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Development and Evaluation of Minimum-Tillage Production Systems for Sweet Corn and Snap Beans

by John Luna
and Mary Staben
Department of Horticulture
Oregon State University
Corvallis, Oregon

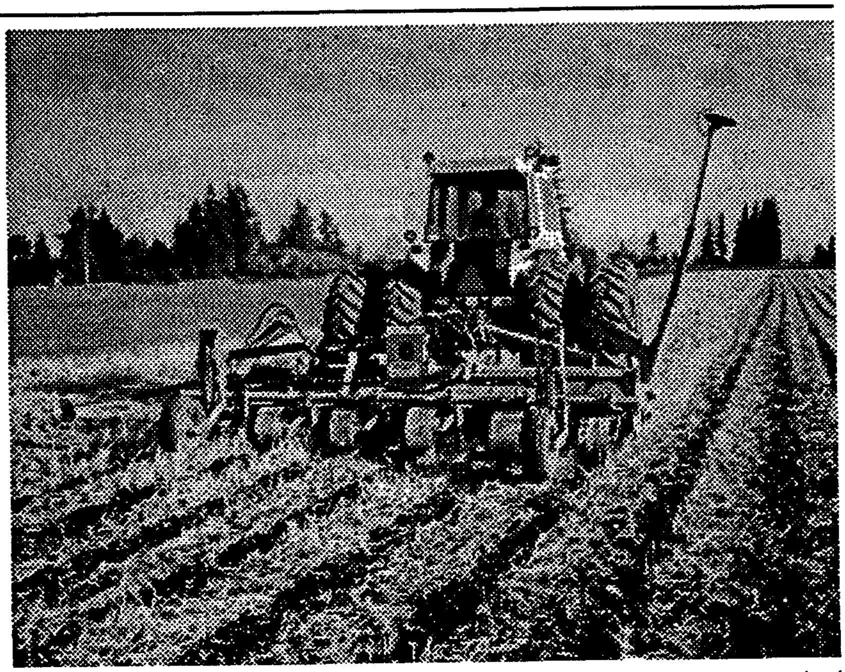

Fig. 1. A strip-till system uses killed cover crops as a surface mulch. Standard planting equipment is used to plant into the tilled strips.

Grower Participants

Mark and Mike Dickman
Dickman Farms, Mt. Angel
Carl and Jack Hendricks
Hendricks Farms,Stayton
Steve and Alan Keudell
Keudell Farms, Stayton
Ray Stafford
Kraemer Farms, Mt. Angel
Rod Chambers
Mari-Linn Farms, Jefferson

ABSTRACT

This project focuses on developing and evaluating strip-tillage vegetable production systems which integrate winter-annual cover crops. Goals include increasing farm income and enhancing soil and water quality. A participatory, on-farm research project was conducted with six vegetable producers in western Oregon during 1997 and 1998. The strip-till system (Fig. 1) was compared to "grower tillage" practices in ten large-scale, on-farm comparison trials for sweet corn and snap bean production. The strip-till system increased economic value of sweet corn production in 78% of the 9 on-farm trials, by an average of $74 per acre, which includes increase in crop value and savings in tillage costs. In 2 of the 9 trials (22%), there was an average net loss of $30 per acre. In both of these trials, however, yield reduction could be attributed to causes not directly related to the tillage system. Both of the snap bean trials produced a net gain in income, although the 1997 trial was compromised by placing the treatments in fields with different crop rotational histories.

The integrated vegetable production system developed here offers the potential to increase net profit to the growers, improve water quality through reduction of leaching and surface runoff, and enhance soil quality through conservation of soil organic matter and biological diversity. There is also a potential to reduce pesticide inputs through enhanced biological control of plant pathogens and insect pests. Reduced tillage dramatically reduces weed germination and mulches help suppress weed growth. Fertilizer inputs can be dramatically reduced by the use of legume cover crops and from the enhanced nutrient capture and recycling from cereal cover crops.

