FINAL REPORT

Title: Alternative Weed Control Options for High Density Apple Orchards

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SIGNIFICANT FINDINGS

- Mulches increase growth of newly planted apple on dwarfing rootstocks, and can increase vigour of established trees.
- Increased tree vigour is sustained for at least 8 years after planting by an organic mulch, e.g. shredded paper.
- Increased tree vigour generally results in higher yields.
- Geotextile mulch does not sustain increased vigour beyond early years after planting.
- Surface applied organic amendments do not increase tree vigour or yield in the short term.
- Organic amendments improve chemical, physical and biological soil properties indicating potential long term growth and yield benefits.
- Mulches significantly reduce moisture loss from soil surfaces during summer months.
- Mulches affect soil moisture distribution favourably, encouraging improved root growth and distribution.
- Spray-on mulch provides good weed control when used over soil surface applied organic amendment or when combined with the herbicide CASORON.
- Spray-on mulch provides temperature moderating and moisture conserving effects comparable to other organic mulches.

OBJECTIVES: SUMMARY OF 3 YEARS

1. **Summerland Research Centre Trials**
   a) Maintain and collect weed control, crop vigour, yield and plant nutritional data on mulched and cover crop trials established in 1994, 1997 and 1998.
   b) Measure the effect of mulches on the chemical, physical and biological properties of soils.
   c) Establish a new planting to study spatial distribution of moisture in mulched and non-mulched plots.
   d) Conduct a lysimeter trial to measure effect of mulches on moisture loss from the soil surface.

2. **Commercial Orchard Trials**
   a) Evaluate the interaction of mulches, nitrogen and irrigation levels on growth and yield of Braeburn/M.9 in Allan Bros. Orchard, Naches.
   b) Evaluate the effect of mulches and cover crops on weed control, tree growth, yield, fruit quality in Red Delicious/M.26 plots in Wenatchee Valley College orchard.

3. **Spray-on mulch development trials**
   a) Conduct preliminary evaluations of mulch mixes and combinations in regular orchard plots with new and established trees.
   b) Develop a field sprayer, a mulch packaging system and slurry mix suitable for orchard applications.
   c) Apply spray-on mulch in a number of grower orchards using different mixes and evaluate for weed control, soil moisture and soil temperature effects.
   d) Prepare a preliminary cost comparison of spray-on mulch with other methods of orchard weed control.

METHODS

All trials were conducted in recently planted high density apple orchards in Summerland and Oliver, BC, and Tonasket, Wenatchee and Naches, Washington. Three orchards at the Summerland Research Centre were planted specifically for research on alternative methods of weed control, and a newly planted orchard in Naches had mulch, organic amendment, nutrition and irrigation treatments imposed in a designated research area very shortly after planting. Two trials at Summerland and one at Oliver, BC, Tonasket and Wenatchee, WA were established in existing orchards. All trial orchards had standard management for all practices except those studied in the experiment.

In 2001, six spray-on mulch trials using a field applicator were established, one at the Summerland Research Centre and five in grower orchards in Oroville, WA, Oliver, Summerland, Peachland and Kelowna, BC. Spray-on mulch was prepared as a slurry of a dried, short fibre by-product of the newsprint recycling industry with added chopped cereal or flax straws and, in some cases, a tackifier (glue), and/or a herbicide.

Treatments in the Spartan/M.9 trial, reported on mainly herein, were: (1) Check; 3-4 applications of glyphosate/yr, (2) similar glyphosate plus 45 T/ha pasteurised sewage sludge from the Greater Vancouver Regional District (GVRD) applied in 1994 and 1997, (3) shredded paper mulch applied at 25 kg/plot alone or, (4) over 45 T/ha GVRD or, (5) over Kelowna composted biosolids, (6) alfalfa hay mulch at 30 kg/plot, and (7) black geotextile mulch. Some mulch was reapplied each spring after controlling, with glyphosate, the few emerging weeds. Irrigation was through a drip system and approx. 40 g N was applied as 34.5-0-0 with the irrigation each year.

