Strip Tillage for Sweet Corn Production: Yield and Economic Return

John M. Luna and Mary L. Staben
Department of Horticulture, 4017 Agricultural and Life Sciences Building, Oregon State University, Corvallis, OR 97331

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Abstract. Two strip tillage systems for sweet corn production were compared to conventional tillage systems in western Oregon. A power take-off rotary tiller configured to till six rows per pass was used in 1997 and 1998; a shank/coulters strip tillage machine was used in 1999 and 2000. A paired t test experimental design was used in field-scale, on-farm research with eight replications in 1997–98 and 12 replications in 1999–2000. Sweet corn was harvested using the participating growers’ corn pickers and yield was determined. A subset of the participating growers recorded types of machinery and labor for tillage operations and total costs were computed for each tillage system. The rotary strip tillage system produced 900 kg ha⁻¹ greater corn yields (P = 0.11) than conventional tillage. The shank/coulters strip tillage system produced yields comparable to conventional tillage (P = 0.95). The rotary strip tillage system reduced total tillage costs by an average of $38.50/ha compared to conventional tillage (P = 0.03) and reduced machinery operating time by 0.59 h/ha⁻¹ (P = 0.01). The shank/coulters strip tillage system reduced tillage costs by $36.50/ha compared to conventional tillage (P = 0.003) and reduced machinery operating time by 0.47 h/ha⁻¹ (P = 0.001). Slugs damaged corn in several strip tillage fields requiring the use of slug bait to prevent economic damage. Herbicides used in conventional tillage systems were generally effective in the strip tillage systems. Mechanical cultivation with standard cultivating equipment was more difficult in some of the strip tillage fields with heavy cover crop residue.

Conservation tillage practices have been widely adopted for agronomic crop production, yet most vegetable growers continue to use intensive tillage for seedbed preparation (Hoyt et al., 1994). Benefits of conservation tillage have been discussed in previous publications, including reduced equipment and labor costs, reduced soil erosion, improvements in soil quality, and in some situations, increased yields (Abdul-Baki and Teasdale, 1993; Blevins et al., 1983; Coolman and Hoyt, 1993; Johnson and Hoyt, 1999).

Strip tillage is a form of conservation tillage that involves cultivation of narrow bands, or strips in the row area, separated by bands of undisturbed soil. Strip tillage has the potential advantages of providing a suitable seedbed for vegetable crop establishment while leaving surface residues in the inter-row area to reduce soil erosion. Equipment for strip tillage has usually consisted of a modified rototiller (rotary strip tiller) (Petersen et al., 1986) or a subsoiling shank and fluted coulter system (shank/coulters system) (Wilhoit et al., 1990).

Yield response of vegetable crops to strip tillage has been variable. In a Pennsylvania study, Grenoble et al. (1989) reported that strip tillage systems reduced snap bean yields compared to the conventional tillage in all three years of the trial. Bottenberg et al. (1999) found that strip tillage also reduced snap bean yields by 20% compared to conventional tillage when planted into rye cover crop mulches in an Illinois study. These authors used a rototiller to prepare the strips and speculated that the tillage depth (10 to 20 cm) was not sufficient to ensure adequate root development. Comparing tillage systems for sweet pepper production in New Hampshire, Loy et al. (1987) reported yield losses from strip tillage. In studies involving cabbage in Virginia (Wilhoit et al., 1990) and tomatoes in Ontario, Canada (McKeown et al., 1988), no differences in yield were observed between strip and conventional tillage systems.

This study reported herein was conducted to develop and evaluate strip tillage systems for sweet corn production in the Willamette Valley of western Oregon. In an earlier Oregon study by Peterson et al. (1986), strip tillage reduced sweet corn yield from 7% to 16%. This experiment involved strip tilling into wheat straw residue and was conducted for 1 year. We conducted a replicated study at the Oregon State Univ. Vegetable Research Farm in 1993 to evaluate a rotary strip tillage system for sweet corn production. The strip tillage system produced comparable sweet corn yields to a conventional plow/disk tillage system (unpublished data).

