

Research Reports

Spray-on-mulch Technology for Intensively Grown Irrigated Apple Orchards: Influence on Tree Establishment, Early Yields, and Soil Physical Properties

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SUMMARY. Use of and interest in organic mulches for both integrated fruit production (IFP) and organic fruit production is increasing given recent efforts to reduce pesticide inputs and improve soil health. A series of four experiments was conducted in the southern interior of British Columbia over 5 years to investigate the use of a spray-on-mulch (SOM) slurry, comprised primarily of recycled waste newsprint fiber, as an effective method to control excessive weed competition and enhance tree establishment and performance. In four experiments, 'Gala', 'Granny Smith', 'Ambrosia', and 'Honeycrisp' apple (*Malus × domestica*) trees on 'Malling 9' ('M.9') rootstock were exposed to a series of treatments including a glyphosate check, SOM waste paper, SOM over an organic underlay, SOM incorporated with dichlobenil or tackifier, SOM over black landscape fabric, rowcover cloth, or polyethylene plastic. SOM provided superior weed control in comparison with the glyphosate check treatment, a standard orchard practice in many modern orchards in North America. SOM application over compost, paper, and especially over cloth barriers were found to be more effective weed barriers than SOM alone. In comparison with glyphosate checks, SOM improved tree growth during tree establishment. Although the addition of dichlobenil provided season-long weed control, tree growth was diminished in comparison with SOM alone and remained similar to that of the glyphosate checks. There was little or no benefit of including a 2.5% tacking agent to help improve SOM integrity and long-term surface stability. When applied to bearing 4-year-old trees, SOM provided similar tree vigor as glyphosate checks over four growing seasons. The addition of landscape fabric, plastic, or cloth underlay material in combination with SOM improved tree vigor in formative years, but this benefit diminished over time. SOM-treated trees had greater cumulative yields over glyphosate checks after 3 years of production. SOM provided significant temperature moderation during the summer and winter months and provided moisture conservation during the summer. There were few SOM effects on plant nutrient status.

Recent interest in minimizing the use of agrochemicals in fruit production to safeguard environmental and human health has

stimulated interest in both IFP and organic fruit production systems. Although several options for nonchemical control of insects and diseases exist,

including disease-resistant cultivars and alternatives to soil fumigation, alternative weed control methods in high density apple plantings have been unsatisfactory with negative effects on production (Schenk and Wertheim, 1992).

Use of organic mulches is a traditional weed control method that offers important benefits by maintaining a high quality soil environment (DongGeun et al., 2009; Hogue and Neilsen, 1987). With increased availability and diversity of mulch materials, a renewed interest in mulching technology has been documented (Hogue et al., 2003; Merwin, 2003; Merwin et al., 1995), especially when land disposal of organic wastes is discouraged and recycling is an option. More recently, with bans placed on the burning of wood wastes, cereal, and hay straw, these materials have become available in large quantities. This increased availability has coincided with reports of increased tree vigor and yield associated with mulching in orchard trials (Merwin and Stiles, 1994; Neilsen et al., 2003a). Other beneficial effects of mulches, including improved soil moisture content (Merwin et al., 1995), improved soil structure (Neilsen et al., 2003b), positive effects on fungal and insect pests (Brown and Tworokski, 2004), moderated soil temperature, and increased biological activity (Forge et al., 2003; Tahir et al., 2005) have added to the desirability of organic mulching as an orchard management practice.

The relative cost of mulching, especially compared with chemical weed control, and concern over rodent damage to trees (Merwin et al., 1999; Wiman et al., 2009) have been major impediments to its widespread adoption by orchardists. An important factor in the higher cost of mulching is ease and method of application. Mulch that can be sprayed on a tree row using machinery would increase the speed and convenience of application, thereby reducing overall costs. Preliminary studies (Hogue et al., 2003; Neilsen et al., 2004) found that SOM, using a slurry mix of recycled newsprint waste and chopped cereal straw at the rate of 3 kg·m⁻² [dry weight (DW)], was effective in preventing emergence of most, but not all annual weeds. A complete weed season-long barrier would require additional

measures such as higher application rates, underlay materials to prevent weed growth, additives to improve SOM, or the addition of a residual herbicide to provide long-term prevention of weed escapes. The objective of this study was to develop and evaluate a SOM technology using organic waste materials, which would provide the same crop yield and soil quality benefits as traditional organic mulches with added convenience and reduced cost to producers.

Materials and methods

Spray-on-mulch, a by-product of the newsprint recycling industry, was obtained from Newstech Recycling Partners (Burnaby, BC, Canada). Following pulping and drying, $\approx 15\%$ of a nonreusable short fiber material, referred to as newsprint residual, is separated from the recycled fibers. Newsprint residual is blue-gray in appearance, has a pH of 8, conductivity of $7\text{--}8\text{ dS}\cdot\text{m}^{-1}$, bulk density of $160\text{ kg}\cdot\text{m}^{-3}$ (uncompressed), up to 18% moisture, 54% organic matter, and a C:N (carbon:nitrogen) ratio of 137:1. Its chemical analysis (DW basis) was: $360\text{ g}\cdot\text{kg}^{-1}$ C, $3\text{ g}\cdot\text{kg}^{-1}$ N, $52\text{ g}\cdot\text{kg}^{-1}$ calcium (Ca), $120\text{ mg}\cdot\text{kg}^{-1}$ potassium (K), $241\text{ mg}\cdot\text{kg}^{-1}$ phosphorus (P), $703\text{ mg}\cdot\text{kg}^{-1}$ magnesium (Mg), $425\text{ mg}\cdot\text{kg}^{-1}$ iron (Fe), $40\text{ mg}\cdot\text{kg}^{-1}$ manganese (Mn), $77\text{ mg}\cdot\text{kg}^{-1}$ zinc (Zn), and $176\text{ mg}\cdot\text{kg}^{-1}$ copper (Cu) (Hogue et al., 2003).

Application technology

Spray-on-mulch applications were made using a customized applicator [Fig. 1A (Transform Compost, Abbotsford, BC, Canada)] consisting of a 2000-L metal tank, high speed power take off mixing shaft with metal agitator knives to break up electrostatically dried newsprint residual. A 4.85-kW gasoline engine (model

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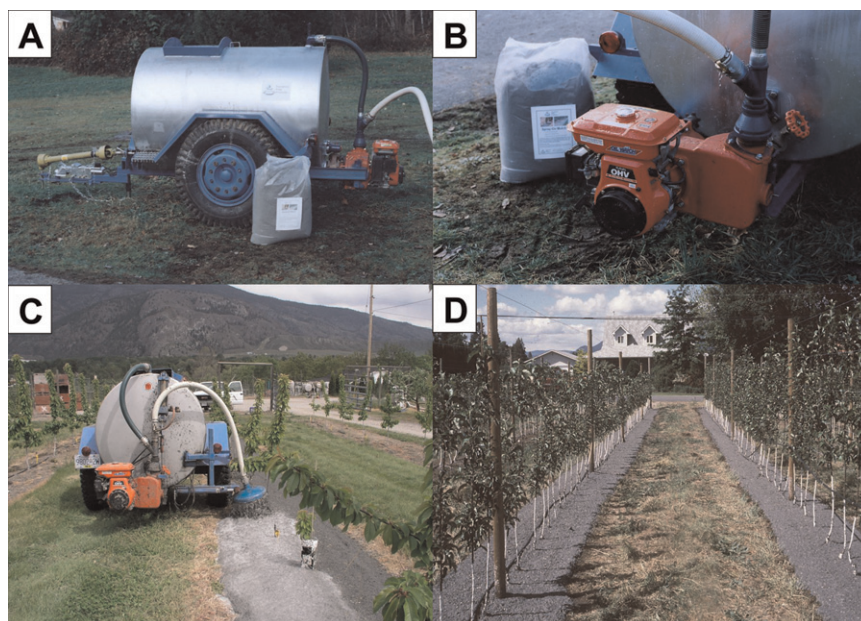


Fig. 1. Spray-on-mulch (SOM) applications were made using a (A) customized applicator equipped with a (B) recirculating trash pump and gate valve to regulate output and direct the slurry onto the tree row using a (C) splash plate. (D) The SOM formed a hard crust on the surface that acted as barrier to weed germination and growth.

GH280F0L3YOW; Kubota Canada, Markham, ON, Canada) was used to power a recirculating “trash” pump (Fig. 1B) with a 2.5-inch discharge pipe. A hydraulically actuated gate valve controlled by the tractor operator was used to regulate output and direct the slurry onto the tree row using a splash plate (Fig. 1C). When the gate valve was closed, the material

passed into the top of the tank to facilitate mixing.

