SECTION 1

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General Information

1. **Project Number:** USDA 94-COOP-1-0515 LNE 94-40
   Grant Number: 26212
   Funding Period: February 1, 1995 to January 31, 1998

2. **Project Title:** Integrating New Cultivation Technology and Photocontrol of Weeds to Reduce Herbicide Use in Vegetables

3. **Project Coordinator:**
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4. **Type of Report:** Annual and final

5. **Date of Report:** November 30, 1997

6. **Reporting Period:** December 13, 1996 to November 30, 1997

7. **Major Participants:** No change

8. **Cooperators:** No change

9. **Project Status:** New (continuing): received SARE/ACE funding for the first time

10. **State of Expenditures** (cumulative)

Labor	46,300.31
Equipment	6,085.00
Travel	1863.20
Maintenance/Operations	11,455.06
TOTAL	65,703.57

SECTION II

Annual Report: USDA 94-COOP-1-0515 LNE 94-40

1. Objectives

A. To determine the feasibility of use and limitations of different types of cultivation implements in snap beans, transplanted broccoli, potatoes, beets, and sweet corn.

B. To determine the effect of weed growth stage on selectivity to flex-tine implements.

C. To investigate the potential for photocontrol of weeds common to Northeastern agricultural fields.

2. Abstract

After three years of research, cultivation trials in transplanted broccoli, snap beans, sweet corn, and potatoes have been completed. The flex-tine cultivators, used once and followed by an inter-row cultivation, were able to replace herbicides in the short season crop, transplanted broccoli. While two cultivations could also provide adequate weed control in snap beans, a mid-season crop, untimely precipitation can cause cultivation failure resulting in reduced yields. In potatoes, a long-season crop, cultivation alone can also result in yields equal to those with the use of broadcast herbicides, though weed control is less effective. Greater weed populations may reduce potato yields in years of low precipitation or produce large amounts of weed seeds that cause severe weed infestations in subsequent crops. For these reasons, the use of banded herbicides and inter-row cultivation in snap beans and potatoes provides the least risk and greatest economic returns to growers. Sweet corn, a long-season crop, cannot compete effectively with weeds early in the growing season; therefore, cultivation must be supplemented with banded herbicides. Expected herbicide reductions with banded applications would be 1.25, 6.25, 1.67, and 2.5 lb ai/A for broccoli, snap beans, potatoes, and sweet corn, respectively. Research trials and experimentation by growers indicate that, to be effective, the flex-tine harrows must be used when weeds are at the two-leaf stage or smaller. The currently available cultivator models are also limited in that they are not appropriate in size for all crop row spacings and/or cannot be easily adjusted. Overall, it is expected that for long-term economic viability, growers will face less risk if they are flexible and are equipped to use both cultivation and herbicides on an as-needed basis. Attempts to employ cultivation in the dark or with shielded implements (photocontrol) have met with variable success. Though in some instances weed emergence can be reduced by as much as 50%, the practical significance of photocontrol has yet to be determined.

3. Specific Project Results

A. Findings and Accomplishments

Objective 1. Feasibility studies. Three years of cultivation research in potatoes have now been completed. The results are similar to the findings in snap beans and sweet corn in that banded herbicides supplemented by cultivation can control weeds as effectively as broadcast herbicides without cultivation. Weed control with

cultivation alone is less effective than with banded herbicides, though yields are not reduced. Apparently, early season weed control with cultivation alone and the hilling operation six to eight weeks after planting are sufficient to prevent weed interference with the potato crop. Though less effective weed control with cultivation alone did not reduce potato yields in these trials, it may in years in which growing conditions are more severe than they have been in the last three years. Moreover, substantial weed populations that remain late in the season with cultivation alone may deposit large amounts of weed seeds that can effect subsequent crops.

A trial conducted to determine the effectiveness of flex-tine harrows at different weed growth stages (see Objective 2.) confirmed some of the results of previous trials in snap beans. Banded herbicides with flex-tine cultivation controlled weeds as well as broadcast herbicides and resulted in similar snap bean yields. Cultivation alone with flex-tine harrows was not sufficient to control weeds, however, and yields were reduced where cultivation was not supplemented with banded herbicides. The inability to properly adjust the flex-tine tools, particularly in wet soils, may have contributed to the less effective weed control with cultivation alone.

