Evaluation of New Cultivation Tools to Reduce Labor Requirements in Matted-row Strawberry Culture

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ADDITIONAL INDEX WORDS. *Fragaria × ananassa*, flex-tine harrow, finger weeder, brush hoe, tillage, weed control, weed management

SUMMARY. Three new cultivation tools were compared with a traditional between-row cultivator, an herbicide control, and the conventional herbicide-plus-cultivator weed management program used in a first-year strawberry (*Fragaria × ananassa*) planting. The new implements were (1) a Rabe Werk flex-tine harrow, (2) a Buddingh finger weeder, and (3) a Bärtschi brush hoe. The traditional implement was a double-headed multivator. The flex-tine harrow performed poorly. Its use appeared to stimulate germination of weed seeds as end-of-season weed biomass was high, and yield the following year was low. It was also the most labor-intensive treatment to maintain. The finger weeder reduced in-row weed growth dramatically, and productivity of this treatment was high, but its use required additional between-row cultivation with another implement. The brush hoe, while classified as a between-row weeder, reduced in-row weed growth as well, and yields for brushed plots were also high. Cultivation with a multivator resulted in good weed control between rows and high yields, but hand-weeding requirements within the row were high. Weed growth and yields were unacceptable when the herbicide was used alone, but an early-season pre-emergent herbicide application, followed by a single late-season hand weeding and cultivation, resulted in a dramatic reduction in weeds at the end of the year and a notable increase in yield the following year. The conventional herbicide-plus-cultivation weed-management program, used in the establishment year by growers who plant in the perennial matted-row system, continues to be a good choice if labor is both plentiful and affordable; however, the finger weeder and brush hoe are viable alternatives for situations in which labor is scarce. Organic growers, and growers who plant in nontraditional annual systems, may benefit from their use as well.

Weed management continues to be a major challenge for strawberry growers who plant in the traditional matted-row production system where mother plants are set in spring and daughter plants fill in the rows over the first growing season (Hancock et al., 1997). Previous research has shown that weed control in the planting year, particularly early in the season, is important for the success of this system (Pritts and Kelly, 2001). Plastic mulch is used in annual systems to control weeds, but it prevents runner rooting in matted rows. Herbicides suppress weeds, but few are labeled for use in the establishment year. Manual labor needed for hand weeding and hoeing is typically scarce and expensive. Because these standard techniques of managing weeds are not ideal for matted-row strawberries, cultivation tools are of great interest.

Before the development of synthetic herbicides in the mid-1900s, growers relied on mechanical cultivation as their primary means for controlling weeds. Fifty years later, many producers, especially organic producers, continue to rely on this tactic. This dependence has intensified in recent years, as government regulations regarding the use of pesticides have become increasingly strict, and consumer expectations for reduced pesticide use have risen.

The cultivation implement most commonly used by strawberry growers today is a single- or multiple-head rotary tilling cultivator (Fig. 1A and B).

However, a number of problems have been associated with its use (Table 1). Most notably, weeds growing within the crop row are unaffected by cultivation with this implement, so supplemental in-row control strategies must be employed. In addition, tillage of between-row areas frequently moves weed seeds from below ground to the soil surface, where conditions are ideal for germination. Other problems associated with repeated use of this implement include deterioration of soil structure, increased soil erosion, and compaction of clayey soils.

Vegetable growers have had to contend with many of the same challenges that strawberry growers face and in recent years have begun to look more closely at a number of alternative weed-management tools. Some of these are simply refined versions of traditional equipment, while others are novel high-tech tools. Each has their advantages and disadvantages (Table 1), and all have been used with varying degrees of success (Table 2). Our objective was to examine their utility and efficacy in matted-row strawberries.

Description of nontraditional implements

The spring- or flex-tine harrow is typically used as a broadcast weeder (Fig. 2A and B). This unit uses large numbers of flexible wire tines, set closely in rows across the length of multiple “floating” bars, to scratch the soil surface and uproot tiny weed seedlings. Cultivation depth is controlled by a number of factors, including tine diameter and tension, three-point hitch height, and gauge wheel setting. On some models, individual tines can be raised and lowered, allowing the unit to be used as a between-row cultivator as the crop matures.