Spray-on-mulch and other treatments

Spray-on-mulch treatments consisted of $3\text{ kg}\cdot\text{m}^{-2}$ newsprint residual and $0.5\text{ kg}\cdot\text{m}^{-2}$ chopped wheat straw applied in a 1-m-wide strip centered on the tree rows. In Expt. 3, $0.6\text{ kg}\cdot\text{m}^{-2}$

Units			
To convert U.S. to SI, multiply by	U.S. unit	SI unit	To convert SI to U.S., multiply by
0.4047	acre(s)	ha	2.4711
29.5735	fl oz	mL	0.0338
0.3048	ft	m	3.2808
0.0929	ft ²	m ²	10.7639
3.7854	gal	L	0.2642
40.7458	gal/ft ²	L·m ⁻²	0.0245
2.54	inch(es)	cm	0.3937
6.4516	inch ²	cm ²	0.1550
0.4536	lb	kg	2.2046
1.1209	lb/acre	kg·ha ⁻¹	0.8922
4.8824	lb/ft ²	kg·m ⁻²	0.2048
16.0185	lb/ft ³	kg·m ⁻³	0.0624
0.0254	mil	mm	39.3701
1	mmho/cm	dS·m ⁻¹	1
28.3495	oz	g	0.0353
305.1517	oz/ft ²	g·m ⁻²	0.0033
7.4892	oz/gal	g·L ⁻¹	0.1335
0.001	ppm	g·kg ⁻¹	1000
0.001	ppm	g·L ⁻¹	1000
0.1	ppm	mg/100 g	10
1	ppm	mg·kg ⁻¹	1
2.2417	ton/acre	Mg·ha ⁻¹	0.4461
(°F - 32) ÷ 1.8	°F	°C	(1.8 × °C) + 32

shredded office paper was included in the tank mixture.

The straw was chopped with a commercial forage harvester to provide pieces less than 5-cm long. The slurry was made by mixing 180 kg newsprint residual (DW) and 20 kg chopped straw, and as required per the treatment protocol, 2.5% [volume/volume (v/v)] tackifier, a guar gum-based “organic glue” (DS-Tack-FX; Quality Seeds, Langley, BC, Canada), or 24 kg shredded office paper (Canada Revenue Agency, Penticton, BC, Canada). These were mixed to a total volume of 2000 L water and applied at each application date to obtain a rate of 3 kg·m⁻² (30 Mg·ha⁻¹) newsprint residual. The right consistency of the slurry was important, but difficult to obtain given that the newsprint residual must be mixed vigorously to break up the balled short fiber. After application, the material formed a hard crust on the surface that acted as barrier to weed germination and growth (Fig. 1D); however, cracks subsequently formed with orchard traffic and exposure to rain and irrigation. Any weeds that germinated were permitted to grow until spot treatment with glyphosate in accordance with the application schedule indicated in Table 1. The dates of initial and repeat applications of SOM

for the various field trials are indicated in Table 1. Reapplications were often a lighter consistency, designed to anneal the surface by filling cracks and damage to the foundation.

To match the standard nonresidual herbicide practice in local commercial orchards for maintenance of an in-row weed-free strip, multiple annual applications of 1.08 kg·ha⁻¹ glyphosate (Roundup Transorb; Monsanto Canada, Winnipeg, MB, Canada) were made as required at rates of ≈0.1 L·m⁻² (Table 1).

EXPERIMENTS 1–4. Three SOM experiments were initiated in 2001 in commercial orchards in the Okanagan Valley of British Columbia, Canada. Orchards were microirrigated from May to October and fertilized according to local industry standards. Pest and cultural management practices followed standard practices for the region (British Columbia Ministry of Agriculture and Lands). Trees were grown in a 2.0-m-wide weed-free strip centered on the tree row.

Experiment 1 was conducted in a commercial orchard near Peachland, BC, Canada (lat. 49°44'32"N, long. 119°46'19"W), growing in a Rutland (Orthic Dark Brown) sandy loam soil over moderately coarse parent material, with gravelly and stony textures, rapid permeability and

low water holding capacity, and moderate organic matter (Wittneben, 1986). Trees of ‘Gala’/‘M.9’ were planted in Apr. 2001 at a spacing of 0.6 × 3 m (5556 trees/ha) and trained as super spindle. Three treatments were applied in a randomized complete block design with five replications between 2001 and 2004; each treatment plot contained five measurement trees and a guard tree between plots to minimize treatment interference. Treatments consisted of: 1) a herbicide check treated with glyphosate applied two to four times per season, 2) SOM, and 3) SOM applied over a 6 kg·m⁻² (60 Mg·ha⁻¹ DW basis) municipal composted biosolids (MCB) and wood waste (Ogogrow; City of Kelowna, BC, Canada) (applied the first year alone).

Experiment 2 was conducted in a commercial orchard in east Kelowna, BC, Canada (lat. 49°44'32"N, long. 119°46'19"W) growing in a Rutland (Orthic Dark Brown) sandy loam soil over soil with properties similar to that in Expt. 1 (Wittneben, 1986). Trees of ‘Granny Smith’/‘M.9’ were planted in Apr. 2000 at a spacing of 0.9 × 3.5 m (3175 trees/ha) and trained as super spindle. Four treatments were applied in a randomized complete block design with five replications between 2001 and 2004;

Table 1. Dates of application for spray-on-mulch (SOM) and glyphosate made to various apple cultivars in Expts. 1–4 during 2001–05.

Expt. 1		Expt. 2		Expt. 3		Expt. 4	
Glyphosate check ^z	SOM treatments ^y	Glyphosate check	SOM treatments	Glyphosate check	SOM treatments	Glyphosate check	SOM treatments
<i>SOM application dates</i>							
NA ^x	9 May 2001	NA	6 June 2001	NA	29 May 2001	NA	6 June 2002
NA	4 June 2002	NA	12 June 2002	NA	29 May 2002	NA	20 July 2003
NA	29 May 2003	NA	27 May 2003	NA	22 May 2003		
<i>Glyphosate application dates</i>							
7 June 2001	7 June 2001	28 June 2001	28 June 2001	24 May 2001	24 May 2001	2 June 2002	2 June 2002
9 July 2001	9 July 2011	3 Aug. 2001	3 Aug. 2001	25 June 2001	25 June 2001	16 Oct. 2002	16 Oct. 2002
17 Aug. 2001	23 June 1905	30 Apr. 2002	30 Apr. 2002	3 Aug. 2001	3 Aug. 2001	2 May 2003	2 May 2003
25 Oct. 2001	25 Oct. 2001	12 June 2002	12 June 2002	1 May 2002	1 May 2002	7 July 2003	7 July 2003
30 Apr. 2002	30 Apr. 2002	24 Sept. 2002	25 June 2002	2 July 2002	2 July 2002	30 July 2003	30 July 2003
25 July 2002	25 July 2002	6 May 2003	24 Sept. 2002	23 Aug. 2002	23 Aug. 2002	3 May 2004	3 May 2004
6 May 2003	6 May 2003	21 Aug. 2003	6 May 2003	6 May 2003	6 May 2003	25 June 2004	25 June 2004
26 June 2003	26 June 2003	23 Apr. 2004	26 June 2003	10 July 2003	10 July 2003	13 Aug. 2004	13 Aug. 2004
12 May 2004	12 May 2004	22 June 2004	21 Aug. 2003	28 Aug. 2003	28 Aug. 2003	22 Apr. 2005	22 Apr. 2005
28 July 2004			23 Apr. 2004	5 May 2004	5 May 2004	13 Aug. 2005	13 Aug. 2005
			22 June 2004	23 June 2004	23 June 2004		
				6 Aug. 2004	6 Aug. 2004		

^zThe glyphosate check treatment consisted of 1.08 kg·ha⁻¹ (0.964 lb/acre) glyphosate applied after each weed valuation.

^ySOM was applied at a rate of 3 kg·m⁻² (0.61 lb/ft²).

^xNA = not applicable.

each treatment plot contained five measurement trees and a guard tree between plots to minimize treatment interference. Treatments consisted of: 1) a herbicide check treated with glyphosate one to three times per season, 2) SOM, 3) SOM with 71 g·m⁻² (2.5% v/v) tackifier, and 4) SOM incorporated with 5 kg·ha⁻¹ dichlobenil (Casoron 50 WP; Chemtura Canada, Elmira, ON, Canada).

Experiment 3 was conducted in a commercial orchard located in Summerland, BC (lat. 49°34'17"N, long. 119°38'10"W) growing in a Osoyoos (Orthic Brown) sandy loam soil over moderately coarse parent material, with gravelly and stony textures, rapid drainage, and low fertility, organic matter, and water holding capacity (Wittneben, 1986). Trees of 'Ambrosia'/'M.9' were planted in 1998 at a spacing of 0.6 × 3.0 m (5555 trees/ha) and trained as super spindle. Two treatments were applied beginning in 2001 (fourth leaf) in a randomized complete block design with five replications between 2001 and 2004; each treatment plot contained 10 measurement trees and a guard tree between plots to minimize treatment interference. Treatments consisted of: 1) a herbicide check treated with glyphosate three times per season and 2) SOM.