In 1997, four growers had an opportunity to use the brush hoe and the flex-tine harrows in a variety of vegetable crops and strawberries. The growers found the flex-tine harrows to be effective in a number of crops, including potatoes, carrots, snap beans, sweet corn, and strawberries. These tools did cause significant crop injury and stand reduction, however, depending upon the crop (even crop variety) and stage of crop development. Additional limitations mentioned by all growers were the size and lack of adjustment of the implements. The width of the cultivators works well with the 30-inch row spacing used at the research farm, but many growers use other spacings and/or a variety of row arrangements. With some row spacings, growers found it necessary to overlap passes with the cultivator to achieve adequate weed control, thereby increasing the time required and the cost of cultivation. In some situations, the cultivators could not be used without damaging one or several crop rows. The current design of these implements makes it difficult if not impossible to adjust to all row arrangements. Simply increasing the width of the implements could overcome some of these difficulties, while other problems would require redesigning certain features of the tools. Nevertheless, the growers' experiences suggest that the currently available cultivators can provide satisfactory weed control after determining where their use is most appropriate.

Objective 2. Effect of weed growth stage on susceptibility to flex-tine harrows. A flex-tine harrow was used, with and without banded herbicides, to cultivate snap beans when weeds were at the preemergence, two-leaf, four-leaf, preemergence plus two-leaf, and preemergence plus four-leaf stages. As in the previous year's trial, snap beans cultivated with flex-tine harrows at the two-leaf weed stage (the cotyledon stage of bean plant development) suffered plant stand and yield reductions. Flex-tine cultivation was most effective when weeds were at preemergence or the two-leaf stage. These findings were corroborated by the experiences of the growers experimenting with the flex-tine harrows in snap beans and other crops: weeds were not sufficiently controlled unless they were at the two-leaf stage or smaller.

Objective 3. Photocontrol of weeds. An unreplicated trial was conducted to repeat previous research on the effect of light on weed germination after cultivation. Areas of plowed, bare ground were disked either during the day or the night and

then either harrowed at night, during the day, or during the day with a shielded harrow. The trial was conducted twice during the 1997 season. There was a distinct difference in number of weeds emerging after daytime disking versus nighttime disking. The number of weeds emerging after night disking was, on average, half the number emerging after daytime disking. The harrow treatment had less of an impact on weed emergence. Night harrowing tended to result in the smallest number of emerged weeds, about 30% less than that with the shielded harrow or daytime harrowing. This effect was more pronounced earlier in the season; later in the season weed emergence was more variable. These results concur with the findings of the previous years: in 1995 a similar reduction in weed emergence was observed and in 1996, differences in weed emergence were not seen when cultivation occurred later in the growing season. A complete analysis of the effect on different weed species is still forthcoming.

B. Dissemination of Findings - 1997

Research results have been presented at grower meetings, field days, regional, national, and international meetings of weed scientists. In addition, growers have had an opportunity to experiment with the cultivation tools under a variety of cropping systems. A fact sheet for distribution to extension agents and growers was published and more detailed research results will be available shortly in the annual publication, "Cornell Vegetable Weed Science Research Results". A manuscript for publication in the peer-reviewed journal, "Weed Technology" has been submitted and has received initial review. A paper entitled, "Mechanical in-row cultivation in row crops" was presented at the Second International Weed Control Conference in Copenhagen, Denmark. Based on the findings of this research, a project has begun, with separate funding, to evaluate use of these cultivation tools in horticultural production on Long Island, New York. In addition, reports from this project have stimulated the initiation of similar research projects in North Carolina and California. There is great interest in these tools amongst strawberry researchers and producers. The primary investigator has been asked to submit a research proposal to the North American Strawberry Association and invited to address a national meeting on the use of novel cultivation tools in fruit production.

C. Site Information

All of the studies were conducted in upstate New York. Soils at the research farm were either Howard gravel loams or Eel silt loams. Soils on the farms of the grower-cooperators have been both gravel and clay loams. Early season precipitation was ample though temperatures were below normal. Excessive moisture and slow crop development made it difficult to cultivate in a timely fashion in some instances. The latter part of the season was characterized by warmer temperatures and by lower than normal precipitation. Where cultivation was successfully timed early in the season, the lack of rainfall helped prevent later infestations; where cultivation failed to adequately control weeds, crops suffered from the increased competition for scarce moisture.