Introduction

Extensive tillage is used to prepare land for vegetable crop production with 5 - 10 separate tillage operations (Fig. 2). While tillage can have a beneficial effect of loosening soil compaction, killing unwanted vegetation, and aerating the soil, spring planting schedules in Western Oregon frequently require soil preparation under excessively wet soil conditions. Tillage under wet conditions can have severely detrimental effects to soil structure and can accelerate soil compaction problems. Tillage has also been shown to increase the rate of microbial oxidation of soil organic matter, reducing organic matter content in the soil. Minimum tillage systems, particularly no-till, has been used extensively in the mid-west, and the Eastern United States for field corn and soybean production, and with some success in vegetable production in some areas of the country. The strip-tillage system developed in this project for vegetable crops offers a compromise between tilled and no-till systems in that the tilled strip allows the soil to warm up prior to planting. Cold, wet soils have been a frequent problem in no-till systems in northern latitudes.

Fig. 2. Conventional tillage can degrade soil structure, increase chance of erosion, and cause compaction.

How the strip-till system works.

This system is based on the successful establishment of a winter-annual cover crop in the fall. Following the harvest of the previous crop, a rough seedbed is usually worked using minimal tillage (such as a disk harrow), and a cereal/legume cover crop is planted. This fall-planted cover crop has been shown to scavenge soil nitrogen during the winter, reducing leaching of nitrate into the ground water. The legume component of the cover crop mixture adds nitrogen from fixation of atmospheric nitrogen.

In the spring, 2-6 weeks prior to planting the vegetable crop, the cover crop is usually killed with glyphosate. Management of cover crop biomass is critical in this step. If the cover crop is killed too early (usually February or March), there is little cover crop residue left by the time of vegetable planting to protect the soil from rainfall compaction and to provide adequate weed-suppressive, moisture-conserving mulch. If the cover crop is killed too late, the cover crop biomass has become too great to be easily incorporated by the strip-rototiller. A flail mower can be used to shred the cover crop prior to strip tillage, but flail mowing is a slow and expensive farming operation.

We have used a modified Northwest Tillers Strip-Till Rotovator in this project to till six 8" wide strips on 30" centers. The normal "L" shaped tines have been replaced with curved "saber" tines and metal shield within the tiller confine the loosened soil to the tilled strip area. In the 1998 trials, modifications were made to the tiller to increase forward ground speed. A fluted coulter and a cultivator shank set approx. 8" deep was added in front of each set of rotovator tines. These soil opening devises increased ground speed from approx. 2 mph to 3.5 mph. This increase is significant in terms of reducing operational costs and enabling growers to till sufficient acreage during narrow windows of favorable soil moisture conditions resulting from western Oregon's typically rainy spring weather. In the 1998 trials, a press wheel was also added behind each set of tines to firm the seedbed.

Procedures

Varying conditions encountered on the different farms created an excellent "field laboratory" for exploring potential constraints of the reduced tillage system. In 1998 five trials involving sweet corn were established and two trials involving snap beans. The cooperating growers planted winter annual cover crops in the fall prior to the year of the trial. These cover crops were killed with glyphosate prior to spring tillage. Each on-farm trial consisted of two tillage treatments: "grower tillage" and strip-tillage. Standard tillage procedures varied among the cooperating farms and fields within farms depending on soil conditions, ranging from 4-10 tillage operations per field. The strip-tillage treatment consisted of a single pass of the 6-row Northwest Farm Tiller machine. Plot sizes for the tillage treatments varied among farms, but were all at least one acre. One trial in 1998 involved 6 acres in each treatment. Sweet corn and snap beans were planted using the collaborating growers' standard 6-row planting equipment. Most growers applied fertilizer alongside the row at planting time. Sweet corn fertilization also included a side-dress nitrogen application when the corn was approx.12-14" tall. Weed control programs varied among the collaborating farms, ranging from broadcast residual herbicide applications with no cultivation to banded herbicides applied in a 10" band over the tilled row combined with cultivation between the rows (Fig 3).