We decided to continue our work using on-farm research methodology because of soil compaction resulting from commercial scale farm equipment and the wide array of soil types, cropping histories, and tillage systems used by Oregon vegetable growers. On-farm research is advantageous for studies that involve interactions of soil types, crop rotations, and farming equipment (e.g., compaction) and where the constraints of a working farm are needed to evaluate the performance of a system (Lockeretz, 1987). On-farm research is also useful to test new techniques under a range of conditions to encounter potential problems and limitations that might not be seen under experiment station conditions (Rzewnicki et al., 1988). We also wanted to actively involve farmers because of their practical experience with farm machinery. Because farmers are often skeptical about results that come from small plots in traditional experiment station field trials (Francis et al., 1986), we believed the adoption of strip tillage would also be accelerated through the process of collaborative on-farm research.

Materials and Methods

Farm fields were located in the central Willamette Valley of western Oregon and experiments were conducted over a 4-year period, 1997–2000. The experimental design was a paired t test, with two tillage treatments, 1) strip tillage and 2) conventional tillage. Each field served as a replicate, with eight total fields in the 1997–98 experiment and 12 total fields in the 1999–2000 experiment. Fields were selected with relatively uniform soil type and vegetative cover for the field, but soil types and cropping histories varied among the fields (Table 1). Plot areas were selected in portions of the field and the tillage treatments randomly assigned. In 1997–98, tillage treatment plot sizes were typically 0.5 to 1 ha; in 1999–2000, plot areas were typically 3 to 6 ha. The term “conventional tillage” will be used in this paper to describe the various forms of tillage used by the cooperating grower to produce a residue-free seedbed. The kinds of machinery and number of passes across the field varied among farmers and years. These practices typically consisted of moldboard plowing or ripping, disking, and rototilling or field cultivating. Each cooperating grower, however, used specific combinations of tillage equipment based on soil conditions.

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Table 1. Predominant soil type, cover, previous crop, and sweet corn variety for fields in 1997–2000 tillage experiments.

| Year | Field | Soil series and family | Cover crop | Previous crop | Sweet corn cultivars |
|------|-------|------------------------|------------|---------------|---------------------|
| 1997 | C-1   | Cloquato silt loam     | Mondo oat and common vetch | Sweet corn | GH 2684 se        |
| 1997 | B-1   | Wapato silty clay loam | Cayuse oat and common vetch | Snap beans | Santiam sh2        |
| 1997 | B-2   | Cloakamas gravel silt loam | Winter killed Cayuse oat and annual ryegrass regrowth | Snap beans | Jubilee su         |
| 1997 | B-3   | Nekia silty clay loam  | Winter killed Cayuse oat and annual ryegrass regrowth | Fine fescue | GH 2684 se        |
| 1997 | A-1   | Cloquato silt loam     | Steptoe barley | Snap beans | Jubilee su         |
| 1998 | F-1   | Amity silt loam        | Monida oat | Snap beans | Northern Xtra-Sweet sh2, Jubilee su |
| 1998 | D-1   | Salem gravel silt loam | Winter wheat | Snap beans | Jubilee su         |
| 1998 | E-1   | Cloquato silt loam     | Volunteer winter wheat | Winter wheat | Jubilee su         |
| 1999 | F-2   | Chehalis silt loam     | Winter wheat | Snap beans | Northern Xtra-Sweet sh2, Supersweet |
| 1999 | B-4   | Sifton Variant gravelly loam | Walken oat and common vetch | Snap beans | Jubilee sh2        |
| 1999 | B-5   | Saturn Variant silt loam | Perennial ryegrass | Perennial ryegrass | Jubilee su |
| 1999 | B-6   | Chapman loam           | Walken oat and common vetch | Perennial ryegrass | Jubilee su |
| 1999 | B-7   | Abiqua silty clay loam | Celia triticale and common vetch | Perennial ryegrass | Jubilee su |
| 1999 | B-8   | Sifton gravelly loam   | Winter wheat | Snap beans | Jubilee su         |
| 2000 | G-1   | Aloha silt loam        | Cayuse oat | Broccoli | Jubilee su |
| 2000 | G-2   | Woodburn silt loam     | Cayuse oat | Table beets | Jubilee su |
| 2000 | H-1   | Concord silt loam      | Perennial ryegrass | Perennial ryegrass | GH 2684 se |
| 2000 | H-2   | Amity silt loam        | Walken oat, common vetch and Austrian field peas | Snap beans | GH 2684 se |
| 2000 | F-3   | Amity silt loam        | Monida and Cayuse oats | Snap beans | Jubilee su |
| 2000 | B-8   | Cloakamas gravel silt loam | Tall fescue | Tall fescue | GH 2684 se |

was modified to till strips =30 cm wide × 30 cm deep because participating growers believed a wider and deeper tilled strip would improve corn growth and development. A smooth cylinder press wheel was also added to the tiller behind each strip to firm and smooth the seedbed.