Composite leaf samples were collected in mid-July and analyses were carried out on 250 mg subsamples of oven-dried material (Technicon Autoanalyser). Soil samples were analyzed by Griffin Laboratories, Kelowna, BC. Soil carbon and nitrogen were analyzed in a LECO CNS Analyser. Soil moisture retention capacity was determined from 5 cm (diameter) x 2 cm samples using pressure plate equipment (McKeague, 1978). Bulk density was carried out by the method described by Culley (1993) and wet aggregate stability by Angers and Mehuys (1993). Infiltration rate was a modification of the method described by Walter and Skogerboe (1984).

RESULTS AND DISCUSSION

1. Summerland Research Centre Trials

a) Long term trials

Spartan/M.9

The vigour of trees under mulch has been consistently better than in the herbicided check plots, either with or without surface applied organic amendment. The difference has not always been as clear for yield. Both growth and yield of trees under geotextile mulch, and to a lesser extent that of trees in alfalfa hay mulch, has gradually decreased relative to that of trees under shredded paper mulch (Table 1).

Table 1. Tree growth and yield of Spartan/M.9 as affected by soil management treatments, 2001.

Treatment	TCSA (cm^2)		Yield (kg/tree)	
	1997	2001	1997	2001
Check	4.6 c[z]	11.5 d	3.2 c	14.7 b
GVRD[x]	4.5 c	11.6 d	4.5 bc	14.7 b
Paper mulch (PM)	7.4 a	**17.4 a**	6.5 a	**20.4 a**
Alfalfa mulch	6.1 ab	13.4 cd	3.7 bc	16.1 b
Kel.[y] + PM	6.4 ab	**15.1 bc**	5.3 ab	**19.6 a**
Geotextile mulch	5.8 bc	12.4 d	5.2 ab	16.0 b
GVRD + PM	7.3 ab	**16.2 ab**	5.4 ab	**19.6 a**

[x]GVRD: Minimally composted sludge from Greater Vancouver Regional District, BC.

[y]Kel.: Composted biosolids from City of Kelowna, BC.

[z]Means within a column followed by the same letter are not significantly different at the 5% level according to Duncan's multiple range test.

In the last four seasons, the cumulative yield of check trees was 33.8 kg/tree compared to 48.6 kg/tree for trees in Kelowna compost and paper mulch, an increase of 30.4%. **Over that period in an orchard at 1.25 x 3.5m spacing the mulched trees would have produced 3382 kg more fruit per hectare than trees in regular herbicide management.**

Golden Delicious/M.9

The results in this trial have been very similar to those in the Spartan/M.9 trial. Trees in mulched plots have been larger than those in non-mulched plots from the beginning of the trial in 1997, and generally their yields have been higher (Table 2).

Table 2. Effect of organic amendments and shredded paper mulch on growth and yield of Golden Delicious/M.9 planted in 1997, and some treatment effects on soil microbial populations and soil NO_3^- levels.

Treatment	TCSA (mm^2)	Yield (kg/tree)	Soil microbial biomass[z]	Soil NO_3^- (ppm)
Check	669 b	8.6 c	0.85 b	9.0 b
Envirowaste[y]	672 b	8.8 c	1.07 ab	**39.5 a**
Enviro/Zn, Cu, B	669 b	9.2 bc	---	---
GVRD	709 b	8.7 c	---	---
Enviro + PM	**1028 a**	11.0 ab	**1.45 a**	**40.4 a**
Enviro/Zn, Cu, B + PM	**989 a**	**11.5 a**	---	---
GVRD + PM	**1021 a**	**11.5 a**	---	---
PM	**931 a**	10.6 abc	1.02 ab	2.6 b

[z]Soil microbial biomass was measured by a method developed by T. Forge, using the UV absorbancy of a soil extract and
based on work by Turner et al. 2001.
[y]Envirowste: Composted yard waste from consolidated Envirowaste Industries, Aldergrove, BC.