Cover Crop Biomass, Nitrogen and Carbon Content. Cover crop samples were taken in each field just prior to or immediately after the cover crop was killed with a glyphosate application. Six 0.25 m^2 quadrat samples were randomly selected in the field and clipped at ground level. Samples

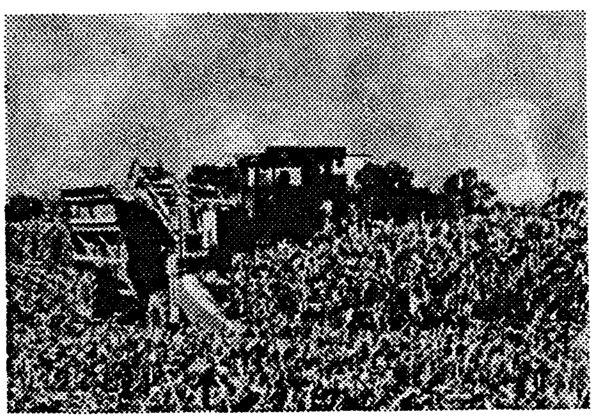

Fig. 3. Crop yields were determined using the growers' harvesting equipment, trucks were weighed and crop grade determined at the processing plant.

were returned to the Central Analytical Laboratory and weighed and analyzed for total N and C content.

Yield and Economic Benefits. Crop harvests

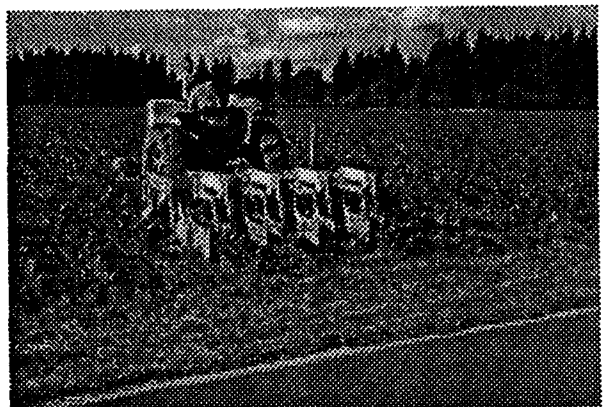

Fig.4. Band application of herbicide over the tilled strips, combined with between-row cultivation can reduce herbicide inputs by 66%.

were made using the growers' equipment (Fig. 4) and weights and grades were determined at the processing plant. The area required to fill each truckload was measured. A comparison of the relative economic benefit of the strip-till system compared to the standard tillage systems was conducted using two components: (1) economic value of the crop (yield, grade and price) and (2) calculating costs of tillage for the two systems. Tillage costs were estimated using information on specific equipment and number of operations used by the collaborating growers and cost estimates from the WSU Publication, *Pacific Northwest Farm Machinery Costs:1997*, by R. Smathers and G. Willet.

Soil Temperature. Soil temperature measurements were taken approx. 4" below the soil surface in each tillage treatment in two sweet corn fields using Hobo® electronic temperature loggers. The day the crop was planted temperature loggers were buried within the planted row and temperatures recorded on an hourly basis to determine daily maximum and minimum temperatures. Growing season degree days were calculated using a lower threshold temperature of 50 degrees F; degree-days for the germination period were calculated for the first 7 days after the logger was installed.

Soil Moisture. Estimates of soil moisture were made in the sweet corn trial at Dickman Farms and Keudell Farms. Watermark® sampling blocks were installed at two soil depths, 6 and 12 inches, with four sensors installed at each depth and in both tillage treatments. Measurements were made three times during the growing season timed to try to catch dry down periods between irrigations.

Soil and Plant Nitrogen. To address the question of nitrogen availability to the crop plants in the two tillage systems, both soil and plant tissue nitrogen were sampled in one field.

Soil nitrate was sampled at Dickman Farms when the corn plants were approx. 12", the phenological stage recommended for the presidedress nitrogen test (PSNT). This soil sampling test has been demonstrated to have practical value in assisting growers to adjust nitrogen fertilizer rates based on predicted N availability from the soil. Five samples were taken in each treatment block, with each sample being a composite of 20 soil cores taken to a depth of 6". Samples were placed on ice until they were overnight mailed to Agri-Check Laboratory.