In 1997 five field trials were established on three farms; four trials were established in 1998 on three farms. All fields contained either winter annual cereal or cereal/legume cover crops. Glyphosate herbicide was used to kill cover crops and existing vegetation in the fields several weeks prior to strip or conventional tillage. Although fertilization, insect, and weed control practices varied among farms over the 4 years of the project, within a single field these production practices were generally the same in the strip tillage and conventional tillage blocks. In a few fields, however, weed problems occurred in the untilled middle areas in the strip tillage blocks that required mechanical cultivation. Sweet corn was planted using the growers' six-row planting equipment and standard commercial pickers were used for harvest.

1999–2000. In 1999, the group of growers participating in this project decided to build a new strip tillage machine using a shank/coultersystem to replace the PTO-driven strip rotovator. In this system, a front disk coulter with a depth wheel cuts through crop residue and vegetation, followed by a subsoiling shank...
that operates to a depth of ≈35 cm. A double set of fluted coulters mixes and chops the soil, and a clod-crushing basket follows (Fig. 2). This machine was developed in an effort to increase the speed of the strip tillage operation. The rotary strip tillage machine used in 1997–98 was operated at ≈2.9 km·h⁻¹, where the new shank/coulters strip tillage machine could be operated up to 9.6 km·h⁻¹. A “Ripper-Stripper” strip tillage machine (Unverferth Mfg. Co., Kalida, Ohio) with a similar shank/coulter design was also used in some of the 1999–2000 trials. Six tillage trials were established each year in 1999 and 2000. All growers except one (Field F-3) made a second pass with the shank/coulters strip tillage machine in 2000 to improve seedbed conditions. The cooperating growers used their equipment to plant, manage, and harvest the crop.

Corn stand establishment. Corn stand establishment was estimated in all tillage blocks in 1999 and 2000 by counting the number of corn plants in a 2-m length of row at 20 randomly selected locations in the field. This sampling occurred ≈3–4 weeks after planting when plants were typically 8 to 12 cm tall. Corn stand establishment data were not taken in the 1997–98 trials.

Corn yield, grade, and crop value. Sweet corn was hauled to the processing facility where truck weights and crop grades and percent usable ears were determined for each load. Sweet corn grade, or maturity, is based on the percent kernel moisture and was calculated by taking two 20-kg samples of corn per truckload. Grades (maturity) of the sweet corn are based on a scale of one to five, where one is highest value as the corn is less mature and five is lowest value as the corn is more mature. Prices paid to growers for “Jubilee” corn in 2000 were used to calculate crop values for all 4 years. A measuring wheel was used to measure plot length and width in 1997 and 1998. In 1999 and 2000 a global positioning system (GPS) receiver (CMT, Corvallis, Ore.) and geographic information system (GIS) software were used to determine the area of each plot for yield calculation. Crop value was calculated from yield and price paid for each grade.

Tillage costs. To estimate tillage costs, data on machinery use and labor were collected from several of the cooperating growers who had interest in this aspect of the project. Growers recorded information after each tillage operation. Horsepower rating and wheel drive of each tractor, implement type and width, number of passes and operation speed were recorded. Labor rates for the equipment operators were standardized across farms at $14/h based on average labor rates paid in the Willamette Valley. Smathers and Willet (1997) provided estimates of machinery operating costs. Tractor and implement operation cost per hour were based on annual tractor use of 700 h and annual implement use of 200 h, which were from a survey of the growers involved in the project. Operating costs were combined with tractor speed, equipment efficiency ratings (Rotz and Bowers, 1991), and labor costs to produce a cost per hectare for each combination of tillage passes. For our calculations, we used a constant price of $0.22/L for the price of off-the-road diesel purchased in bulk. The cost of diesel in the Willamette Valley in Oct. 1999 was $0.20/L, but by Aug. 2000 it was $0.32/L.

Data analysis. Data were combined across both years of the rotary strip tillage treatments and both years of the shank/coulters strip tillage treatments. A paired t test was used to compare yield, grade, stand counts, and costs from tillage treatments.

Results

Corn stand establishment. Tillage treatments had no effects on the average density of corn plants in the 1999–2000 trials (P = 0.76) (Table 2).