Soil moisture measurements using time domain reflectometry (TDR) method were made in an attempt to relate the vigour and yield increase of mulches to factors other than the the excellent weed control provided by mulching. These were unsuccessful partly due to the very rocky nature of the soil. Organic amendments increased soil NO_3^- levels, but not mulching. However, soil microbial biomass measurements indicated that mulching was favourable when combined with an organic amendment.

Gala/M.9

This trial was established to test whether an easily applied mulch would be as effective in promoting growth of apple trees on dwarfing rootstocks in a coarse soil as shredded paper mulch. The second objective was to evaluate cover cropping as a possible alternative to mulches. Trials at WVC established in 1998 had a similar objective.

Spray-on mulch produced a similar plant growth response as shredded paper mulch. Growth increase was not as pronounced as in previous trials but a significant effect was obtained, on the other hand, results so far with cover crops in this trial, fall rye, hairy vetch, oriental mustard and white clover have indicated that these offer no real benefit over the simpler and cheaper grassed alley-herbicide strip management of check plots.

1.b) Soil physical, chemical and biological characteristics

Soil Physical Characteristics

Bulk density measurements showed that all treatments except the geotextile mulch affected the soil structure favourably, but only the soil under Kelowna compost plus paper mulch soil was significantly improved (Table 3). Infiltration data showed much clearer effect of treatments, with all treatments except geotextile and paper mulch alone improving infiltration rates. Wet aggregate stability was low for all treatments, as could be anticipated in a coarse soil, but the Kelowna compost plus paper mulch caused a significant improvement.

Table 3. Effects of tree row management on some physical characteristics of the surface soil (0-15 cm) after six years.

Treatment	Bulk density (g/mL)	Infiltration rate (L/hr)	Wet aggreg. stability (%)
Check	1.44 a	**5.5 cd**	3.8 b
GVRD	1.24 ab	14.6 ab	6.7 ab
Paper mulch (PM)	1.33 a	10.0 bc	5.8 ab
GVRD + PM	1.26 ab	**20.6 a**	7.3 ab
Kel. + PM	**1.08 b**	16.0 ab	**8.4 a**
Alfalfa mulch	1.26 ab	15.5 ab	4.5 b
Geotextile	1.41 a	3.4 d	4.4 b

Soil Chemical Characteristics

The geotextile and paper mulch treatments did not increase soil carbon and N, while all treatments with organic amendments and the alfalfa mulch did (Table 4). Cation exchange capacity was increased significantly only by the Kelowna compost plus paper mulch, while it was significantly reduced under the geotextile mulch. All treatments except geotextile mulch increased EC but alfalfa hay mulch more than doubled the readings, an indication of its contribution of N compounds and K to the soil. The only treatments that significantly affected soil pH were the GVRD amendment,which reduced it slightly, and paper mulch which increased it slightly.

Table 4. Effect of tree row management on some chemical characteristics of the surface soil (0-15 cm) after six years.

Treatment	C (%)	N (%)	CEC[z] (meq/100g)	EC[z] (mS/cm)	pH[y]
Check	1.0 d	0.10 cd	17.2 bc	0.15 cd	6.8 bc
GVRD	**1.9 a**	**0.18 a**	21.5 ab	0.24 b	6.1 d
Paper mulch (PM)	1.3 cd	0.12 bc	18.5 bc	0.19 b	7.5 a
GVRD + PM	**1.7 abc**	0.15 ab	20.8 ab	0.22 b	7.0 b
Kel. + PM	**1.7 ab**	0.14 b	**23.3 a**	0.21 bc	7.0 b
Alfalfa mulch	1.5 bc	0.14 b	19.0 ab	**0.34 a**	6.6 c
Geotextile	0.9 d	0.09 d	15.2 d	0.11 d	6.8 b

[z]CEC = cation exchange capacity; EC = electrical conductivity.

