shredded paper (SP)	7561	30	2	11	1573	11	19	0.2	0.36	0.08	0.02
Mow-and-blow (MB)	550	36	4	13	16	2	2	0.3	0.04	0.02	0.01
NS											
Commercial fertilizer (CF)	285	50	11	28	24	6	1	0.4	0.46	0.37	0.04
Poultry litter (PL)	683	50	61	87	281	12	5	1.3	1.38	0.67	0.10

Results were from a bulk analysis derived from random samples of the mulches or nutrient sources, and were representative of the treatments.

University of Arkansas Main Agricultural Experiment and Extension Center in Fayetteville (latitude, 36.1N; longitude, 94.1W; altitude, 427 m) in March 2006. Precipitation was 52 mm in June, 235 mm in August, and 25 mm in October during year 1; 5 mm in March and 81 mm in May during year 2; and 172 mm in March, 129 mm in May, 172 mm in July, and 160 mm in September during year 3. Trees were planted 2 m apart with 4 m between rows for an approximate density of 1250 trees per ha. Trees were trained as a 3.5-m-tall vertical axis with a two-wire trellis system for support. The soil series on the site was a mixture of a Captina silt loam (fine-silty siliceous, active, mesic Typic Fragiudults) and Pickwick silt loam (fine-silty, mixed semiactive, thermic Typic Paleudults) with pH of 5.5. Soil was moderately drained. Trees were well watered by micro-sprinkler using one emitter per tree. Emitters were equally spaced in an irrigation line approximately 50 cm from the tree trunks. The experiment was a 4 × 3 factorial of four ground cover management systems (GMS) and three nutrient sources (NS). The four GMS mulches included urban green compost from leaves, grass, and small brush (GC); uncomposted wood chips (WC); shredded paper mulch (SP); and mow-and-blow green mulch (MB). GC was naturally composted by monitoring temperature and moisture content by the City of Fayetteville for approximately 4–6 months and then screened to remove large items. WC was shredded wood and limbs from various trees, also obtained from the City of Fayetteville. The GMS mulches were split-plot for nutrient sources applied. The NS treatments included formulated, certified organic pelletized fertilizers (10N–$2P_2O_5$–$8K_2O$, Nature Safe®) (CF); composted poultry litter (PL); and a control (no additional fertilizer, NF) in which all nutrition came from the ground cover.

On the mulched-treated plots (GC, WC, and SP), an approximately 8- to 12-cm-thick layer of mulch was initially applied only under the planted trees (1 m of mulch around each tree) in April 2006. It was reapplied in April to maintain the mulch depth in years 2 and 3. Inter-row areas were managed by sod culture. The purpose of the GMS mulches was to control undertree competitive vegetation. For the MB plots, the grass was mown and tilled as needed during each season, and the mown grass clippings were blown under the trees as an on-site-produced mulch. Annual nutrient applications (PL and CF) were made at rates equivalent to approximately 50 g of actual N per tree per year each April. Fruits were allowed to develop on the GC- and WC-treated trees in the third season but not on the SP and MB trees that did not achieve their enough growth to bear fruits. GC- and WC-treated plots had 7.0 and 4.2 g of N in fruit per tree, respectively (Choi et al., unpublished manuscript).

2.2. Nutrient analysis

The nutrient concentrations of the GMS and NS treatments were analyzed at the beginning of the season after application in year 3. Random samples of ground cover were collected from each square meter of the mulches. Nutrient sources were also randomly sampled. Samples of each ground cover and nutrient source were dried and analyzed as a combined bulk sample during the summer in year 3. The total nutrient inputs from the GMS and NS treatments were estimated per tree by multiplying the dry weight by each nutrient concentration (Table 1).

Soil and tree responses to the treatments were measured as described below. Soil was sampled with a 2-cm-diameter soil probe from depths of the 0–10 and 10–30 cm in mid-June, August, and October in year 1; in mid-March and May in year 2; and in mid-March, May, July, and September in year 3. After the 8–12-cm-thick mulched layer was excluded, a soil probe was used to extract samples from three different points equally spaced in a line 0.5 m from each tree trunk. The soil samples from the three points per tree were mixed together in a polyethylene film bag. The samples were dried and sieved through a 2-mm mesh sieve, and the pH and electrical conductivity (EC; salt content) were measured. The percent weight loss-on-ignition (LOI) in the soil was calculated (Schulte and Hopkins, 1996). Soil organic matter (OM, %) was then estimated from the LOI (%) according to the formula: $(0.7 \times \text{LOI}) - 0.23 = \text{OM}$ (%) (Johnson-Beebout et al., 2009). Nitrate (NO_3^-) was analyzed using the colorimetric method on autoanalyzer (SKALAR Ltd., Norcross, U.S.A.), and the other nutrient concentrations were determined by the Mehlich 3 extractable method at the University of Arkansas Nutrient Analysis Laboratory. Soil suction lysimeters (Soilmoisture Equipment Corp., Santa Barbara, U.S.A.) were installed in three replications in each treatment in early spring at 30 cm depth at the tree drip line to collect soil solution samples on the same dates as soil sampling. About 50–200 mL of soil solutions were collected from each lysimeter and analyzed for NO_3^- and pH.

Leaves from a mid-position of year 3's shoots were sampled monthly from May to October. The samples were dried at 70 °C for three days and ground to pass a 2 mm mesh screen. The samples were analyzed by combustion LECO FP 428 Nitrogen Analyzer (LECO Corp., St. Joseph, U.S.A.) for total N and inductively coupled plasma spectrometry for the other nutrient elements, such as phosphorous (P), potassium (K), calcium (Ca), magnesium (Mg), iron (Fe), manganese (Mn), zinc (Zn), cooper (Cu), and boron (B) at the University of Arkansas Nutrient Analysis Lab. The total leaf area per tree was calculated by removing 1/25 of the total leaves from each tree, a 4% sampling, in year 3 (Wünsche and Palmer, 1997): the removed leaves were measured with a LI-3000 A Area Meter. The total leaf area was estimated by multiplying the area of the removed leaves by 25. Total foliar N content was estimated in August in year 3. Tree height was measured monthly from May to September in year 3. Vegetation (weeds) from each tree in the GC, WC, SP, and MB mulch treatments was harvested, dried, and weighed.

2.3. Statistical analysis

The data analysis was performed using the PROC GLM procedure in statistical analysis system (SAS Institute version 8.2, Cary,