Experiment 4 was established in a 'Honeycrisp'/'M.9' orchard planted in 24 Apr. 2002, at the Pacific Agri-Food Research Center, Summerland, BC, Canada (lat. 49°33'59"N, long. 119°38'12"W), growing in an Osoyoos (Orthic Brown) sandy loam soil over moderately coarse parent material, with gravelly and stony textures, rapid drainage, and low fertility, organic matter, and water holding capacity (Wittneben, 1986). Trees were spaced at 1 × 3 m (3333 trees/ha) and trained as super spindle and had alleyways seeded with a dryland mix of 42% crested wheatgrass (*Agropyron cristatum*), 33% perennial rye grass (*Lolium perenne*), and 25% kentucky bluegrass (*Poa pratensis*). Irrigation water was applied on alternate days as required, using 4 L·h⁻¹ emitters, spaced 25 cm on either side of each tree. Eight treatments were applied in a randomized complete block design with five replications; each treatment plot contained four measurement trees and a guard tree between plots to minimize treatment interference.

Treatments consisted of: 1) glyphosate check, 2) SOM, 3) SOM over 4.5 kg·m⁻² (45 Mg·ha⁻¹ DW basis) MCB, 4) SOM over black landscape fabric (Pro-Weed-X®; Dalen Products, Knoxville, TN), 5) SOM over a 0.6-mil spunbound polypropylene rowcover material (Reemay® cloth, style 206, 34 g·m⁻²; Fiberweb, Old Hickory, TN), 6) SOM over 1.1-m-wide 4-mil black polyethylene, 7) SOM over polyethylene over 4.5 kg·m⁻² (DW basis) MCB, and 8) SOM incorporated with 3 kg·ha⁻¹ dichlobenil (Casoron 50 WP). To prevent herbicide injury, dichlobenil was excluded in the SOM during the first year of planting.

Fertilizers were applied annually through the irrigation system, commencing in 2002 with a total of 10 g/tree P as 10N-14.8P-0K (first year only) and 30 g N as 34.5N-0P-0K at weekly intervals over an 8-week period beginning in mid-May annually, soon after full bloom. Fruit were thinned by hand ≈50-60 d after full bloom to maintain maximum final crop loads at harvest of less than 6 fruit/cm² trunk cross-sectional area (TCA).

GENERAL. Gravimetric soil moisture measurements were taken two to four times during the growing season for Expts. 1-3. A well-mixed composite of four soil cores (2-cm diameter) extracted from the top 15 cm of the soil profile of each experimental unit, 25 cm from the drip line, was dried at 105 °C to a constant weight. Soil moisture was calculated as a percentage on a DW basis.

Several times during each growing season and immediately before reapplication of glyphosate, weed growth was visually estimated to the nearest 1% to indicate natural weed pressure at various times over the course of the experiment. Periodic measurements were made in each of four 0.1-m² quadrants randomly sampled within each plot. Periodic measurements were also made to monitor the weed species by counting the total number of each within each plot.

Trunk diameter at 30 cm above the bud union was measured in the Spring of 2001 and repeated each fall to indicate tree growth. A 30-leaf sample for each treatment and replicate was collected in mid-July, 1999-2003, from the midportion of extension shoots of the current years'

growth. All samples were oven dried at 65 °C and ground in a stainless steel Wiley mill (A.H. Thomas Co., Philadelphia, PA). Leaf N was determined using a combustion analyzer (model FP-528; LECO, St. Joseph, MI) and leaf K, Ca, Mg, K, Mn, Fe, and Cu using an inductively coupled argon plasma spectrophotometer following the methods described earlier (Hogue et al., 2010). For Expt. 4 alone, a random sample of 10 fruit free of blemishes was taken at harvest and for N, P, K, Ca, Mg, and B analyses. Samples were rinsed under running, distilled water and then air dried. Chemical analysis was conducted on a composite of opposite, unpeeled quarters from each apple minus stem tissue and seeds. Fruit N was determined on a 0.125-g subsample of freeze-dried sectors using the methods and instrumentation described earlier for leaf samples. Fruit P, K, Ca, Mg, and B was determined by blending tissue with 1.5 times their weight of distilled water. A 150-mL subsample was further homogenized with a high-speed tissue homogenizer. A weighed 9-mL subsample of homogenized slurry was digested in 5.4 mL of concentrated sulfuric acid (H₂SO₄) containing sodium sulfate (Na₂SO₄) (1.8 g), copper (0.36 mL 25% copper sulfate solution), and selenium (0.67 g·L⁻¹) at 380 °C for 1 h. All fruit nutrient data were expressed on a fresh weight (FW) basis.

Total yield, number of harvested and preharvest dropped fruit per tree were recorded annually on 17 Sept. 2003, 3 Sept. 2004, and 6 Sept. 2005 for Expt. 4 only.

For Expt. 3, soil temperature was recorded in four replicate plots per treatment using an electronic data logger (model CR7; Campbell Scientific, Edmonton, AB, Canada) equipped with copper constantin thermocouples buried at a depth of 5 and 15 cm in the soil. Temperatures were recorded between 15 May 2001 and 26 Oct. 2003 at 5-s intervals and averaged hourly. Mean daily temperatures were averaged over the month for each replicate plot, and a monthly time series plot of soil temperature at 5 cm for the untreated control and mulch treatments was generated (Fig. 2). Daily soil minimum and maximum temperatures, based on hourly data, were used to determine extreme temperature

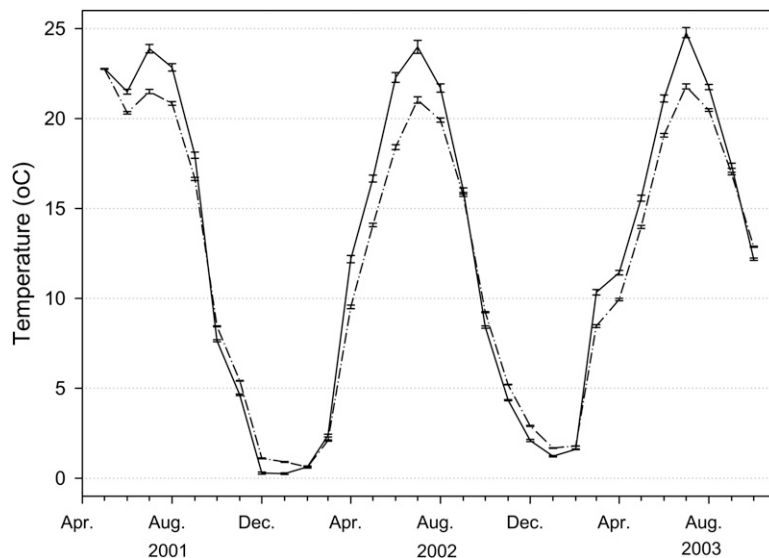


Fig. 2. Monthly average soil temperature at a depth of 5 cm (2.0 inches) as affected by glyphosate only (solid line) and mulch (dashed line) treatments in 2001–03. Error bars represent SE for each month; $(1.8 \times ^\circ\text{C}) + 32 = ^\circ\text{F}$.

maxima and minima values at 5- and 15-cm depths for the untreated and mulch treatments each year (Table 5). As a way of integrating temperature differences over time, thermal accumulation (heat units $>5^\circ\text{C}$) and loss (chill units $<5^\circ\text{C}$) were estimated using a degree day model with base 5°C (Doel et al., 1990; Honeycutt and Potaro, 1990; Jones, 1992). Heat and chill units were calculated as the sum of the daily difference in mean daily temperature and base 5°C when the mean daily temperatures were above and below 5°C , respectively (Table 6). These were then summed for each quarter (4-month periods) between 2001 and 2003 (Table 6).

Analysis of variance using Proc GLM (SAS version 9.2; SAS Institute, Cary, NC) was conducted on measured variables, and mean separation was performed using Duncan's multiple range test. Weed coverage percent data were transformed using the arcsin transformation; however, treatment differences were similar between transformed and untransformed value, and therefore the means that are presented represent the untransformed values. Analysis of covariance using Proc MIXED, and the variable crop density, was performed on mean fruit weight to evaluate the treatment effects on mean fruit weight at harvest independent of crop load (Marini, 2002).

Results and discussion

TREE VIGOR. In Expt. 1, SOM and SOM over compost markedly improved tree growth in years 2–5 ($P < 0.0001$ all years) compared with glyphosate only, as measured by TCA (Table 2). By year 5, TCA among trees receiving SOM treatments were 33% larger than the glyphosate check trees. No additional benefit was achieved when compost underlay was added to the SOM. In Expt. 2, TCA of SOM-treated trees after year 2 was also consistently greater than from those receiving the glyphosate check. However, when dichlobenil was incorporated with the SOM, tree growth was significantly less than SOM alone and was comparable to that of the glyphosate checks. Furthermore, TCA in trees treated with the SOM plus 2.5% tackifier was similar to the glyphosate check trees in 4 of 5 years. In Expt. 3, no significant treatment effect on TCA was observed between 2001 and 2004. Overall growth of trees in Expt. 3 was markedly lower than the other three experiments when based on similar tree age, and perhaps for this reason, the trees were not as responsive to SOM treatments. Also, because of the older tree age, perhaps the effects of previous conditions could not be overcome by treatment imposition in the 4th year.