In studies that examined the effects of harrowing on weed growth and crop productivity, a number of

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
0.3048	ft	m	3.2808
0.0929	ft ²	m ²	10.7639
2.54	inch(es)	cm	0.3937
1.1209	lb/acre	kg·ha ⁻¹	0.8922
1.6093	mph	km·h ⁻¹	0.6214
28.3495	oz	g	0.0353
2.2417	ton/acre	t·ha ⁻¹	0.4461

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Fig. 1. (A) Double-headed rotary tilling cultivator (side rear view) and (B) close-up of the rotating blades of one of the heads. Note that the protective shielding has been removed to show the rotating blades underneath.

researchers reported inferior weed control (Table 2). However, in most cases, weed biomass of the harrowed plots was equivalent to that of the broadcast herbicide treatment, and no yield losses occurred. A number of factors has been implicated in the relative successes or failures witnessed in these studies, including crop growth characteristics and maturity; weed species, density, and growth stage; soil characteristics; amount and timing of precipitation; ambient temperature; cultivation timing, intensity, and frequency; and timing of herbicide application and cultural practices (Ascand and Bellinder, 1996; Bellinder et al., 2000; Colquhoun et al., 1999).

Near- and in-row cultivators include spider, finger, torsion, and spring hoe weeders. Spider weeders use pairs of ground-driven, rotating, metal-toothed wheels that straddle the crop row and push soil into the row, burying weeds, or pull soil out of the row, dislodging them (Fig. 3A). Finger weeders operate on much the same principle; however, rubber “fingers” replace the metal teeth (Fig. 3B). The distance between the wheels, as well as the angle of the wheels, can be adjusted to accommodate a variety of crops and growth stages. Torsion and spring hoe weeders differ in that they use pairs

Table 1. Advantages and disadvantages of selected cultivating tools used for strawberry weed management.

Implement	Weed control	Mode of action	Advantages	Disadvantages
Multivator	Between-row	Rotating blades slice weeds’ subsoil	Provides season-long control Effective on larger weeds Little crop damage Moderately fast	Does not control in-row weeds High impact on soil structure Promotes weed seed germination
Flex-tine harrow	Broadcast	Wire tines scratch soil surface, uprooting tiny weed seedlings	Adaptable Loosens crusted soils Low impact on soil structure Fast	Time-consuming to set up Soil must be dry Relatively ineffective on emerged weeds Promotes weed seed germination
Finger weeder	In-row	Rubber “fingers” mounted on steel cone wheels pull weeds out of crop row	Ground-driven, so can be used on smaller tractors	Must be supplemented with between-row cultivation Field must be level Soil must be loose Ineffective on larger weeds Relatively slow Promotes weed seed germination
Brush hoe	Between-row	Looks and works like a street sweeper Brushes rip, shred, and smother weeds	Provides early to midseason control Useful in moist soil Effective on larger weeds Low impact on soil structure Does not bring weed seeds to soil surface	Does not control in-row weeds Requires a relatively large tractor Requires two operators Rows must be straight and precisely spaced Slow Expensive

Table 2. Cultivation implements and their effect on weed control and yield, compared with herbicide treatment, of various vegetable crops.