[y]pH readings in water.

1.c) Lysimeter trial

Mulching and Water Use

Lysimeter compartments with and without apple trees (Gala/O.9) growing in them had a thin layer of shredded paper covered with spray-on-mulch applied to the soil. The total amount of water used to maintain soil moisture was recorded for the period from mid-June to mid-August, 2000 and from May to Sept., 2001. In 2000, mulched compartments with no trees in them used an average of 47 L of water over that period while the non-mulched plots required 224 L of water to maintain the same soil moisture (Fig. 1a). This represents approximately 1.15 L of water lost per day per m^2 for non-mulched soil. For the average high density orchard with a 3.5 m distance between rows and a 1.2 m herbicided row strip, this would represent about 4000 L of water/day/ha of orchard conserved by mulching. The pattern for water loss from the soil surface in 2001 was essentially the same as in 2000 (Fig. 1b).

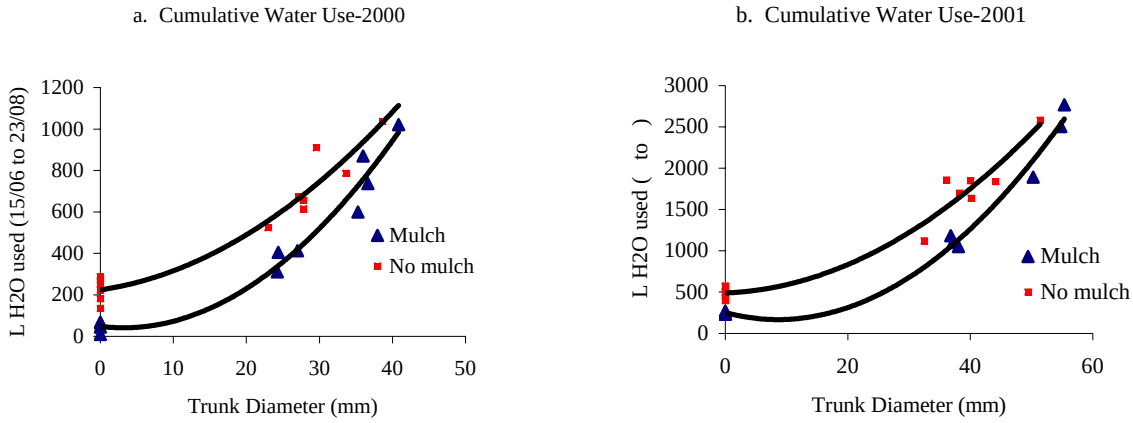

Figure 1. The effect of mulch on water consumption from June 15 to Aug. 23, 2000 and May to Sept., 2001 by Gala/O.3 apple trees growing in lysimeter compartments with a 2.25m^2 surface area.

1.d) Spatial distribution of moisture

A planting of Braeburn/M.26 was successfully established during the 2001 growing season. Measurements of soil moisture levels (Enviroscan) and water and nutrient downward movement (PCAP's) were made in mulched and non-mulched plots irrigated at different levels. Preliminary data will be reported by D. Neilsen.

2. Commercial orchard trials

a) Braeburn/M.9, Allan Bros. Orchards

Trees in this trial, established in 2000, showed increased growth in response to mulching in their first year. Irrigation, N levels and an organic amendment did not influence growth in year 2000. In 2001, as in the previous year, only mulching increased growth, while the other factors did not. None of the treatments increased yield.

This early crop response pattern appears to be very similar to that observed in other trials reported on. In establishment years, mulching improves growth, and differences in vigour generally persist eventually resulting in greater yields.