The weaker growth in Expt. 3 is likely a direct result of both the weak-

growing cultivar Ambrosia (Cline, 2009) and higher intertree competition as a result of the higher planting density at which trees were planted in Expt. 3 (Preston, 1960). In Expt. 4, significant differences in tree vigor were observed in all 4 years of the study ($P = 0.02$ – 0.05). In year 1, tree growth was greatest among trees receiving any landscape fabric, plastic, or cloth underlay material in combination with SOM as well as trees treated with dichlobenil. Growth was least in trees receiving the SOM over plastic over compost, which was comparable to those receiving the glyphosate check. Treatment differences diverged in years 2 and 3 with the glyphosate check trees consistently among the smallest. By 2005 (year 4), tree vigor among trees receiving SOM treatments was similar and displayed 21% (SOM alone) to 38% (SOM over rowcover cloth) greater vigor than trees receiving the glyphosate checks. The results of improved tree vigor in response to plastic or cloth underlay are consistent with studies done earlier in the same region (Utkhede and Hogue, 1998).

YIELD AND FRUIT WEIGHT. Early tree yields were monitored in Expt. 4 during the first 3 years of bearing (2003–2005) (Table 3). Although no significant differences in yield were observed in any one year among treatments, significant differences in cumulative yield were observed by year 4 ($P = 0.01$). Trees receiving the SOM treatment alone, SOM over compost, and SOM over plastic over compost had the greatest cumulative yields, whereas the trees receiving the glyphosate check and SOM over plastic had the lowest cumulative yields. The remaining treatments had intermediate cumulative yields. Mean fruit weight was highly influenced by SOM treatments during 2003–05 when adjusted for crop load using covariate analysis. In 2004 and 2005, there were significant crop load covariate effects on fruit weight (data not shown). Treatment differences were not consistent across years although fruit from SOM alone or SOM over plastic over compost-treated trees were among the largest. This same effect was observed when fruit weight was averaged over 3 years. In contrast, fruit weight from trees treated with glyphosate, SOM over rowcover cloth, or landscape fabric were the smallest ($P < 0.0001$),

Table 2. Tree trunk cross-sectional area (TCA) of various apple cultivars as affected by groundcover management systems in Expts. 1–4 during 2001–05.

Groundcover management system ^y	TCA (cm ²) ^z					
	Spring 2001	Fall 2001	Fall 2002	Fall 2003	Fall 2004	Fall 2005
<i>Tree age (years)</i>						
Expt. 1—‘Gala’	1	2	3	4	5	
Glyphosate check	0.87	1.94 b ^x	3.29 b	4.11 b	4.64 b	NA
Spray-on-mulch (SOM)	0.98	2.22 a	4.24 a	5.32 a	6.19 a	NA
SOM over compost	1.01	2.45 a	4.36 a	5.54 a	6.46 a	NA
<i>P</i> value	0.085	<0.0001	<0.0001	<0.0001	<0.0001	
<i>Tree age (years)</i>						
Expt. 2—‘Granny Smith’	2	3	4	5	6	
Glyphosate check	1.72	2.91 b	5.87 ab	8.85 b	12.05 b	NA
SOM	1.79	3.49 a	6.89 a	10.75 a	15.83 a	NA
SOM + tackifier agent	1.68	3.01 ab	6.42 a	9.67 ab	14.21 ab	NA
SOM + dichlobenil	1.60	2.72 b	5.32 b	8.51 b	12.61 b	NA
<i>P</i> value	0.500	0.024	0.025	0.048	0.023	
<i>Tree age (years)</i>						
Expt. 3—‘Ambrosia’	4	5	6	7	8	
Glyphosate check	1.20	1.57	1.99	3.09	3.85	NA
SOM	1.21	1.60	2.07	3.41	4.19	NA
<i>P</i> value	0.771	0.642	0.375	0.091	0.114	
<i>Tree age (years)</i>						
Expt. 4—‘Honeycrisp’			1	2	3	4
Glyphosate check	NA	NA	2.03 c	2.95 b	4.10 c	4.93 b
SOM	NA	NA	2.14 bc	3.29 b	4.67 bc	5.97 a
SOM over compost	NA	NA	2.25 bc	3.71 ab	5.11 ab	6.34 a
SOM over fabric landscape cloth	NA	NA	2.37 abc	3.65 ab	5.14 ab	6.17 a
SOM over rowcover cloth	NA	NA	2.63 a	4.28 a	5.70 a	6.81 a
SOM over polyethylene plastic (poly)	NA	NA	2.33 abc	3.75 ab	5.00 abc	6.13 a
SOM over poly over compost	NA	NA	2.08 c	3.72 ab	5.24 ab	6.45 a
SOM + dichlobenil	NA	NA	2.47 abc	3.59 ab	4.98 abc	6.11 a
<i>P</i> value			0.024	0.025	0.048	0.023

^z1 cm² = 0.1550 inch².

^yTreatments consisted of a glyphosate check [1.08 kg·ha⁻¹ (0.964 lb/acre) glyphosate] applied after each weed evaluation, SOM at a rate of 3 kg·m⁻² (0.61 lb/ft²), municipal composted biosolids and wood waste (Ogogrow; City of Kelowna, BC, Canada) applied at 6 kg·m⁻² (1.23 lb/ft²) dry weight basis, a 2.5% (v/v) guar gum-based tackifier (DS-Tack-FX; Quality Seeds, Langley, BC, Canada) used to help improve SOM adhesion and long-term surface stability, the residual herbicide dichlobenil at 5 kg·ha⁻¹ (4.46 lb/acre) for longer-term weed control, 1.2-m-wide (3.94 ft) stripe of black landscape fabric (Pro-Weed-X®; Dalen Products, Knoxville, TN) on the side of each tree, 1.2-m-wide stripe of 0.6-mil (0.015 mm) spunbound polypropylene rowcover material (Reemay® cloth, style 206; Fiberweb, Old Hickory, TN) on the side of each tree, and 1.2-m-wide stripe of 4-mil (0.102 mm) black polyethylene.

^xValues with the same letter within a given column are not significantly different according to Duncan’s multiple range test at *P* = 0.05.

NA = not applicable (data not recorded).

although those fruit were still very large.

SOIL MOISTURE. In 2001, soil moisture in the top 15 cm of the profile of Expt. 1 was greatest in SOM over compost treatment and intermediate

in the SOM alone treatment before 14 Sept., in comparison with the glyphosate check (Table 4). During the measurement dates after this period, soil moisture levels were similar between the SOM and SOM over compost

treatments, both of which were consistently greater than the glyphosate check. In Expt. 2, SOM treatments (including tackifier and dichlobenil) had consistently higher soil moisture levels in comparison with the glyphosate check. On 18 Aug. 2003, soil moisture within the SOM plus tackifier and SOM plus dichlobenil treatments was intermediate between the SOM alone and glyphosate check. In Expt. 3, soil moisture levels in the SOM treatment were greater than the glyphosate check in four of eight measurement dates. Periods when differences were less pronounced were associated with the application of trickle irrigation. These data are consistent with other reports in the literature where mulch has been demonstrated to increase soil moisture (Neilsen et al., 1986, 2003b).

SOIL TEMPERATURE. There were highly significant treatment effects on monthly mean soil temperature in Expt. 3, which tended to be greatest during the mid winter and summer months and less during the late winter/early spring and autumn months (Fig. 2). At a depth of 5 cm, soil temperature during the summer and winter months was as much as 4 °C cooler and 2.5 °C warmer in the SOM treatments, respectively, in comparison with the glyphosate checks. During the months of September–November and the month of February, monthly mean soil temperatures among treatments were similar. The monthly mean soil temperatures of the above treatments at 15 cm followed a very similar but slightly attenuated pattern as those at 5 cm (data not shown). Analysis of monthly extreme minimum and maximum temperature events over the 3 years of the experiment indicated soil temperatures at a depth of 5 cm were as much as 1.8–2.1 °C warmer in the winter and 3.0–8.5 °C cooler in the summer for the SOM treatments in contrast to the glyphosate checks (Table 5). At a depth of 15 cm, SOM treatments were as much as 4.1–5.9 °C warmer in the winter and 5.8–12.3 °C cooler in the summer in contrast to the glyphosate checks. In each quarter between 2001 and 2003, significant treatment differences existed in the number of soil heat units (Table 6). Over the July–September quarters, soil temperatures within the SOM treatments had ≈175 fewer heat units

Table 3. Fruit yield and mean fruit weight of 'Honeycrisp' apples as affected by groundcover management systems in Expt. 4 during 2003–05.