D. Economic Analysis

Initial analysis of cost of production data from sweet corn and snap bean grower surveys has been completed. Although more detailed analysis must be performed,

preliminary indications are that cultivation combined with banded herbicides could reduce weed control costs at least $15/A and $6/A in snap beans and sweet corn, respectively, without a reduction in yield. In snap beans, a combination of cultivation tools could provide weed control equivalent to standard herbicide treatments, allowing an even greater cost reduction. A more complete cost analysis will consider the increased risk of weed control failure due to the difficulty of cultivating in a timely fashion.

4. Potential Contributions and Practical Applications

A. Overall Impact on Production, Environment, and Profits

Cultivation can replace herbicides in short-season vegetable crops such as transplanted broccoli and snap beans and can supplement banded herbicides in sweet corn and potatoes. Doing this will decrease herbicide use by 1.25, 6.25, 1.67, and 2.5 lb ai/A in broccoli, snap beans, potatoes, and sweet corn respectively. However, caution is in order, as environmental conditions, particularly precipitation, can have a severe negative impact on the timeliness and eventual success of cultivation and can significantly increase a grower's economic risks. To date, it is apparent that growers are best served if they have the potential to be flexible, having different types of cultivation tools for different stages of crop growth and herbicides for use on an as-needed basis. This need for flexibility and multiplicity of strategy components increases dramatically with farm size.

B. Pesticide Reduction

Treflan (trifluralin)
- Pest: grass and broadleaf weeds
- Rate: 0.5 to 1.0 lb ai/A
- Loss Potential: material is in possible danger of cancellation due to Delaney clause issues; it is the "workhorse" of vegetable production and its loss will severly limit vegetable production and economic viability of growers.
- Alternatives: handweeding, Goal, Devrinol, Poast

Eptam (EPTC)
- Pest: grass and broadleaf weeds
- Rate: 3.0 to 4.0 lb ai/A
- Loss Potential: uncertain, may be dropped by manufacturer.
- Alternatives: Dual, Poast, Basagran, Reflex, Frontier

Dual (metolachlor)
- Pest: grass and broadleaf weeds, hairy galinsoga, yellow nutsedge
- Rate: 1.5 to 2.0 lb ai/A
- Loss Potential: uncertain, it is one of a group of herbicides which is being scrutinized because of ground and surface water contamination concerns. It is one of the most effective materials available for control of nutsedge, hairy galinsoga, and annual grasses. It is important as an herbicide rotation product as weed species have not developed resistance to it, thus it aids in preventing the development of herbicide resistance.
- Alternatives: Basagran, Poast, Reflex

Sencor/Lexone (metribuzin)
- Pest: broadleaf weeds and some annual grasses
- Rate: 0.5 to 1.0 lb ai/A

Loss Potential: unknown
Alternatives: Dual, Prowl, Lorox, Poast, Matrix

Lorox (linuron)
Pest: broadleaf weeds
Rate: 1.0 to 2.0 lb ai/A
Loss Potential: unknown
Alternatives: Sencor, Dual, Prowl, Poast, Matrix

Basagran (bentazon)
Pest: broadleaf weeds, yellow nutsedge
Rate: 0.5 to 1.0 lb ai/A
Loss Potential: unknown
Alternatives: Dual, Frontier, Reflex

C. New Hypotheses

1) While cultivation alone may control weeds sufficiently in short- or mid-season crops to prevent yield loss in many years, weeds not controlled by cultivation will reduce yields when resources (water and nitrogen) are limited.
2) Large late-season weed populations not controlled by cultivation alone will result in great increases in the weed seed bank and affect yields of subsequent crops.
3) The effectiveness of photocontrol varies with time of season and weed species.