Plant tissue nitrogen content was also estimated at Dickman Farms at the same time of soil nitrate testing by taking five random samples per tillage block. Each sample consisted of 5 whole 12" corn plants clipped at the soil surface. Samples were cooled and analyzed by Agri-Check Laboratory for nitrogen content.

Corn stalk nitrate levels were sampled on 5 farms on the same day as the corn was harvested. Stalk nitrate has been used to estimate the final status of the corn plant at harvest in terms of accumulated nitrogen in the plant. We cut the bottom 8" of stalk for the sample, with 5 samples of 15 stalks each taken in each tillage treatment on each farm. Stalks were dried, ground, and analyzed for nitrate content by Central Analytical Laboratory.

Earthworm Abundance. Estimation of earthworm (*Lumbricus terrestris*) abundance was conducted using an expulsion solution containing ground cooking mustard (7.1g/l water). Each sample area was defined by a metal ring 0.6 m in diameter and 0.25 m deep. Five samples were taken per tillage plot in sweet corn. Sample sites were randomly selected in each plot, although in the strip tillage plots the rings were placed so that approximately 25% of the area in the ring was in the tilled strip to reflect the proportion of tilled to untilled area in these plots. Rings were placed on the soil surface and rotated until the bottom edges were firmly embedded in the soil. Soil was pressed along the bottom outside edge to create a seal. Any vegetation or debris found in the ring was carefully removed and 1.85 l of solution was poured into each ring. Ten minutes later a second pour of 1.85 l of solution was made and earthworms were collected for an additional 10 minutes.

Soil Arthropod Sampling. Relative activity of predacious soil-dwelling beetles and spiders were estimated by placing pitfall traps in each tillage block at the Keudell Farms Galvins field. Pitfall traps consisted on one-pint plastic containers buried in the soil with the lip of the cup flush with the soil surface. The traps will filled approximately half way with antifreeze (to kill and preserve the trapped arthropods), and a 9" x 9" plywood cover was suspended over the trap to protect from rainfall and irrigation. Five traps were randomly placed in each tillage treatment; trapped arthropods were removed weekly and the traps refilled with antifreeze.

Results

May, 1998, was an extraordinarily wet month, exceeding all previous records for rainfall in many areas of the Willamette Valley. Since a large acreage of sweet corn and snap beans are planted in May, wet fields were clearly an obstacle to spring tillage and vegetable crop planting. There were few suitable windows of opportunity for field work, and in most cases the soil was too saturated for proper cultivation. Since the strip-till plots were paired with whole fields of "standard" tillage fields, the strip-tiller had to be used to prepare seedbeds to be planted on the same day as the standard tillage blocks. In most situations encountered, the soil was considered too wet for rototilling, but the fields were tilled regardless in order to meeting the planting schedule. The strip-tiller worked remarkably well, considering the conditions, producing very satisfactory seed beds. There were two fields where the strip-tiller simply would not function because a combination of wet, clayey soil and excessive cover crop residue. Where the soil was too wet, the tiller filled with mud and was unusable. In the second field, the oat cover crop was not killed with herbicide until very late, resulting in more than 5 tons of dry matter biomass per acre. This thick, dead cover crop residue became entangled on the disk coulters and shanks running in front of the tiller, and the tiller tines also became clogged. There was clearly too much cover crop residue for strip tillage. No experiments were established in these fields.

Five sweet corn and two snap bean trials were established, however two of these fields were excluded from the analysis. In one sweet corn field, the strip-till block was established on the edge of the field next to a drainage ditch. This block was very poorly drained and contained cobbly areas. During tillage operations, this block was very wet, but a fair seed bed was obtained. The soil was so wet during planting, however, that the tractor became stuck. Although reasonable corn stands were obtained initially, later stand loss resulted from an unidentified insect (?) pest. In this field, the standard tillage block yielded 9.2 tons/acre compared to 8.1 tons/acre for the strip-till. There clearly indications that the strip-till system experienced an unidentified pest damage that the standard tillage block didn't, however the cooperating grower suggested that this field be dropped from the analysis because of the other soil drainage problems associated with the strip-till block.