Groundcover management system ^x	Yield (kg/tree) ^z				Mean fruit wt (g) ^y			
	2003	2004	2005	Cumulative	2003	2004	2005	3-yr avg
Glyphosate check	1.4	4.6	5.6	11.6 b ^v	332 bcd	340 ab	213 d	294 e
Spray-on-mulch (SOM)	1.5	6.8	7.9	16.2 a	345 abc	357 a	272 a	324 a
SOM over compost	1.6	8.7	6.4	16.7 a	349 ab	323 c	253 ab	307 cd
SOM over fabric landscape cloth	1.4	7.2	5.9	14.4 ab	327 cd	354 a	263 ab	313 bc
SOM over rowcover cloth	1.3	7.0	6.4	14.8 ab	322 de	337 ab	248 b	305 cde
SOM over polyethylene plastic	0.9	5.8	5.2	11.9 b	310 e	321 bc	260 ab	300 de
SOM over poly over compost	1.5	6.9	7.3	15.8 a	362 a	344 a	252 b	320 ab
SOM + dichlobenil	1.3	6.6	6.8	14.8 ab	337 bcd	355 a	233 c	308 cd
<i>P</i> value	0.183	0.190	0.189	0.010	<0.0001	0.001	<0.0001	<0.0001

^x1 kg = 2.2046 lb.

^yMean fruit weight was adjusted using covariate analysis and crop load (no. of fruit/tree) as a covariate; 1 g = 0.0353 oz.

^zTreatments consisted of a glyphosate check [1.08 kg·ha⁻¹ (0.964 lb/acre) glyphosate] applied after each weed evaluation, SOM at a rate of 3 kg·m⁻² (0.61 lb/ft²), municipal composted biosolids and wood waste (Ogogrow; City of Kelowa, BC, Canada) applied at 6 kg·m⁻² (1.23 lb/ft²) dry weight basis, 1.2-m-wide (3.94 ft) stripe of black landscape fabric (Pro-Weed-X®; Dalen Products, Knoxville, TN) on the side of each tree, 1.2-m-wide stripe of 0.6-mil (0.015 mm) spunbound polypropylene rowcover material (Reemay® cloth, style 206; Fiberweb, Old Hickory, TN) on the side of each tree, and 1.2-m-wide stripe of 4-mil (0.102 mm) black polyethylene, and the residual herbicide dichlobenil at 5 kg·ha⁻¹ (4.46 lb/acre) for longer-term weed control.

^vValues with the same letter within a given column are not significantly different according to Duncan's multiple range test at *P* = 0.05.

Table 4. Soil moisture content at a depth of 0–15 cm (5.9 inches) as affected by groundcover management systems applied to several apple cultivars in Expts. 1–3 during 2001–03.

Groundcover management system ^x	Soil moisture content (% by vol)							
	9 July 2001	17 Aug. 2001	21 Aug. 2001	14 Sept. 2001	31 July 2002	21 Aug. 2002	22 July 2003	18 Aug. 2003
Expt. 1								
Glyphosate check	10.4 c ^y	10.9 c	10.9 c	13.6 c	5.6 c	9.1 b	5.2 b	7.7 b
Spray-on-mulch (SOM)	14.4 b	15.3 b	15.3 b	15.3 bc	10.4 b	16.5 a	14.2 a	15.7 a
SOM over compost	18.7 a	19.9 a	19.9 a	17.6 ab	10.1 b	14.9 ab	13.3 a	13.5 ab
<i>P</i> value	0.001	<0.0001	<0.0001	0.007	0.001	0.024	0.004	0.056
	16 Aug. 2002	12 Sept. 2002	4 Aug. 2003	18 Aug. 2003				
Expt. 2								
Glyphosate check	14.2 b	16.9 b	17.3 b	18.9 b				
SOM	28.7 a	21.2 a	23.7 a	24.1 a				
SOM + 2.5% tackifier	27.3 a	21.7 a	23.6 a	22.7 ab				
SOM + dichlobenil	27.9 a	21.3 a	26.4 a	23.2 ab				
<i>P</i> value	<0.0001	0.010	0.010	0.109				
	2 Aug. 2001	9 Aug. 2001	26 July 2001	5 Sept. 2001	22 July 2002	21 Aug. 2002	11 July 2003	28 Aug. 2003
Expt. 3								
Glyphosate check	17.7	18.0	13.9	12.8	19.3	14.1	18.1	16.7
SOM	21.6	20.0	23.6	16.7	20.4	18.9	25.3	24.0
<i>P</i> value	0.025	0.298	0.052	0.051	0.511	0.035	0.007	0.010

^xTreatments consisted of a glyphosate check [1.08 kg·ha⁻¹ (0.964 lb/acre) glyphosate] applied after each weed evaluation, SOM at a rate of 3 kg·m⁻² (0.61 lb/ft²), municipal composted biosolids and wood waste (Ogogrow; City of Kelowa, BC, Canada) applied at 6 kg·m⁻² (1.23 lb/ft²) dry weight basis, a 2.5% (v/v) guar gum-based tackifier (DS-Tack-FX; Quality Seeds, Langley, BC, Canada) used to help improve SOM adhesion and long-term surface stability, the residual herbicide dichlobenil at 5 kg·ha⁻¹ (4.46 lb/acre) for longer-term weed control.

^yValues with the same letter within a given column are not significantly different according to Duncan's multiple range test at *P* = 0.05.

compared with the glyphosate check treatments (average over 3 years). During the first (January–March) and fourth (October–December) quarters, SOM treatments had statistically greater heat units, whereas glyphosate check treatments accumulated statistically greater chilling units.

These soil temperature data are consistent with observations in other mulch studies where topsoil under mulch showed the lowest thermal amplitudes and the highest minimum temperatures during winter month (Andrade et al., 2010). Rogers (1939) suggested that the onset of root growth of apple occurs at 6.2 °C; therefore,

SOM effects on early season soil temperatures are likely to influence root growth. Young (1992) found that exposure of roots to warm temperature during the dormant period had significant effect on spring root and shoot growth and bud development. Gur et al. (1972) reported that root growth was also reduced

Table 5. Yearly extreme minimum and maximum monthly soil temperatures at two depths as affected by orchard management systems applied to ‘Ambrosia’ apple trees in Expt. 3 during 2001–03.

Yr	Depth 5 cm (2.0 inches)				Depth 15 cm (5.9 inches)			
	Extreme minimum temp (°C) ^z		Extreme maximum temp (°C)		Extreme minimum temp (°C)		Extreme maximum temp (°C)	
	Glyphosate check ^y	Spray-on-mulch (SOM) ^y	Glyphosate check	SOM	Glyphosate check	SOM	Glyphosate check	SOM
2001	-3.0	-1.3	37.8	34.8	-0.7	3.8	35.6	33.2
2002	-3.3	-1.3	35.1	26.6	-0.7	5.2	27.4	23.5
2003	-1.9	-0.1	33.4	26.5	0.2	4.3	27.7	24.2

^z(1.8 × °C) + 32 = °F.

^yTreatments consisted of a glyphosate check [1.08 kg·ha⁻¹ (0.964 lb/acre) glyphosate] applied after each weed evaluation and SOM at a rate of 3 kg·m⁻² (0.61 lb/ft²).

Table 6. Soil heat and chill unit accumulation above and below base 5 °C (41.0 °F) for 3-month periods between May 2001 and Dec. 2003, at a depth of 5 cm (2.0 inches). Temperatures were monitored in glyphosate check and spray-on-mulch (SOM) treatments applied to ‘Ambrosia’ apple trees (Expt. 3).

Yr	3-mo. period	Heat units >5 °C ^z			Chill units <5 °C		
		Glyphosate check ^y	SOM ^y	Significance	Glyphosate check	SOM	Significance
2001	May–June	490	466	*	0	0	
	July–September	1525	1349	*	0	0	
	October–December	112	139	*	183	136	*
2002	January–March	14	46	***	367	348	NS
	April–June	1093	809	**	0	0	
	July–September	1437	1248	**	0	0	
	October–December	136	154	*	146	87	**
2003	January–March	21	58	***	213	194	*
	April–June	1004	829	**	0	0	
	July–September	1502	1333	**	0	0	
	October–December	SOM	204	*	0	0	

^zData were accumulated starting on 16 May 2001 and ending on 26 Oct. 2003.

^yTreatments consisted of a glyphosate check [1.08 kg·ha⁻¹ (0.964 lb/acre) glyphosate] applied after each weed evaluation and SOM at a rate of 3 kg·m⁻² (0.61 lb/ft²).