Implement	Crop	Weed control	Yield	Reference
Einböck flex-tine harrow (Einböck, Dorf, Austria)	Onion (<i>A. cepa</i>)	In-row equivalent	Reduced	Ascard and Bellinder (1996)
		Hand weeding time reduced 40%		
	Sugar beet (<i>Beta vulgaris</i>)	In-row inferior	Reduced	Ascard and Bellinder (1996)
	Cabbage (<i>B. oleracea</i> var. <i>capitata</i>)	Overall control equivalent or inferior	Equivalent or greater	Bellinder et al. (1996)
	Potato (<i>Solanum tuberosum</i>)	In- and between-row inferior	Equivalent	Bellinder et al. (2000)
	Broccoli (<i>B. oleracea</i> var. <i>italica</i>)	In- and between-row equivalent	Equivalent	Colquhoun et al. (1999)
	Snap bean (<i>P. vulgaris</i>)	In-row inferior	Reduced	Colquhoun et al. (1999)
Rabe Werk flex-tine harrow (Rabe Agrarsysteme GmbH & Co., Bad Essen, Germany)		Between-row equivalent or inferior		
	Sweet corn ^z (<i>Z. mays</i>)	Between-row equivalent or inferior	Equivalent	Colquhoun et al. (1999)
	Cabbage	Overall control inferior	Equivalent	Bellinder et al. (1996)
	Potato	In- and between-row inferior	Equivalent	Bellinder et al. (2000)
	Broccoli	In- and between-row equivalent	Equivalent	Colquhoun et al. (1999)
	Snap bean	In- and between-row inferior	Reduced	Colquhoun et al. (1999)
	Sweet corn ^z	Between-row equivalent or inferior	Equivalent	Colquhoun et al. (1999)
Buddingh finger weeder (Buddingh Weeder Co., Dutton, Mich.)	Onion	In-row equivalent	Reduced	Ascard and Bellinder (1996)
Bezzerrides torsion weeder (Bezzerrides Brothers, Inc., Orosi, Calif.)		Hand weeding time reduced 60%		
	Onion	In-row equivalent	Equivalent	Ascard and Bellinder (1996)
Bärtschi brush hoe (Bärtschi-FOBRO AG, Hüsliwil, Switzerland)	Carrot ^z (<i>D. carota</i>)	Hand weeding time reduced 45%		
		Between-row equivalent	Equivalent	Baumann and Slembrouck (1994)
	Broccoli	In-row equivalent	Equivalent	Colquhoun et al. (1999)
		Between-row equivalent or superior		
	Snap bean	In-row equivalent or inferior	Equivalent or reduced	Colquhoun et al. (1999)
		Between-row equivalent or superior		
	Sweet corn ^z	Between-row equivalent	Equivalent	Colquhoun et al. (1999)

^zIn-row weeds were controlled using a banded pre-emergent herbicide at planting.

of fixed, flexible, metal tines or plates to disturb the soil and displace weeds.

Few studies on the use of near- or in-row cultivators in vegetable crops exist. Ascard and Bellinder (1996) examined the feasibility of

managing in-row weeds in onion (*Allium cepa*) using a Buddingh finger weeder (Buddingh Weeder Co., Dutton, Mich.) and Bezzerrides torsion weeder (Bezzerrides Brothers, Orosi, Calif.) (Table 2). They found

that both implements were relatively effective at controlling in-row weed growth, and each reduced hand-weeding time significantly compared with the chemical control. More aggressive cultivation (6 km·h⁻¹, 2–4 cm

Fig. 2. Two flex-tine harrows: (A) Rabe Werk flex-tine cultivator (front view) (Rabe Agrarsysteme GmbH & Co., Bad Essen, Germany); (B) Einböck flex-tine cultivator (side frontal view showing a close-up of the tines) (Einböck, Dorf, Austria).

depth) resulted in greater weed suppression than less aggressive cultivation ($3 \text{ km} \cdot \text{h}^{-1}$, 0–4 cm depth), and while an early cultivation reduced crop stand, a second later cultivation resulted in little plant loss. Productivity of the torsion-weeder treatment equaled that of the chemical standard; however, dramatic yield losses were reported for the finger-weeder treatment. In general, the success of both weeders was determined largely by (1) the precision with which the plants were set at planting and (2) the driving skills of the operator.

Between-row cultivators are numerous and varied, and include “static” field cultivators equipped with shovels, sweeps, knives, or wings; “dynamic” ground-driven implements such as the rotary hoe and basket weeder; and “power-driven”

equipment such as the rotary tilling cultivator and brush weeder. Developed in Switzerland relatively recently, the brush weeder looks and works like a street sweeper (Fig. 4). Horizontal-axis brush weeders have multiple, large, wheel-shaped brushes that spin in the direction of travel, while vertical-axis models have numerous, smaller, revolving, circular brushes. Large weeds are eliminated by the tearing and shredding action of the brushes, while small weeds are smothered by the fine layer of dust that the machine generates. Gauge wheels are used to control cultivation depth. Although typically classified as a between-row cultivator, the brush hoe is also capable of controlling in-row weeds by the suffocating, ridging, and de-ridging capabilities of its brushes.