5. Farmer Adoption and Direct Impact

A. Changes in Practice

The research projects have spanned four years and grower interest has been enormous throughout. The snap bean and cabbage processing groups in the state have contributed support to the projects for two and three years, respectively. Grower attendance, particularly of organic growers, at on-farm demonstrations has been good. Including attendance at all meetings and demonstrations, more than 800 growers have been exposed to the research to date. Several growers have taken steps to buy, or make for themselves, the flex-tine type cultivators. Other growers are refurbishing older model flex-tine harrows and rotary hoes. Additional funding has been obtained to expand the research to herb and flower production on Long Island. Researchers and producers have demonstrated a keen interest in evaluating these tools for use in strawberry production. Equipment dealers have realized that there is a new market for cultivation tools and have taken steps to bring in some of the types being sold in Europe. All three of the flex-tine manufacturers who have contributed to this project (and one who did not) now have distributors in the U.S. or Canada. Availability of the tools is now not so questionable.

B. Operational Recommendations

One of the most critical points identified by the research is that growers who intend to rely on cultivation for the *majority* of their weed control, must cultivate the first time *before the weeds even appear*, i.e., in the "white thread stage". In working with growers who have used the flex-tine tools, it is evident that many are reluctant to cultivate until they see the weeds, which may often be too late for effective control. Those who have taken our advice have become converts to *preemergence cultivation*. Secondly, in longer season crops it is apparent that, if economic sustainability is to be maintained, growers must be prepared to use strategies other

than or in addition to cultivation if yield reductions are to be avoided. Whereas handweeding may be cost-effective in fresh market vegetable production, it is cost-prohibitive in processing vegetable production. Lastly, *timeliness is of the essence*, whether it is in regard to the first cultivation event or a later one. If cultivation is missed at the appropriate time, yield reductions are almost guaranteed. Timeliness becomes *an even greater problem as farm size increases*.

C. Farmer Evaluations
See attached documents.

6. **Producer Involvement** (cumulative) [+ WIDER AUDIENCE EXPOSURE]
Number of growers/producers in attendance at:

Workshops (2); (total = 285, growers = 85)
Conferences (3) 335
Field Days (7) 340
Grower Meetings (4) 380
Out of State Conferences/Meetings (4) 550
Professional Meetings, US (6) 250
Professional Meetings, International (2) 200

7. **Areas Needing Additional Study**
Continuing research is needed mechanical tools and strategies for controlling weeds in small-seeded vegetable crops. Also the effectiveness of cultivation under conditions of limited resources and its impact on weed infestations in subsequent years should be investigated. Finally, the reasons for the variable results with the efforts at photocontrol need to be identified.

8. **Photographs**
See attached identification form.

Slide Identification Form

Project Number: USDA 94-COOP-1-0515 LNE 94-40
Project Coordinator: Robin R. Bellinder Phone: (607) 255-7890
Project Title: Integrating New Cultivation Technology and Photocontrol of Weeds to Reduce Herbicide Use in Vegetables.

Slide No. 1 Date: 6/30/94 Location: Thompson Vegetable Research Farm
Subject: Rabe Werk flex-tine harrow in potatoes
Significance: Provides preemergence and early postemergence in-row as well as between-row weed control.

Slide No. 2 Date: 6/30/94 Location: Thompson Vegetable Research Farm
Subject: Spider gang cultivator in potatoes
Significance: Provides postemergence weed control, primarily between-row.

Slide No. 3 Date: 7/97 Location: Thompson Vegetable Research Farm
Subject: Shielded harrow used in photocontrol experiment
Significance: Intended to achieve the benefits of dark cultivation without the risk of crop injury caused by poor vision.

Slide No. 4 Date: 8/97 Location: Thompson Vegetable Research Farm
Subject: Sampling of weeds in the photocontrol experiment
Significance: Weed counts indicated that fewer weeds emerged in plots cultivated in the dark versus those cultivated in daylight.

Slide No. 5 Date: 6/27/97 Location: Thompson Vegetable Research Farm
Subject: Weed sampling quadrats in dark cultivated plot.
Significance: Weed counts indicated that fewer weeds emerged in plots cultivated in the dark versus those cultivated in daylight.

Slide No. 6 Date: 6/27/97 Location: Thompson Vegetable Research Farm
Subject: Weed sampling quadrats in light cultivated plot.
Significance: Weed counts indicated that fewer weeds emerged in plots cultivated in the dark versus those cultivated in daylight.