NS, *, **, ***Nonsignificant or significant at *P* = 0.05, 0.10, and 0.01, respectively.

at soil temperature above 30 °C and that damage to leaves occurred when temperatures exceed 35 °C as a result of the transport of anaerobic respiration products from the root. Further study is required to ascertain the specific temperature moderating effects of SOM on root growth, budbreak, and apple growth and development.

WEED GROWTH. Three of the four experiments in this study were conducted in commercial orchards where acceptable weed control was required. As a result, it was necessary to include glyphosate in the control treatments. Furthermore, glyphosate (1% to 2% by volume) was applied every 6–8 weeks to all treatment plots to manage any weed emergence and growth, an industry-accepted practice and rate of use. This study sought to compare new weed growth and/or re-establishment of weed growth in the control and SOM treatments; therefore, glyphosate applications were necessary in all treatment

plots to standardize weed evaluation observations.

Quantitative analysis of the number of weed species per plot, averaged overall sampling dates, and the percent distribution of 21 species by number is indicated in Table 7. The predominant weed species were influenced by orchard location and treatment, which varied across experiments. In Expts. 1–3, glyphosate check treatments consistently had more weeds per plot than any of the plots containing SOM. In Expt. 1, the addition of compost underlay provided marginally better weed control in comparison with the SOM alone. The predominant weeds found in plots treated with the glyphosate were red root pigweed (*Amaranthus retroflexus*), chickweed (*Stellaria media*), and barnyard grass (*Echinochloa crus-galli*). The addition of SOM resulted in a greater prevalence of quack grass (*Elytrigia repens*), storks bill (*Erodium cicutarium*), and buckwheat (*Polygonum convolvulus*).

A slightly higher distribution of pale smart weed (*Polygonum lapatifolium*) was observed with the addition of compost to the SOM treatment. In Expt. 2, treatments containing SOM alone or with tackifier or dichlobenil additives had markedly fewer weeds per plot than the glyphosate check plots. The two dominant species found in the glyphosate check plots were shepherd’s purse (*Capsella bursa-pastoris*) followed by buckwheat. The SOM treatment reduced the amount of shepherd’s purse but increased the prevalence of smart weed, vetch (*Vicia cracca*), and field horsetail (*Equisetum arvense*). The addition of tackifier did not change the weed distribution appreciably, whereas the addition of dichlobenil eradicated most weeds from the plots. In Expt. 3, the predominant weed species in the glyphosate check plots were henbit (*Lamium amplexicaule*), shepherd’s purse, and red root pigweed. Spray-on-mulch reduced the average

Table 7. Average total number of weed species and species distribution as affected by groundcover management systems applied to various apple cultivars in Expts. 1–3 during 2001–03. Dominant weed species for each treatment are highlighted in boldface type.

Groundcover management system ^y	Mean weeds (total no./m ²) ^x	Observation dates (no.)	Weed species (% of total) ^z																				
			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
Expt. 1																							
Glyphosate check	4.8 a ^w	5	15	0	9	10	0	7	5	6	16	3	1	0	10	5	0	6	6	1	1	0	0
Spray-on-mulch (SOM)	1.8 b	5	9	1	15	14	1	6	2	17	6	0	1	2	8	3	0	5	10	0	1	0	0
SOM over compost	0.5 b	5	7	4	9	25	0	2	0	22	4	0	0	0	6	4	1	2	15	0	0	0	0
P value	<0.0001	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Expt. 2																							
Glyphosate check	6.9 a	6	4	0	0	0	0	4	1	0	0	0	0	0	2	6	25	0	0	49	0	9	0
SOM	2.0 b	6	6	17	0	1	0	6	0	0	0	0	0	0	12	0	31	0	0	7	0	19	0
SOM with 2.5% tackifier	1.2 b	6	2	26	0	6	0	10	1	0	0	0	0	0	12	0	28	0	0	8	0	6	0
SOM + dichlobenil	0.1 b	6	0	0	0	0	0	0	0	0	0	0	0	0	32	2	0	0	0	50	0	17	0
P value	<0.0001	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Expt. 3																							
Glyphosate check	4.6 a	3	5	0	0	1	3	6	7	2	16	0	2	0	7	6	0	1	0	21	0	0	24
SOM	0.8 b	3	—	0	0	5	6	3	8	2	7	0	0	0	21	8	0	0	0	8	0	0	28
P value	<0.0001	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—

^x1 = chickweed (*Stellaria media*); 2 = field horsetail (*Equisetum arvense*); 3 = stork's bill (*Erodium cicutarium*); 4 = buckwheat (*Polygonum convolvulus*); 5 = clover (*Trifolium repens*); 6 = dandelion (*Taraxacum officinale*); 7 = common mallow (*Malva neglecta*); 8 = quack grass (*Elytrigia repens*); 9 = redroot pigweed (*Amaranthus retroflexus*); 10 = creeping yellow cress (*Rorippa sylvestris*); 11 = groundsel (*Senecio vulgaris*); 12 = black medick (*Medicago lupulina*); 13 = barnyard grass (*Echinochloa crus-galli*); 14 = lamb's quarter (*Chenopodium album*); 15 = pale smartweed (*Polygonum lapathifolium*); 16 = prostrate pigweed (*Amaranthus greeseanus*); 17 = yellow foxtail (*Setaria glauca*); 18 = shepherd's purse (*Capella bursa-pastoris*); 19 = knotweed (*Polygonum aviculare*); 20 = vetch (*Vicia cracca*). The dominant weed species by treatment are highlighted in boldface type.

^yTreatments consisted of a glyphosate check [1.08 kg-ha⁻¹ (0.964 lb/acre) glyphosate] applied after each weed evaluation, SOM at a rate of 3 kg-m⁻² (0.61 lb/ft²), municipal composted biosolids and wood waste (Ogrogrow; City of Kelowna, BC, Canada) applied at 6 kg-m⁻² (1.23 lb/ft²) dry weight basis, a 2.5% (v/v) guar gum-based tackifier (DS-Tack-FX; Quality Seeds, Langley, BC, Canada) used to help improve SOM adhesion and long-term surface stability, and the residual herbicide dichlobenil at 5 kg-ha⁻¹ (4.46 lb/acre) for longer-term weed control.

^z1 weed/m² = 0.0929 weed/ft².
^wValues with the same letter within a given column are not significantly different according to Duncan's multiple range test at P = 0.05.

number of weeds per plot by ≈80%; in these plots, henbit and barnyard grass were the primary weed species found.

Total weeds per plot and estimated area covered in the designated weed-free region beneath trees are indicated in Tables 8 and 9, respectively. Total weeds per plot was statistically greater in the glyphosate check plots in 23 of 26 instances across the four experiments and over the several years that the experiments were conducted (Table 8). In Expt. 1, the addition of compost improved weed control in nearly 50% of the instances when significant treatment differences existed. In Expt. 2, weed pressure was greatly reduced through the addition of SOM in four of five instances over 3 years. Adding the tackifier to SOM slurry did not improve weed control efficacy appreciably, but the addition of dichlobenil provided complete weed control for the entire growing season.

Weed coverage within the designated weed-free area of each plot, expressed as a percentage occupying a 1-m² grid, is indicated in Table 9. In 24 of 30 instances across the four experiments and over the several years, the glyphosate check treatments had a greater percentage weed growth than treatments including SOM (Table 9). In Expt. 1, SOM and SOM over compost treatments had consistently less percent weed coverage than the glyphosate check treatments in 2001 and 2002. In Expt. 2, SOM plus dichlobenil provided additional weed control over the SOM alone treatment in only one of four instances where significant treatment differences existed. On occasions where no significant treatment differences were observed, weed observation dates were within 3–4 weeks of a glyphosate reapplication, and as a result, weed growth had not re-established in the non-SOM treatment plots. In Expt. 3, of the 12 observation dates, weed coverage was significantly less in the SOM treatment by 10 times (83%). Effective weed control was maintained with the SOM treatments in this commercial plot, as indicated by low weed percent coverage values consistently at or below 5%, except in early Spring of 2002 and 2003. In Expt. 4, significant treatment differences in percent weed coverage existed during all seven observation dates between 2002 and 2005. Glyphosate check treatments

Table 8. Total weeds as affected by groundcover management system applied to several apple cultivars. Dates represent the time weed observations were made for each treatment between 2001 and 2005 (Expts. 1–4).