Studies comparing the use of brush hoe cultivators with conventional weed management regimes are scarce. Baumann and Slembrouck (1994) reported that between-row brushing provided weed control equal to that of the chemical standard in carrot (*Daucus carota*). In general, similar studies of transplanted broccoli (*Brassica oleracea* var. *italica*), snap bean (*Phaseolus vulgaris*), and sweet corn (*Zea mays*) reported similar results (Colquhoun et al., 1999). However, a few exceptions are worth noting. Cultivation resulted in significantly improved between-row weed control in broccoli, when weather conditions favored rapid weed seed germination immediately following transplanting, and weeds had already reached the cotyledon stage of development by the time the herbicide was applied. In studies of snap bean, efficacy varied with soil type. Greater between-row control was achieved with cultivation on a gravelly site; however, on a neighboring silt loam site, poorer in-row control in the brush-hoed plots resulted in significantly reduced yields.

Materials and methods

A study designed to evaluate the use of three new cultivation implements in a first year strawberry planting was initiated in 1998 on a Howard gravelly loam (loamy skeletal mixed mesic Glossoboric Hapludalf) soil at the H.C. Thompson Vegetable Research Farm in Freeville, N.Y.

The implements were (1) a Rabe Werk flex-tine harrow broadcast weeder (Rabe Agrarsysteme GmbH & Co., Bad Essen, Germany), (2) a Buddingh Model C in-row finger weeder (Buddingh Weeder Co.), and (3) a Bärtschi brush hoe between-row cultivator (Bärtschi-FOBRO AG, Hüsli, Switzerland). These were compared with (4) a Multivator Model FL (COMEB, Bologna, Italy) traditional between-row rotary tilling cultivator, (5) an herbicide control, and (6) the conventional herbicide-plus-cultivation weed management program typically used by growers in the planting year.

Shortly before planting, the site was plowed, disked, and cultivated. A second cultivation was performed on the day of planting. Experimental plots were 3 m wide and 12 m long. ‘Jewel’ strawberry plants were set on

Fig. 3. (A) Spider weeder (front view showing metal-toothed wheels) and (B) close-up the rubber "fingers" of a Buddingh finger weeder (front view) (Buddingh Weeder Co., Dutton, Mich.).

Fig. 4. Bärtschi horizontal-axis brush weeder (front view) (Bärtschi-FOBRO AG, Hüswil, Switzerland).

18 May. In-row spacing for all treatments was 0.5 m. Between-row spacing varied depending on implement: 4 ft in the flex-tine harrow, finger-weeder, multivator, and herbicide plots, and 30 inches for the brush hoe plots. Each plot contained two rows of plants.

Each new implement was used on an "as needed" basis to control weed growth, and timing of treatment varied depending on implement (Table 3). In the flex-tine harrow and finger-weeder plots, cultivations were performed when weeds were in the white-thread or cotyledon stage of development. In the finger-weeder treatment only, in-row weed control was supplemented with between-row control using a multivator. Tillage operations occurred less frequently for the brush hoe treatment since this device could work when weeds were large. Cultivations were performed after weeds had a minimum of four true leaves but before their average height exceeded 15 cm. Plants were allowed to runner freely, and runners were directed into the crop row at regular intervals throughout the season.

Each implement was used until it was determined that its use would interfere with plant or runner establishment. The last date of cultivation with the flex-tine harrow and finger weeder was 3 July, while the last use of the brush hoe was 13 July. Following this, weeds were left to grow unchecked until it became evident that their presence was inhibiting crop growth. All plots were then hand weeded in-row and multivated between rows, and each weed-free plot was split in half lengthwise. Lastly, one half of each plot was treated with the recommended rate of napropamide herbicide (2.5 lb/acre a.i.), while the other half was left untreated. Harrowed plots were weeded and cultivated on 13 July and treated with napropamide the following day; finger-weeder and brushed plots were cleared of weeds on 11 Aug. and treated with the herbicide on 19 Aug. All weed management tactics were then suspended in these plots for the duration of the field season.

The multivator was equipped with a 66-inch-wide frame and two 12 to 15-inch-wide heads, and was used to manage between-row weed growth. Because the multivator

Table 3. Timing of field operations in a first-year planting of 'Jewel' strawberries.