2.b) Wenatchee Valley College

The initial mulch trial was established in May 1999 on Red Delicious/M26 (planted 1995). Treatments included: Control (no mulch, ROUNDUP for weed control); wood chip; shredded paper;

and chopped alfalfa hay. Cover crops were established in late August 1999: dwarf white clover, oriental mustard, and winter rye. The clover is still growing, while the mustard and rye were only used for one season. One set of clover plots has been mowed 1-2 times per season, while the other set was suppressed with Roundup in 2000 and with flaming in 2001.

Table 5. Effect of mulches and cover crops on growth, yield and leaf N in Red Delicious/M.26 established orchard.

Treatment	TCSA	Yield (lb/tree)		Leaf N, 2000
	(% incr. 99-01)	2000	2001	(%)
Control	46.5 c	34 b	31 a	2.0 d
Wood chip mulch	**58.4 b**	33 b	32 a	1.9 de
Shredded paper mulch	50.0 bc	38 b	32 a	2.0 de
Chopped alfalfa mulch	**75.7 a**	**61 a**	30 a	**2.5 a**
Fall rye cover crop (cc)	41.8 c	41 b	36 a	1.8 e
Mustard cc	47.7 c	37 b	35 a	2.1 cd
White clover cc (mowed)	51.0 bc	41 b	45 a	**2.2 bc**
White clover cc (herbicided)	**59.7 b**	42 b	48 a	**2.3 b**

Growth and Yield

After three growing seasons, two mulch and one cover crop treatment increased growth of trees established before the trial was initiated, an indication of a strong treatment effect (Table 5). There were no differences in fruit yield in 1999 and 2001, but in 2000 yield was highest for alfalfa. There was small increase in fruit weight due to alfalfa in 1999 and 2000. Alfalfa provided a large input of N in the year of application, confirmed by the higher leaf N and measured leaf greenness.

Weed Control

Wood chips (4 in. layer) provided good weed control for the first three seasons. Shredded paper also gave good weed control but needed to be added each year. A poor stand of mustard cover crop encouraged weed growth in early season while chopped alfalfa encouraged weed growth later in the season. Wheeler fall rye inhibited weed growth before and after being cut and spread on the plots. Healthy stands of white clover effectively outcompeted weeds.

N mineralization in alfalfa mulch plots and white clover cover crops

ABS 3 inch tubes were inserted in the soil to a depth of 8 inches to exclude tree roots. The soil within the tubes was sampled at different dates and N measured. Some tubes were covered to prevent irrigation from leaching N. The soil within the covered tubes was kept moist by watering regularly.

Alfalfa led to elevated soil N (50 ppm) compared to the control (4ppm) in the first year, but N levels declined in the second and third year. Intensive monitoring of the clover plots was carried out to determine whether the clover is adding N to the system for trees to benefit from. When tree roots were excluded, a measurable release of N from the clover was detected. Trees in clover plots also had the highest leaf greenness and appeared most vigorous in 2001.

3. Spray-on mulch development trials

a) Preliminary evaluation of mulch mixes

The three main components in the spray-on mulch slurry were tested in a wide range of concentrations and combinations in the laboratory before being evaluated in field plots. Long fibre materials evaluated included cereal and flax straw, grass and alfalfa hay, shredded paper. Several glues, or takifiers, were used and a range of slurry thicknesses were tested.

b) Applicator

In the fall of 2000, a tractor drawn 500 gallon field mulch applicator with PTO-run high speed mixing capabilities was constructed. The 2.5 inch outlet pump, with a recirculating mode, can be regulated to deliver a range of slurry volumes to a splash plate manifold.

c) Orchard trials

In the spring of 2001, five large-plot field trials for tractor drawn application were established, five in grower orchards and one at the Research Centre.

Research Centre trial

A trial was established in an orchard replant site with very high weed pressure to evaluate the efficacy of herbicide pre-application to the soil or mixed into the spray-on mulch slurry. Plots were 20 x 1m, replicated 4 times.

Table 6. Effect of spray-on mulch treatments on control of annual and perennial weeds in high weed pressure site, AAFC Research Centre.