Yield and crop value. The rotary strip tillage system increased sweet corn yields by 900 kg·ha⁻¹ over the conventional tillage system in 1997 and 1998 trials (P = 0.11) (Table 3). There was no tillage effect on crop grade (P = 0.90). Average crop value was increased by $95.00/ha (P = 0.11) (Table 3). The shank/coulters strip tillage system produced the same average yields as the conventional tillage system in 1999 and 2000 (P = 0.95) (Table 4). Neither crop grades (P = 0.95) nor crop values (P = 0.93) were significantly different between tillage treatments (Table 4).
Tillage costs. The rotary strip tillage system reduced total tillage costs by an average of $38.50/ha compared to conventional tillage ($36.50/ha, Table 2). The shank/coulter strip tillage system reduced tillage costs by an average of $25.52/ha in tillage costs. Interestingly in this study, the results that cooperators were favoring with strip tillage during the 1997 and 1998 trials influenced the number of tillage operations used in the conventional tillage blocks in 1999 and 2000. For example, in 1997–98, conventional tillage averaged $90.11/ha (Table 5), whereas in 1999–2000, conventional tillage costs averaged only $71.86/ha (Table 6). As one farmer said at a group discussion meeting, "We've learned a lot about conventional tillage by doing strip tillage."

We have not found any increase or decrease in insect pest damage associated with strip tillage in the 20 paired tillage system comparisons reported in this study (data not reported). However, in two paired trials in 2001 (data not reported), outbreaks of the garden symphylan (Scutigerella immaculata) damaged sweet corn in the strip tillage blocks. Winter and Spring 2001 were exceptionally dry, which may have allowed greater symphylan survival and population growth. Also, tillage has historically been used as a cultural method to suppress symphylan populations (Umble et al., 2001). Adding a second pass for the strip tillage system clearly increases the tillage cost. For example, in 1999 and 2000, single-pass operations (Fields D-2, F-2, and F-3, Table 6) averaged $25.52/ha in tillage costs. Fields that received two passes with the shank/coulter machine (Fields G-1 and H-1) averaged $50.13/ha in tillage costs. Interestingly in this study, the results that cooperators were favoring with strip tillage during the 1997 and 1998 trials influenced the number of tillage operations used in the conventional tillage blocks in 1999 and 2000. For example, in 1997–98, conventional tillage averaged $90.11/ha (Table 5), whereas in 1999–2000, conventional tillage costs averaged only $71.86/ha (Table 6). As one farmer said at a group discussion meeting, "We've learned a lot about conventional tillage by doing strip tillage."

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Table 2. Impact of tillage treatment on sweet corn stand establishment, 1999 and 2000.

| Year | Field | Corn plants (plants 10 m²) | Mean |
|------|-------|-----------------------------|------|
| 1999 | B-4   | 59.3                        | 60.5 |
|      | B-5   | 59.0                        |      |
|      | B-6   | 48.7                        |      |
|      | B-7   | 59.3                        |      |
|      | D-2   | 67.2                        |      |
|      | F-2   | 68.9                        |      |
| 2000 | B-8   | 66.6                        |      |
|      | F-3   | 67.2                        |      |
|      | F-4   | 61.3                        |      |
|      | F-5   | 55.3                        |      |
|      | H-1   | 54.6                        |      |
|      | H-2   | 58.0                        |      |
| Mean |       | 60.5                        | 59.7 |

P value of t test: 0.76

Table 3. Comparison of rotary strip tillage and conventional tillage systems on sweet corn yield, crop grade, and value, 1997 and 1998.

| Field | Year | Graded yield (Mt·ha⁻¹) | Crop grade | Crop value ($/ha) |
|-------|------|------------------------|------------|-------------------|
|       | Strip till | Conv till | Strip till | Conv till | Strip till | Conv till |
| A-1   | 1997  | 19.3                   | 17.9       | 3.0          | 1.0      | 1937      | 1972     |
| B-1   | 1997  | 16.4                   | 15.9       | 2.0          | 3.0      | 1735      | 1678     |
| B-2   | 1997  | 19.6                   | 18.2       | 2.5          | 3.0      | 2021      | 1819     |
| B-3   | 1997  | 20.0                   | 18.3       | 2.5          | 2.9      | 2056      | 1846     |
| C-1   | 1997  | 17.4                   | 19.6       | 2.5          | 3.0      | 1792      | 1960     |
| D-1   | 1998  | 19.8                   | 17.6       | 3.5          | 4.5      | 1638      |          |
| E-1   | 1998  | 22.6                   | 21.6       | 5.0          | 4.0      | 2073      | 1982     |
| F-1   | 1998  | 26.5                   | 24.6       | ---          | ---      | 2817      | 2708     |
| Mean  |       | 20.1                   | 19.2       | 3.0          | 3.1      | 2045      | 1950     |