Treatment	Field operation	Date
Flex-tine harrow	Harrow	4 June
	Harrow	23 June
	Harrow	3 July
	Multivate	13 July
	Multivate	16 Oct.
Flex-tine harrow + herbicide	Harrow	4 June
	Harrow	23 June
	Harrow	3 July
	Multivate	13 July
	Apply herbicide	14 July
	Multivate	16 Oct.
Finger weeder	Finger weed	19 June
	Finger weed	3 July
	Multivate	13 July
	Multivate	11 Aug.
	Multivate	16 Oct.
Finger weeder + herbicide	Finger weed	19 June
	Finger weed	3 July
	Multivate	13 July
	Multivate	11 Aug.
	Apply herbicide	19 Aug.
	Multivate	16 Oct.
Brush hoe	Brush hoe	19 June
	Brush hoe	13 July
	Multivate	11 Aug.
	Multivate	16 Oct.
Brush hoe + herbicide	Brush hoe	19 June
	Brush hoe	13 July
	Multivate	11 Aug.
	Apply herbicide	19 Aug.
	Multivate	16 Oct.
	Multivate	13 July
Multivator	Multivate	11 Aug.
	Multivate	16 Oct.
	Apply herbicide	2 June
	Multivate	16 Oct.
Herbicide	Apply herbicide	2 June
	Multivate	11 Aug.
	Multivate	16 Oct.
Herbicide + multivator	Apply herbicide	2 June
	Multivate	11 Aug.
	Multivate	16 Oct.

provided no in-row weed control, hand weeding and hoeing were employed in-row. Control measures were initiated after weeds had multiple true leaves but before weeds reached a height of 15 cm or set seed, and these tactics were employed throughout the growing season.

The herbicide-only and the conventional herbicide-plus-cultivation treatments each received a single broadcast application of napropamide herbicide (2.5 lb/acre a.i.) shortly after planting on 2 June. The herbicide-only plots were then left undisturbed for the duration of the season, while the conventional plots were hand weeded and hoed in-row and culti-

vated between-row with a multivator on 11 Aug. when it became apparent that the herbicide had lost its efficacy.

Overall, a total of nine treatment combinations were tested. Treatments were replicated four times, and arranged in a randomized complete block design. Standard cultural practices were followed throughout the study (Pritts and Handley, 1998). Flower trusses were removed, and runners were set in-row at regular intervals in the planting year. Calcium nitrate fertilizer (30 lb/acre) was applied $\approx$ 4 weeks after planting and again 1 month later. Overhead irrigation was used during periods of insufficient rainfall.

All plots were hand weeded, hoed, and multivated at the end of the season on 16 Oct., and napropamide herbicide (4 lb/acre a.i.) was applied on 13 Nov. The planting was mulched on 10 Dec. 1998 and remained covered through 27 Mar. 1999. Plots were hand weeded as needed before fruit ripening to facilitate harvest operations. Harvest commenced on 11 June 1999, and continued through 6 July. The study was ended following harvest in 1999.

Data recorded for each management system in the planting year included the type of equipment used, the number of times and dates it was used, and the cumulative hours of hand weeding required to supplement the implement or herbicide. In addition, end-of-season weed biomass was quantified on 5 Oct. Both in- and between-row growth were assessed by placing a 0.5×1.0 m sampling frame lengthwise both over and between the crop rows in each plot. All aboveground weed growth within these areas was then removed, oven-dried, and weighed. Yield and fruit size data were collected the following year. Analysis of variance was used to test the significance of differences among treatment means (SuperANOVA, Abacus Concepts, Berkeley, Calif.).

Results

Vegetable crops had been grown for many years in the field used for the study. The weed pressure was moderate and relatively uniform, consisting mostly of annuals such as crabgrass (*Digitaria sanguinalis*), yellow foxtail (*Setaria glauca*), field pepperweed (*Lepidium campestre*), and redroot pigweed (*Amaranthus retroflexus*).

When cultivating implements were compared without herbicide use, the flex-tine harrow treatment was significantly more labor intensive than the finger-weeder and brush hoe treatments, and required more than twice as many hours to hand weed as the herbicide control (Table 4). Although harrowed plots were hand weeded half as often as multivated plots, they required a greater total investment of time over the course of the season because of the greater total weed biomass that had to be removed by hand. At the end of the season, harrowed plots and herbicide-alone plots had much more weed

Table 4. Effect of treatment on cumulative hand weeding time and end-of-season weed biomass (1998) and on yield and fruit size (1999).