Groundcover management system ^z	Total weeds (no./m ²) ^y								
	7 June 2001	16 July 2001	15 Aug. 2001	23 Oct. 2001	30 Apr. 2002	25 July 2002	6 May 2003	12 May 2004	28 July 2004
Expt. 1									
Glyphosate check	2.2 a ^x	6	10.3 a	3.3 a	3.4 a	4.7	0 c	1.1 a	2.5 a
Spray-on-mulch (SOM)	6.1 b	6	3.9 b	1.4 bc	1.4 b	3.2	0.2 a	0.2 b	1.0 b
SOM over compost	0.7 c	0	0.3 c	0.3 bc	0.7 bc	1.8	0.1 b	0.1 b	8 b
<i>P</i> value	0.007	0.246	<0.0001	<0.0001	<0.0001	0.160	0.0002	0.0002	0.003
	30 June 2001	9 Aug. 2001	31 Oct. 2001	7 Aug. 2002	18 Aug. 2003				
Expt. 2									
Glyphosate check	5.2 a	10.8 a	4.1 a	13.6 a	0.75				
SOM	1.7 b	6.3 b	1.2 b	0.6 b	0.4				
SOM + 2.5% tackifier	1.2 b	3.7 b	0.7 bc	0.3 b	0.4				
SOM + dichlobenil	0 b	0.1 c	0 c	0.1 b	0.3				
<i>P</i> value	0.0007	0.001	<0.0001	<0.0001	0.31				
	25 June 2001	3 Aug. 2001	25 Oct. 2001	21 Aug. 2002	9 July 2003				
Expt. 3									
Glyphosate check	5.2 a	6.8 a	5.9 a	4.6 a	1.4				
SOM	0.3 b	0.8 b	1.5 b	0.9 b	0.2				
<i>P</i> value	0.015	0.044	0.004	0.007	0.065				
	9 Oct. 2002	26 Nov. 2002	23 May 2003	22 July 2003	3 May 2004	25 June 2004	22 Apr. 2005		
Expt. 4									
Glyphosate check	7.3 a	4.1 a	1.6 a	0.0 c	4.1 a	5.5 a	5.0 a		
SOM	0.7 b	0.6 b	0.2 b	0.2 b	0.4 b	0.3 b	3.9 ab		
SOM over compost	0.6 b	0.4 b	0.2 b	0.2 b	0.3 b	0.5 b	3.3 bc		
SOM over fabric landscape cloth	0.6 b	0.6 b	0.1 b	0.3 a	0.3 b	0.3 b	3.6 bc		
SOM over rowcover cloth	0.1 b	0.7 b	0.1 b	0.3 a	0.3 b	0.3 b	2.5 bc		
SOM over polyethylene plastic	0.3 b	0.3 b	0.1 b	0.0 c	0.2 b	0.2 b	2.5 bc		
SOM over poly over compost	0.2 b	0.3 b	0.2 b	0.1 bc	0.1 b	0.4 b	2.3 c		
SOM + dichlobenil	0.6 b	0.4 b	0.2 b	0.3 a	0.3 b	0.4 b	2.9 bc		
<i>P</i> value	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001		

^zTreatments consisted of a glyphosate check [1.08 kg·ha⁻¹ (0.964 lb/acre) glyphosate] applied after each weed evaluation, SOM at a rate of 3 kg·m⁻² (0.61 lb/ft²), municipal composted biosolids and wood waste (Ogogrow; City of Kelowna, BC, Canada) applied at 6 kg·m⁻² (1.23 lb/ft²) dry weight basis, 1.2-m-wide (3.94 ft) stripe of black landscape fabric (Pro-Weed-X®; Dalen Products, Knoxville, TN) on the side of each tree, 1.2-m-wide stripe of 0.6-mil (0.015 mm) spunbound polypropylene rowcover material (Reemay® cloth, style 206; Fiberweb, Old Hickory, TN) on the side of each tree, and 1.2-m-wide stripe of 4-mil (0.102 mm) black polyethylene, and the residual herbicide dichlobenil at 5 kg·ha⁻¹ (4.46 lb/acre) for longer-term weed control.

^y1 weed/m² = 0.0929 weed/ft².

^xValues with the same letter within a given column are not significantly different according to Duncan's multiple range test at *P* = 0.05.

had markedly more weed coverage within the weed-free area than all the other treatments. Although at times there were significant differences in weed coverage among the SOM treatments, the magnitude of these differences was less than 5%, except in early Spring 2005 when the SOM over plastic over compost underlay had 13% less weed coverage than the SOM alone treatment.

LEAF NUTRITION. Leaf N, P, and Fe concentrations were considered adequate based on regional recommendations (British Columbia Ministry of Agriculture and Lands, 2007)

throughout the experiment and were unaffected by treatments in any the four experiments (data not shown). Leaf N was always above the 21 g·kg⁻¹ (DW) deficiency threshold for apple over the course of the experiments. The lack of significant treatment effects on leaf N levels suggests that tree N status was predominately influenced by the annual fertigation applications rather than by treatment differences associated with variation in N additions or mineralization, as has been previously demonstrated (Nielsen et al., 2007). Leaf P concentration ranged from 2.4 to 4.4, from 1.6

to 2.2, from 1.7 to 2.0, and from 1.4 to 3.8 g·kg⁻¹ P (DW) in Expts.1–4, respectively, throughout the study and was uninfluenced by treatments in all years (data not shown). In Expt. 4, Leaf P levels were slightly but significantly higher in the SOM over compost and SOM over polyethylene plastic over compost in 3 to 4 years (data not shown). This indicates a possible increase in plant available soil P in the compost treatments, enhanced P uptake, or both, perhaps a result of increased soil microbial activity (e.g., vesicular-arbuscular mycorrhizal fungi) (Forge et al., 2008; Morin et al., 1994).

Table 9. Weed coverage within the targeted weed-free area [0.6 m (1.97 ft) on each side of the tree] per plot as affected by groundcover management systems applied to various apple cultivars. Dates represent the time weed observations were made for each treatment between 2001 and 2005 (Expts. 1–4).

Groundcover management system ^a	Weed coverage (% by total area)											
	7 June 2001	31 Oct. 2001	21 Aug. 2002	7 Aug. 2002	12 Sept. 2002	23 July 2003	18 Aug. 2003	22 June 2004	4 May 2004	23 June 2004	6 Aug. 2004	
Expt. 1												
Glyphosate check	38 a ^y	12 a	24 a	8	24 a	0	10	55 a				
Spray-on-mulch (SOM)	8 b	4 b	6 b	6	3 b	1	3	18 b				
SOM over compost	3 b	2 c	4 b	4	2 b	2	7	17 b				
P-value	0.002	<0.0001	0.002	0.136	<0.0001	0.27	0.49	0.002				
Expt. 2												
Glyphosate check	10	19 a	61 a	31 a	21	32	26 a	7 a	41 a	18 a	18 a	
SOM	2	9 b	21 b	3 b	5	9	1 b	1 b	3 b	4 b	4 b	
SOM + 2.5% tackifier	1	3 b	19 bc	4	2 b	2	7	17 b				
SOM + dichlobenil	0	0 b	4 c	3	1 b	1	9	15 b				
P-value	0.059	0.013	<0.0001	0.009	0.012	0.015	0.001	0.004	0.072	0.001	0.003	0.003
Expt. 3												
Glyphosate check	11 a	5 a	24	26 Nov. 2003	3 May 2004	25 June 2004	22 Apr. 2005					
SOM	2 b	1 b	14	3 b	5	9	1 b	1 b	3 b	4 b	4 b	
P-value	0.005	0.035	0.055	0.009	0.012	0.015	0.001	0.004	0.072	0.001	0.003	0.003
Expt. 4												
Glyphosate check	58 a	13 a	0 c	33 a	33 a	44 a	40 a					
SOM	5 b	2 b	1 b	4 b	3 b	2 b	31 ab					
SOM over compost	4 b	2 b	1 b	3 b	2 b	4 b	26 bc					
SOM over fabric landscape cloth	5 b	1 b	2 a	5 b	2 b	2 b	29 bc					
SOM over rowcover cloth	1 b	1 b	2 a	5 b	2 b	2 b	20 bc					
SOM over polyethylene plastic (poly)	2 b	1 b	0 c	2 b	1 b	1 b	20 bc					
SOM over poly over compost	2 b	1 b	0 c	3 b	3 b	3 b	18 c					
SOM + dichlobenil	5 b	1 b	2 a	3 b	3 b	3 b	23 bc					
P-value	<0.0001	<0.0001	<0.0001	0.009	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001

^aTreatments consisted of a glyphosate check [1.08 kg·ha⁻¹ (0.964 lb/acre) glyphosate] applied after each weed evaluation, SOM at a rate of 3 kg·m⁻² (0.61 lb/ft²), municipal composted biosolids and wood waste (Ogogrow, City of Kelowna, BC, Canada) applied at 6 kg·m⁻² (1.23 lb/ft²) dry weight basis, a 2.5% (v/v) guar gum-based tackifier (DS-Tack-FX; Quality Seeds, Langley, BC, Canada) used to help improve SOM adhesion and long-term surface stability, the residual herbicide dichlobenil at 5 kg·ha⁻¹ (4.46 lb/acre) for longer-term weed control, 1.2-m-wide (3.94 ft) stripe of black landscape fabric (Pro-Weed-X®, Dalen Products, Knoxville, TN) on the side of each tree, 1.2-m-wide stripe of 0.6-mil (0.015 mm) spunbound polypropylene rowcover material (Reemay® cloth, style 206; Fiberweb, Old Hickory, TN) on the side of each tree, 1.2-m-wide stripe of 4-mil (0.102 mm) black polyethylene.