P value of t test: 0.11 0.90 0.11

Table 4. Comparison of shank/coulter strip tillage and conventional tillage systems on sweet corn yield, crop grade, value, 1997 and 2000.

| Field | Year | Graded yield (Mt·ha⁻¹) | Crop grade | Crop value ($/ha) |
|-------|------|------------------------|------------|-------------------|
|       | Strip till | Conv till | Strip till | Conv till | Strip till | Conv till |
| B-4   | 1999  | 17.9                   | 15.0       | 2.9          | 2.4      | 1811      | 1554     |
| B-5   | 1999  | 21.1                   | 22.1       | 2.6          | 2.6      | 2155      | 2268     |
| B-6   | 1999  | 18.6                   | 19.4       | 3.0          | 3.2      | 1861      | 1922     |
| B-7   | 1999  | 18.4                   | 14.7       | 3.0          | 2.8      | 1846      | 1483     |
| D-2   | 1999  | 17.7                   | 17.3       | 2.7          | 2.8      | 1806      | 1759     |
| F-2   | 1999  | 21.2                   | 23.0       | ---          | ---      | 2333      | 2555     |
| B-8   | 2000  | 17.8                   | 17.7       | 2.6          | 2.3      | 1819      | 1838     |
| F-3   | 2000  | 17.3                   | 21.9       | 2.2          | 3.6      | 1816      | 2110     |
| G-1   | 2000  | 21.0                   | 21.4       | 3.2          | 3.4      | 2076      | 2100     |
| H-1   | 2000  | 18.7                   | 14.7       | 3.5          | 1.3      | 1831      | 1601     |
| H-2   | 2000  | 16.0                   | 17.1       | 1.0          | 2.0      | 1767      | 1806     |
| Mean  |       | 18.6                   | 18.6       | 2.7          | 2.6      | 1891      | 1886     |

P value of t test: 0.95 0.95 0.93

Crop grade values: #1 $110.20 Mt; #2 $105.70 Mt; #3 $100.19 Mt; #4 $94.17 Mt; #5 $91.67 Mt.

Sweet corn was contracted to other processing companies who paid on yield basis only.
Slugs damaged corn seedlings in several strip tillage fields requiring the use of slug bait to prevent economic damage. Herbicides used in conventional tillage systems have generally been effective in the strip tillage systems. Depending on specific weed situations, some changes in herbicide materials and application timing may be required for effective weed control. A second application of glyphosate just prior to planting may be essential for effective weed control.

Although this study focused on using strip tillage for sweet corn production. Oregon growers have successfully used this system for squash and transplanted broccoli. In 2001, eight vegetable growers purchased or manufactured strip tillage machines and planted more than 1200 ha of vegetable crops using strip tillage. The rapid adoption of strip-tillage systems in western Oregon has demonstrated the potential for vegetable production. However, continued research is needed on the impact of strip tillage on soil moisture, irrigation requirements, and symplyman populations.

**Literature Cited**

Abdul-Baki, A.A. and J.R. Teasdale. 1993. A no-tillage tomato production system using hairy vetch and subterranean clover mulches. HortScience 28:106-108.

Blevins, R.L., M.S. Smith, and W.W. Frye. 1983. Changes in soil properties after 10 years of no-tillage and conventional tilled corn. Soil & Tillage Res. 3:135-146.

Bottenberg, H., J. Masuinas, and C. Eastman. 1999. Strip tillage reduces yield loss of snap bean planted in rye mulch. HortTechnology 9:235-240.

Coolman, R.M. and G.D. Hoyt. 1993. The effects of reduced tillage on the soil environment. HortTechnology 3:143-145.

Grenoble, D.W., E.L. Bergman, and M.D. Orzolek. 1989. Effects of tillage methods and soil cover crops on yield and leaf elemental concentrations of snap bean. Appl. Agr. Res. 4:81-85.

Francis, C.A., A.M. Parkhurst, and R. Thompson. 1986. Designs for on-farm research: Statistical rigor and client credibility, p.111 In: Agronomy abstracts. Agron. Soc. Amer., Madison, Wis.