Slide No. 7 Date: 8/5/97 Location: Thompson Vegetable Research Farm
Subject: Weed control in snap beans cultivated with flex-tine harrow at the 2-leaf weed stage.
Significance: Cultivation alone failed to adequately control weeds.

Slide No. 8 Date: 8/5/97 Location: Thompson Vegetable Research Farm
Subject: Weed control in snap beans with banded herbicides and cultivated with flex-tine harrow at the 2-leaf weed stage.
Significance: Cultivation with banded herbicides provided sufficient though not excellent weed control.

Slide No. 9 Date: 8/5/97 Location: Thompson Vegetable Research Farm
Subject: Weed control in snap beans with broadcast herbicides and cultivated with flex-tine harrow at the 2-leaf.
Significance: Excellent though costly weed control with broadcast herbicides and flex-tine cultivation.

Farmer Evaluations

Summary of conversations with growers, Jim Barber, Frank Wiles, and Doug Lemoy.

Jim Barber - Jim was unable to use the Rabe Werk flex-tine cultivator in many crops (those without 30-inch row spacing) due to the fact that the guide/adjustment wheels were spaced such that he could not cultivate without risking damage to the crop. Additionally it was not possible to adjust the wheels so that they would not run over the crop rows at different spacings. Jim was able to use the flex-tine harrow in snap beans on 30-inch spacings and was able to get satisfactory weed control with cultivation alone. He made three to four passes when bean plants were four inches tall and weeds were at the two-leaf stage.

Frank Wiles - Frank used the Lely flex-tine cultivator in strawberries, squash, and pumpkins and found that the success of the weed control was highly dependent on the stage of weed growth. While the Lely did not provide completely adequate weed control, he believed that if he had cultivated 6-10 days earlier, when weeds were smaller, then the weed control would have been more than acceptable. Frank also experienced problems with the gauge/adjustment wheels running over the crop rows and was unable to prevent the problem by moving the wheels on the tool bar. He did like the ability to adjust individual tines and the effectiveness of the tool in cultivating between two closely spaced rows of strawberries.

Doug Lemoy – Doug used the brush hoe in direct seeded cucurbits. He found it gave effective control of broadleaf weeds up to 3" tall and was able to cultivate without serious damage in cucumbers and pumpkins up to the 3 true leaf and 6-8 true leaf stages, respectively. Though weed control with the brush hoe was good, Doug was uncertain as to whether or not it was better than other tools. The brush hoe was difficult to adjust for different row spacing, a process made more frustrating by the fact that nuts and bolts were of all different sizes. Another drawback was the lack of response to steering by the operator seated behind the brush hoe. The range of motion that the person steering the hoe could achieve was small. Also, the steering operator was not sufficiently protected to keep from getting covered in dust. Doug would liked to have used the brush hoe in transplanted crops like cabbage, broccoli, tomatoes, and peppers but feared doing too much damage to them.

The following is a letter received from Andrew Leed, of Candor, NY:

Evaluation of Einbock and Lely Finger Tine Weeders

On several occasions during the 1995 and 1996 growing seasons I was able to use an Einbock finger tine weeder, and during 1997 I had the use of a Lely weeder, at Starflower Farm, in Candor, NY. This is a small (3 acre) certified organic vegetable operation, where no herbicides are used, and there is no hired labor for weeding. The crops include a rotation of carrots, potatoes, onions, cabbage, kale, and other minor crops. Weeds that are the greatest problems include galinsoga, purslane, redroot pigweed, and, to a lesser extent, quackgrass. The soil is Lordstown, a

channery silt loam, which has been partially destoned, but still has a very large number of shale fragments in the 1 to 4 inch range, with some larger stone.

In 1995 and 1996, the Einbock weeder was used on potatoes at several stages in crop growth: before crop emergence, at the 2 - 3 inch diameter rosette stage, 4 inches tall, and finally at 6 – 8 inch crop height. Weeds were generally at the white thread through first true leaf stages, but there were some small clumps of grass not previously killed when the field was fit. The weeder provided excellent control, as long as it could be used in a timely fashion. Even many of the grass clumps were turned over, and died when the roots were exposed to the sun. In 1995, the weeder had no observable ill effects on the crop, but because the seed pieces were planted quite shallowly in 1996, there was considerable crop uprooting until the potato plants were about 6 inches tall. Overall, I was pleased with the weeder's performance on potatoes.