Treatment[z]	Weeds/m^{2} [y]	% Weed cover
Check	226	96
Spray-on mulch (SOM)	32	41
TREFLAN EC light incorp. +SOM	20	15
CASORON 50W surface appl. + SOM	3	1
SOM w/CASORON 50W	0	0

[z]Treatments applied on July 19, 2001; TREFLAN at 1 kg a.i./ha, CASORON surface applied and incorporated into spray-on mulch applied at 6 kg a.i./ha.
[y]Weed counts and weed cover evaluation made on Sept 5.

The main perennial weed in plots was creeping yellow cress (Rorippa sylvestris) which was the main weed not controlled by the spray-on mulch. The spray-on mulch-CASORON mix continued to provide complete weed control into late fall.

Summerland Orchard site

Table 7. Effect of spray-on mulch on weed control, soil temperature and soil moisture in 3 yr. old Ambrosia/M.9 trickle irrigated orchard, Summerland, 2001

Treatment	Weeds/m^{2} [y]			Soil temp. °C, 5 cm		Soil moisture[x]
	June 25	Aug. 3	Oct. 25	Low	High	(%, 0-15 cm)
Check	430	7.3	2.2	20.6	**39.9**	16.4
Spray-on mulch[z]	428	0.8	0.8	21.1	26.5	**19.6**

[x] Mean of 5 replicate samples taken at 5 dates from July 26 to Sept. 5
[y] ROUNDUP applied to all plots June 25 and Aug. 3 after weed counts
[z] Spray-on mulch was applied on May 29, 2001. ROUNDUP applied May 24

The first flush of weeds, mostly annuals, were very small on the first evaluation date. After applying ROUNDUP to all plots, spray-on mulch plots remained essentially clean for the rest of the season. Soil temperatures during the warm period were greatly moderated, even at 5 cm depth, by the spray-on mulch. The temperature patterns under the spray-on mulch appears to be very similar to those under other organic mulches (straw, hay, shredded paper). This also appears to be the case for soil moisture. Spray-on mulch appears to be an excellent barrier to surface evaporation, as demonstrated in the lysimeter trial (Figure 1).

Peachland Orchard site

A trial of spray-on mulch with and without a surface applied compost was established in a newly planted high density (0.6 x 3.5m) Gala/M.9 orchard in Peachland, BC.

Table 8. Effect of spray-on mulch and a surface applied compost on weed control and growth of apples planted in 2001, Peachland, BC.

Treatment	Weeds/m^{2} [y]		% Weed cover		Tree growth	
	June 7	Oct. 25	June 7	Oct. 25	TCSA (mm^2)	Shoot gr. (cm)
Check	680	4.3	38	12.0	194 a	156 a
Spray-on mulch (SOM)[z]	190	1.8	8	4.4	222 b	216 b
Compost + SOM	18	0.4	3	1.6	245 b	259 b
Comp/zeolite + SOM	10	0.6	2	1.0	232 b	245 b

[z]Spray-on mulch applied May 9
[y]ROUNDUP applied to all plots after each weed evaluation date, June 7, July 9, Aug.15, Oct. 25

A surface applied compost prior to spray-on mulch application greatly improved weed control. After the first overall application of ROUNDUP (June 7) to control all weeds, weed control was essentially complete for the rest of the season where compost had been used. All spray-on mulch treatments significantly increased tree growth in this newly planted orchard. This crop response is similar to that obtained in other mulch trials in newly planted apple trees.

d) Estimated costs of alternative methods of orchard weed control

Estimating the materials and application costs of mulches with any degree of accuracy was very difficult. The numbers provided (Table 9) are rough estimates to be used mainly for the purpose of comparisons. Application rates were based, for ROUNDUP, geotextile mulch and spray-on mulch, on plots at the Summerland Research Centre, alfalfa hay and wood chips on trials at Wenatchee Valley College orchard, and flaming on a trial in Nova Scotia. Material costs were quite variable, from free for wood chips to expensive, because cost of material itself (geotextile), transportation (spray-on, alfalfa hay, wood chips). Estimating costs of application was the most difficult because of the need, for instance, to extrapolate time and labour cost and the (inefficient) use of application machinery for small test areas. Rigid comparisons of spray-on mulch to lower cost methods of weed control at this early stage of development may not be fair since, with more research, there will be ways of improving its efficacy and decreasing its costs.