Hoyt, G.D., D.W. Mong, and T.J. Monaco. 1994. Conservation tillage for vegetable production. HortTechnology 4:129-135.

Johnson, A.M. and G.D. Hoyt. 1999. Changes to the soil environment under conservation tillage. HortTechnology 9:380-393.

Lockertz, W. 1987. Establishing the proper role for on-farm research. Amer. J. Altern. Agr. 3:132-136.

Loy, S.J., L.C. Peirce, G.O. Estes, and O.S. Wells. 1987. Productivity in a strip tillage vegetable production system. HortScience 22:415-417.

McKeown, A.W., R.F. Cerkaukas, and J.W. Potter. 1988. Influence of strip tillage on yield, diseases, and nematodes of tomatoes. J. Amer. Soc. Hort. Sci. 113:228-331.

Petersen, K.L., H.J. Mack, and D.E. Booster. 1986. Effect of tillage on sweet corn development and yield. J. Amer. Soc. Hort. Sci. 111:39-42.

Roth, C.A. and W. Bowers. 1991. Repair and maintenance cost data for agricultural equipment. Paper No. 911531. Presented at the Intl. Mtg. of the Amer. Soc. of Agr. Eng., Chicago.

Rzewnicki, P.E., R. Thompson, G.W. Lescoing, R.W. Elmore, C.A. Francis, A.M. Parkhurst, and R.S. Moorman. 1988. On-farm experiment designs and implications for locating research sites. Amer. J. Altern. Agr. 3:168-173.

Smathers, R. and G. Willett. 1997. Pacific northwest farm machinery costs. Pacific Northwest Ext. Publ. PNW 346, Pullman, Wash.

Umble, J., R. Berry, and G. Fisher. 2001. Biology and control of the garden symphylan, p. 380-383 In: D. McGrath (ed.). Pacific northwest insect management handbook. Corvallis, Ore.

Vyn, T.J. and B.A. Raimbault. 1992. Evaluation of strip tillage systems for corn production in Ontario. Soil & Tillage Res. 23:163-176.

Vyn, T.J., T.B. Daynard, and J.W. Deetches. 1982. Effect of reduced tillage systems on soil physical properties and maize grain yield in Ontario, p. 151-161 In: A. Butorac (ed.). Proc. of the 9th Conf. of ISTRO, 22-27 June 1982, Osijek, Yugoslavia.

Wilhoit, J.H., R.D. Morse, and D.H. Vaughan. 1990. Strip tillage production of summer cabbage using high residue levels. Appl. Agr. Res. 5:338-342.

**Table 5. Comparison of tillage costs and machinery operating time for rotary strip tillage and conventional tillage practices in 1997 and 1998.**

| Field | Year | Strip till | Conv till | Strip till | Conv till |
|-------|------|------------|-----------|------------|-----------|
| A-1   | 1997 | 99.07      | 101.07    | 1.21       | 1.34      |
| B-2   | 1997 | 45.21      | 111.87    | 0.60       | 1.41      |
| C-1   | 1997 | 37.68      | 100.97    | 0.50       | 1.41      |
| D-1   | 1998 | 47.05      | 115.41    | 0.62       | 1.59      |
| E-1   | 1998 | 40.74      | 55.84     | 0.52       | 1.03      |
| F-1   | 1998 | 39.95      | 55.51     | 0.53       | 0.73      |
| Mean  |      | 51.62      | 90.11     | 0.66       | 1.25      |

P value of t test: 0.03

Based on machinery operating costs from Smathers and Willett (1997).

**Table 6. Comparison of tillage costs and machinery operating time for shank/koulter strip tillage and conventional tillage practices in 1999 and 2000.**

| Field | Year | Strip till | Conv till | Strip till | Conv till |
|-------|------|------------|-----------|------------|-----------|
| D-2   | 1999 | 24.19      | 66.25     | 0.36       | 0.85      |
| F-2   | 1999 | 25.60      | 44.05     | 0.40       | 0.72      |
| F-3   | 2000 | 26.78      | 53.89     | 0.53       | 0.88      |
| G-1   | 2000 | 41.53      | 90.51     | 0.58       | 1.13      |
| H-1   | 2000 | 58.74      | 104.59    | 1.03       | 1.65      |
| Mean  |      | 35.37      | 71.86     | 0.58       | 1.05      |

P value of t test: 0.003

Based on machinery operating costs from Smathers and Willett (1997).