Treatment	Equipment passes (no.)	Hand weeding (no.)	Hand weeding time (h·ha ⁻¹) ^z	Weed biomass (end of season) [dry wt (g/0.5 m ²)] ^y		Yield* (t·ha ⁻¹) ^w	Berry wt (g) ^v
				In-row	Between-row		
Flex-tine harrow	5	2	599	96.9	120.7	8.9	10.4
Flex-tine harrow + herbicide	6	2	360	44.1	55.0	12.3	10.8
Finger weeder	5	2	337	0.9	2.0	11.2	10.5
Finger weeder + herbicide	6	2	319	0.2	0.9	9.1	10.7
Brush hoe	4	2	332	1.3	2.8	11.3	10.9
Brush hoe + herbicide	5	2	309	0.5	0.5	12.0	10.9
Multivator	4	4	464	2.8	2.1	10.1	10.8
Herbicide	2	1	242	90.8	82.9	7.6	10.2
Conventional (herbicide + multivator)	3	2	419	2.3	2.4	10.7	10.3
LSD (0.05)	—	—	76	54.4	37.0	4.7	0.8

^z1 h·ha⁻¹ = 0.4047 h/acre.

^y1 g/0.5 m² = 0.0066 oz/ft².

^zRow spacing of 4 ft (1.2 m) assumed.

^w1.0 t·ha⁻¹ = 0.4461 ton/acre.

^v1 g = 0.0353 oz.

biomass than conventional, finger-weeder and brush hoe-treated plots, and lower yields the following year.

Weed growth between rows in the finger-weeder and brush hoe plots was minimal and was equal to that of the multivator and conventional plots but notably less than that of the harrowed plots. However, the finger-weeder plots required more time to treat than the brush hoe plots, because a multivator also had to be used to control between-row weeds.

A midseason application of napropamide reduced overall hand weeding time and end-of-season weed biomass dramatically in the flex-tine harrow treatment. Labor requirements for the flex-tine harrow/herbicide plots were 40% less than those of the harrowed plots alone, and both in- and between-row weed biomasses were reduced by more than 50% following herbicide application. In contrast, the finger-weeder and brush hoe treatments showed little benefit from the herbicide.

Four hand weeding were needed to maintain low weed levels in the multivator plots, making this treatment 92% more labor intensive than the herbicide control. However, multivator plots were virtually weed free by season's end, whereas the herbicide-only plots were quite weedy because no hand weeding was used in this treatment until the end of the season. A single midseason hand-weeding and cultivation performed after the napropamide had lost its efficacy (conventional treatment) reduced end-of-season weeds signifi-

cantly but nearly doubled the hand weeding requirement when compared with the herbicide-only treatment that was not weeded midseason.

Of the three new implements tested, the finger-weeder and brush hoe treated plots were nearly 30% more productive than the flex-tine harrowed plots. A midseason herbicide application resulted in a 39% increase in yield for the harrowed plots compared with no herbicide, but only a 5% increase in the brushed plots.

Use of the multivator alone resulted in only moderate yields. The treatment with the most weeds (the herbicide control) produced the least amount of fruit; however, when cultivation was used in conjunction with the herbicide (the conventional treatment), a marked increase in productivity occurred.

All of the new implements, used both alone and in combination with a pre-emergent herbicide, performed better than the herbicide control with regards to yield, and most performed better than the traditional multivator. Use of the finger weeder and the brush hoe resulted in yields equivalent to those of the conventional treatment (multivator plus herbicide) but with a smaller time investment and no herbicide. The brush hoe/herbicide and flex-tine harrow/herbicide treatments outperformed the conventional treatment (herbicide plus multivator) both in terms of yield and labor requirement. Fruit size was unaffected by weed management treatment.

We did not use these implements in the second year on established plantings as the finger weeder and flex-tine harrow would have damaged establishing daughter plants. However, the brush hoe and multivator would be suitable for use in established matted-row plantings.