^yValues with the same letter within a given column are not significantly different according to Duncan's multiple range test at *P* = 0.05.

Significant treatment effects on leaf K were observed in two of the four experiments (Table 10). In Expt. 1, leaf K was adequate in all 3 years of the experiment, whereas in Expts. 2 and 3, leaf K was below the critical level of 13 g·kg⁻¹ for all treatments in 2003. In Expt. 4, leaf K levels were considered deficient for all treatments in 2004 and 2005. Although statistical treatment differences in leaf K

were observed over 2 years in Expt. 2, these effects were not consistent among years. In all experiments, there was a gradual decline in leaf K levels over time as tree cropping increased, which is consistent with other studies (Hogue et al., 2010; Neilsen et al., 1998, 2000; Neilsen and Neilsen, 2006).

No significant treatment effects on leaf Ca were observed in any of the

experiments (data not shown). Leaf Ca levels were considered adequate (above the 8 g·kg⁻¹ DW) for Expts. 1, 3, and 4 but ranged from 0.9 to 5.1 g·kg⁻¹ Ca over 3 years for Expt. 2, well below the adequate range. Despite the high Ca concentration of the mulch (Neilsen et al., 2007), no immediate plant benefits indicated by increased leaf Ca could be attributed to its use. This is consistent with other research indicating that plant levels of Ca are more affected by plant physiological processes than available soil Ca (Himmelrick and McDuffie, 1983).

Leaf Mg concentrations were significantly higher in trees in Expt. 3 receiving the glyphosate treatment in 2001 and 2002 (data not shown). No treatment response in leaf Mg was observed in 2003 or in any of the other years for Expts. 1, 2, and 4. While Mg did not fluctuate widely between years and among treatments, it was below the critical level of 0.26 g·kg⁻¹ (DW) in 75% of the plots across all experiments and years (data not shown). There was no indication that SOM influenced leaf Mg levels in Expts. 1, 2, or 4.

Leaf Mn and Zn concentrations were similar among treatments (data not shown) during the study period and were considered adequate for apple growth and development, with the exception of Expt. 2 where Mn and Zn fell below 25 mg·kg⁻¹ Mn (DW) and 20 mg·kg⁻¹ Zn (DW) in all 3 years of the experiment, and Expt. 4 where Mn fell below 25 mg·kg⁻¹ (DW) in 2003–05.

FRUIT NUTRITION. In Expt. 4, no significant treatment effects on fruit N, P, K, Ca, Mg, and B levels were observed in 2002–05 (data not shown). Levels of each nutrient (mg/100 g FW) ranged as follows: N (35–59), P (6–13), K (91–146), Ca (1.9–3.5), Mg (3.8–6.9), and B (0.09–0.24). Based on regional recommendations, levels of Ca and B were deficient; levels of P, K, and Mg were low; and level of N was adequate to excessive (British Columbia Ministry of Agriculture and Lands, 2007; W. Wolk, personal communication).

Although unrelated to treatment, significant amounts of bitter pit were observed when trees began fruiting in 2002. This is likely a function of low fruit Ca levels (Himmelrick and McDuffie, 1983), the high predisposition of ‘Honeycrisp’ to Ca-related

Table 10. Leaf potassium in apples as affected by groundcover management systems, 1998–2005.

Orchard floor vegetation management ^y	Leaf potassium (g·kg ⁻¹) ^z				
	2001	2002	2003	2004	2005
Expt. 1					
Glyphosate check	21.6	16.8	13.1	—	—
Spray-on-mulch (SOM)	23.4	17.7	13.7	—	—
SOM over compost	23.6	18.2	13.2	—	—
<i>P</i> value	0.311	0.753	0.697	—	—
Expt. 2					
Glyphosate check	17.5	14.5 ab ^x	11.2 b	—	—
Spray-on-mulch (SOM)	19.0	15.0 a	11.3 b	—	—
SOM + 2.5% tackifier	18.7	15.1 a	13.2 a	—	—
SOM + dichlobenil	18.3	13.3 b	11.2 b	—	—
<i>P</i> value	0.4289	0.0374	0.0352	—	—
Expt. 3					
Glyphosate check	12.5	13.2	9.6	—	—
SOM	15.3	15.0	10.8	—	—
<i>P</i> value	0.1188	0.0574	0.1381	—	—
Expt. 4					
Glyphosate check	—	16.1 abc	16.7 a	10.9	10.4
SOM	—	17.9 ab	16.1 a	10.3	10.2
SOM over compost	—	15.7 bcd	16.5 a	11.5	10.9
SOM over fabric landscape cloth	—	17.6 ab	16.8 a	10.2	10.3
SOM over polyethylene plastic (poly)	—	17.3 abc	16.7 a	9.9	10.7
SOM over poly over compost	—	18.4 a	17.1 a	11.1	10.6
SOM over plastic over compost	—	14.9 cd	16.2 a	11.4	10.6
<i>P</i> value	NA	0.002	0.028	0.269	0.902

^z1 g·kg⁻¹ = 1000 ppm.

^yTreatments consisted of a glyphosate check [1.08 kg·ha⁻¹ (0.964 lb/acre) glyphosate] applied after each weed evaluation, SOM at a rate of 3 kg·m⁻² (0.61 lb/ft²), municipal composted biosolids and wood waste (Ogogrow; City of Kelowa, BC, Canada) applied at 6 kg·m⁻² (1.23 lb/ft²) dry weight basis, a 2.5% (v/v) guar gum-based tackifier (DS-Tack-FX; Quality Seeds, Langley, BC, Canada) used to help improve SOM adhesion and long-term surface stability, the residual herbicide dichlobenil at 5 kg·ha⁻¹ (4.46 lb/acre) for longer-term weed control, 1.2-m-wide (3.94 ft) stripe of black landscape fabric (Pro-Weed-X®; Dalen Products, Knoxville, TN) on the side of each tree, 1.2-m-wide stripe of 0.6-mil (0.015 mm) spunbound polypropylene rowcover material (Reemay® cloth, style 206; Fiberweb, Old Hickory, TN) on the side of each tree, and 1.2-m-wide stripe of 4-mil (0.102 mm) black polyethylene.

^xValues with the same letter within a given column are not significantly different according to Duncan’s multiple range test at *P* = 0.05.

NA = not applicable.

fruit disorders (Cline and Gardiner, 2005), large fruit size, and greater disposition in early bearing years.

SPRAY-ON-MULCH CONTAMINANTS.

The supplier of the waste paper product chosen for this study did not use colored paper in their recycling stream, which can be a significant source of heavy metals. The composition of Fe, Mn, Zn, and Cu, all essential plant nutrients, were relatively small in the SOM product. Copper at 176 mg·kg⁻¹ was the element of most consequence that would limit loading rates when used commercially. Based on biosolids guidelines for agriculture use in Canada (Ontario Ministry of the Environment and Ontario Ministry of Agriculture, Food and Rural Affairs, 1996), 109 Mg·ha⁻¹ (DW) of paper residue (SOM) would be permitted every 5 years based on the maximum permissible application rates. This is above the 60 Mg·ha⁻¹ (DW) used in this study and would allow for repeat annual application if necessary.

Conclusions

Tree fruit producers are interested in nonchemical methods of weed control that have similar efficacy as other forms of chemical weed control or offer alternative products suitable for organic production systems. The experiments reported in this study investigated the performance of a new technology that provided mechanical application of waste newsprint product to new or established orchards. The newsprint residual used in these studies required the addition of a source of long fiber such as chopped cereal or flax straw, to provide a durable barrier upon drying. The addition of a tackifier agent appeared unnecessary; however, addition of the residual herbicide dichlobenil to the SOM provided season-long weed control. Tangible benefits of the SOM included moderation of soil temperature, conservation of soil moisture, control of weed growth, and increased growth of newly planted apple trees on dwarfing rootstocks in most plantings, consistent with reports on other organic mulches (Beeck et al., 2006; Hartley et al., 1996; Hartley and Rahman, 1997; Hogue and Neilsen, 1987). Primary factors in the commercial adoption of this technology will be the availability of cost-effective sources of mulch product and effective delivery systems able to provide long-term

weed control before the requirement for reapplication. Costs and availability have been investigated in Pacific northwestern North America (Granatstein et al., 2002; Kuchta and Hogue, 2002) but will vary locally. Source material compliance with organic certification programs such as Organic Materials Review Institute (2010) or the National Organic Program (U.S. Department of Agriculture, 2010) in the United States, or the Canadian Organic Standard (Government of Canada, 2009) will further increase utilization among producers interested in organic production systems.

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