The Einbock is a fairly rugged tool, and the pivoted gangs allow the tines to closely follow field contours. The adjustable gauge wheels are a necessity on rolling land, which ours is. The ability to adjust the tine angle for the entire gang with one handle is a very convenient feature. This particular gang arrangement (two gangs side by side) was not ideal for our tillage system, which uses 36 inch row centers for potatoes, and 4 foot beds for other crops. The tool cultivates more than one bed width, but not three bed widths. Similarly, it covers more than the two potato rows straddled by the tractor, but doesn't reach far enough to cultivate four rows. This leads to skips, multiple passes to provide overlap, and interference with adjacent crops. A single gang 6 to 7 feet wide would work best for individual beds or a pair of potato rows, and a 12 to 13 foot tool would handle 4 rows.

In 1997, we had the use of a Lely weeder for most of the growing season. The crops on which it was used include potatoes, carrots, onions (both from transplants and sets), kale, cabbage, tomatoes, and sweet corn. Our experience with the Lely weeder on potatoes paralleled that of the Einbock. Weed control was generally good. The seed pieces were again quite shallow (to speed the emergence of a late planted crop) and some were uprooted by the weeder. This was cultivar dependent, with the more dormant (slower rooting) varieties most easily uprooted. This kept us from blind cultivating those rows. It was necessary to wait until some varieties were 4 to 6 inches tall before the weeder did not uproot too many plants. Row cultivation was performed in these cases. This lead to a somewhat larger number of in-the-row escapes, most of which were later smothered by hilling. I would prefer to plant chitted (presprouted) potatoes at a greater depth, which should circumvent the problem of uprooting by the weeder.

Onions from sets were too easily disturbed by the weeder to make its use practical in this situation. Transplanted onions proved to be more robust, and were cultivated at the 4 and 6 leaf stages. There was some crop damage, and it's useful to have a helper watch the action of the weeder to judge whether cultivation should continue. With this crop, use of this tool is a bit marginal, and I would guess depends on soil type and soil moisture. Corn was weeded with the Lely at 6 and 10 inches, and tolerated that quite well. We did not have an opportunity to try blind weeding of corn. Transplanted tomatoes, cabbage, and kale were partially uprooted by the weeder. That may have been due to slow root expansion in the particularly cold soil early in the 1997 season. The weeder was not tried at its least aggressive

settings, which would have been more appropriate in this situation. Weed control was good, however.

Carrots proved to be an excellent candidate for finger tine weeding. I did not expect this to be the case, given the frail appearance of young carrot plants. Apparently the initial tap root of carrot is quite robust and well anchored, because weeding with the Lely from the 4 true leaf stage until the plants were 6 inches tall gave very little crop damage. Weed control was excellent, until mid-season where purslane was present. This weed caused us to till in about 10% of the crop, rather than resort to intensive hand weeding in that area. Finger tine weeding occurs too early in our carrot crop cycle to effectively suppress purslane. Galinsoga was a lesser problem, and was suppressed by later use of row cultivation, hand weeding, and shading by the crop canopy (4 rows, 10 inches on center, are planted in each 4 foot wide bed.)

The Lely weeder is a somewhat lighter duty tool than the Einbock, and that might be significant with hard use (higher speeds on rough ground.) The single gang configuration worked well, but this tool had the same inconveniences in sizing (for our operation) that the Einbock suffered from. The tines are individually adjustable, which would offer an advantage if the tool was to be used for row cultivation (between the row.) I think that other tools, such as rolling cultivators or other gang cultivators, would perform better in that role, since they are more aggressive than the finger tine weeders, and might perform other functions (such as hilling.) I found the individual tine adjustment to be an inconvenience since each of the many tines had to be moved separately. This strongly discourages the operator from making adjustments necessary to optimize the tine angle for each crop, crop size, weed size and type, soil condition, etc. Occasionally a tine pops out of adjustment, and leaves a largely untilled strip until the operator notices this and corrects it. Manipulating some of the tines is difficult due to interference from the frame and gauge wheels, and can lead to "barked knuckles" if one is not careful. I would be unlikely to purchase a tine weeder of this design.

Andrew Leed
Starflower Farm