Discussion

A single herbicide application after planting provided unacceptable season-long weed control. By the end of the year, weed biomass was high and this undoubtedly contributed to the low yield the following year. Using a multivator during the second half of the season after the herbicide has lost its effectiveness resulted in reasonably good weed control and yield the following year. This combination of herbicide and multivator use is typical of what a strawberry grower does to manage weeds. When the multivator was used without herbicides, yield the following year was similar to the conventional practice just described, although more labor was needed because the multivator was used multiple times and additional hand weeding was required.

Certain nontraditional cultivation tools also provided good weed control and high yields, but not all. For example, the flex-tine harrow alone failed to provide adequate weed control, especially late in the season when it could no longer be used because it would have disrupted runner rooting. In the early season, harrowing appeared to promote germination of weed seeds as its use was

followed by an abundance of newly emerging weeds, consistent with observations by others (Bellinder et al., 2000; Mohler et al., 1997). Several researchers reported reduced yields in harrowed vs. herbicide-treated plots, and attributed differences to crop injury, reduced plant stands, and weed-crop competition (Ascard and Bellinder, 1996; Colquhoun et al., 1999). When late season weeds in harrowed plots were suppressed with herbicide, however, yields were quite high.

In-row cultivation with the finger weeder resulted in excellent weed control and a 48% increase in yield compared with the herbicide control; however, it still required follow-up hand weeding plus cultivation with a multivator. Ascard and Bellinder (1996) also reported significantly reduced hand labor requirements but also a notable reduction in yield in finger-weeder-cultivated vs. herbicide-treated plots in onion.

The brush hoe was an extremely effective weed management tool, reducing both between- and in-row growth dramatically compared with the herbicide-only treatment. Although typically classified as a between-row weeder, the brush hoe also increased in-row control (Colquhoun et al., 1999). In addition, yields of brushed plots exceeded those of herbicide-only plots by 50%.

Our results are similar to studies on vegetable crops. For example, Ascard and Bellinder (1996) reported fewer early season in-row weeds and reduced weeding times when plots were cultivated using a Budding finger weeder vs. an Einböck spring-tine harrow (Einböck, Dorf, Austria). Likewise, Colquhoun et al. (1999) reported that the Bärtschi brush hoe was a more effective weed management tool than the Rabe Werk flex-tine harrow, and they documented higher yields in their brushed plots in broccoli, sweet corn, and snap bean. Differences in these studies were nonsignificant in most cases, but the trends were repeatable over time, across soil types, and in different crops.

Of the three new implements we tested, the finger weeder (with between-row multivator) and the brush hoe showed the most promise for use in strawberry. Compared with the herbicide control, we were able to reduce weed growth dramatically in the planting year, and subsequently increase yield, with only two cultivations and no herbicide use. In addition, use of the finger weeder and brush hoe alone resulted in reduced hand labor requirements compared with the multivator and conventional treatments.

When comparing one implement with the other, purchase price and operational costs also should be considered. For example, the finger weeder is relatively inexpensive, but it requires that a supplemental between-row cultivator be used and that additional field passes be made, because only in-row weeds are controlled by this method. In contrast, the brush hoe requires a high initial capital investment, but it does not require the purchase of a complementary in-row weeder because it does a fairly good job of controlling in-row weeds as well. Additional costs associated with the use of both implements include increased planting and operating costs, as both require that crop rows be straight and precisely spaced at planting, and both must be operated at a relatively slow speed if crop damage or loss is to be avoided. Other factors affecting the affordability of the brush hoe are (1) the brush hoe is a heavy, power take-off (PTO)-driven machine that requires a large tractor to lift and run it, (2) two skilled operators are required for some models, and (3) although it is adaptable to different row widths and spacing, it can be somewhat complicated and time-consuming to adjust. In contrast, the finger weeder is a lightweight, ground-driven implement that can be operated by a smaller tractor, it requires a single operator, and it is easily adaptable.

As pressure to reduce pesticide use intensifies and hand labor becomes increasingly scarce and expensive,

cultivation may become increasingly appealing, justifying the purchase of specialized implements. Organic growers, growers committed to producing fruit without the use of pesticides, and those who plant in the ribbon row or annual system without mulch may find these implements particularly appealing.

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