Table 9. Annual costs of six orchard weed control methods based on material and application costs in plot trials.

Method of weed control	Applic. rate (per acre)	Frequency of applic.	Cost/acre/yr ($US)[z]		
			Material	Applic.	Total
ROUNDUP	0.5 L	4/yr.	24.00	80.00	104.00
Geotextile mulch	3750' x 5'	1/6 yr.	286.45	50.67	337.12
Alfalfa hay mulch	8.5 tons	1/2 yr.	318.75	90.00	408.75
Wood chip mulch	100 cu. yd.	1/3 yr.	200.00	150.00	350.00
Spray-on mulch w/CASORON	3.4 tons	1/1.5 yr.	234.00	211.00	445.00
Flaming	48 lbs	3/yr.	36.00	90.00	120.00

[z]ROUNDUP:	Material: $12/L x 0.5 = $6 x 4 applic. = **$24** Applic.: applic. costs = $40/hr @ 2 A/hr = $20/A x 4 = **$80**
Geotextile:	Material: 600' x 5' roll = $275 x 6.25 rolls = $1718.75/6 = **$286.45** Applic.: tractor and operator @ $30 x 8 = $240 + helper @ $8/hr x 8 = $64 = $304/6 yr. = **$50.67**
Alfalfa hay:	Materials: 8.5 tons @ $65 + $10/ton transp. = $75/ton x 8.5 = $637.50 $637.50/2 = **$318.75** Applic.: tractor,shredder/spreader and operator @ $60/hr x 3 hr = $180.00/2 = **$90**
Wood chips:	Materials: free; transportation $150/25 yd. load x 4 = $600/3 yr **= $200** Applic.: total applic. time = 30 min; travel and loading 12 loads @ 20 min. each = 4 hr. 4.5 hr of combined loader and spreader time @ $40 + $60 = $450/3 = **$150**
Spray-on:	Materials: newsprint waste (drying, transp. packaging) @$48/ton + straw (baling, transp., shredding) @ $35/ton = $83/ton x 3.05 tons/A = $253 + 3.5lbs/A CASORON 85W @ $28/lb = $98 = $351 x 2/3 = **$234** Applic.: 19 tanks/A @ 3 tanks/hr = 6.33 hr. x $50/hr = $316.50 x 2/3 = **$211**
Flaming:	Materials: 3 x 48lbs = 144 lbs @ $0.25/lb = **$36** Applic.: applic. time = 2A/hr @ $60/hr = $30/A x 3 = **$90**

The figures in Table 9 do not take into account important factors, such as the various advantages and disadvantages of each method. For instance, the efficacy of flaming is very limited in the presence of some perennial weeds, requires care to apply safely, can injure trees, burns soil organic matter etc.. On the other hand mulches use waste organic materials, improve soil conditions, increase yields etc.. An accurate cost/benefit analysis would require more data, particularly from large scale grower operations.

Budget Summary - $72,000

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Item	1999	2000	2001
Salary + wages (incl. benefits): Research asst.	14,000	14,000	12,000
Student	---	---	2,000
Grants to cooperators: D. Granatstein	4,000	5,000	4,000
D. Faubion	---	2,000	2,000
Other			1,000[z]
Materials & supplies	2,500	2,500	2,500
Travel	1,500	1,500	1,500
Total	22,000	25,000	25,000

[z] A grant of $1,000.00 had been designated for an economic analysis of mulching in orchards. We were unable to carry this out and the designated amount was used as salary for research assistant.

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