A snap-bean trial was also dropped from the analysis because of a irrigation line blowout which destroyed a section of the 0.9 acre strip-till block and because one area of the strip-till plot had been used as a roadway. In this field, the standard till block produced 4.8 tons /acre and the strip-till block produced 4.1 tons/acre.

Cover Crop Biomass, Nitrogen and Carbon Content. Three of the fields obtained total cover crop biomass of approximately 1.5 tons/acre, with 76 to 103 lbs N/acre (Table 1). One field produced approx. 3/4 ton of biomass with 36 lbs N/acre. The carbon to nitrogen (C:N) ratio of the cover crop tissue ranged from 13 to 19 in the 4 fields. These C:N ratios are in a favorable range to permit rapid nitrogen mineralization and release to the following vegetable crop.

Table 1. Cover crop biomass, nitrogen, and C:N ratios for 1998 strip-till trials.

Grower	Field	Cover Crop	Dry Wt (lbs/A)	Total N (lbs/A)	C:N
Dickman	Field 32	Oat	3174	103	13
Keudell	Frank Mac	Winter wheat	3125	76	19
Kraemer	Norbs	Steptoe barley	1489	36	18
Mari-Linn	South field	Volunteer w. wheat	3125	76	19

Although the optimum cover crop biomass for strip-till systems hasn't been precisely determined, earlier studies we've conducted have suggested an optimum of approximately 2 tons/acre. In the three fields with 1.5 tons of biomass, the soil and cover crop residue were all quite manageable at time of tillage. Delaying timing of cover crop kill for a little longer would allow a slightly greater biomass and N accumulation with perhaps not having a detrimental effect on C:N ratio (becoming too "stemmy" with a high C:N ratio) or have too much biomass to be easily worked with the tillage equipment. Clearly the ratio of legume to cereal grain (or other cover crop) would also have a bearing on optimum cover crop biomass. For certain, more is not necessarily better, as we know that 4-6 tons dry matter per acre is too much biomass and causes problems with incorporation into the soil and can cause N immobilization.

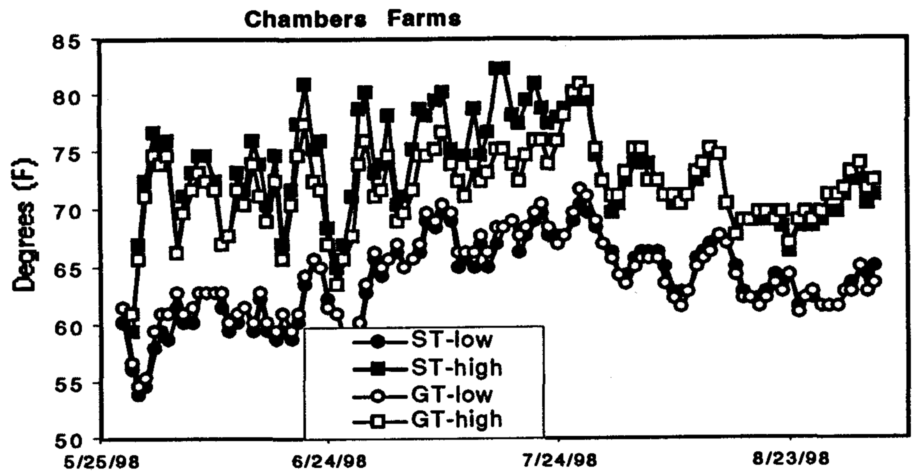

Fig. 5. Soil temperatures measured at a 4" soil depth, Mari-Linn Farms, 1998.

Yield and Economic Analysis. In the remaining 4 sweet corn trials, strip-tillage produced higher yields and increased economic return in all four fields, with an average increase of $56 per acre (Table 2). In the one snap bean trial, the strip-till plots increased economic return by $125 per acre (a 15% increase) compared to the standard tillage practice (Table 2). When considering the crops yields and economic benefits from both years of the study (1997 data are included in Table 2), there is a 78% probability of increasing net return by $74 per acre and a 22% probability of loosing $30 per acre using the strip-till system. However, in both cases of lower economic return for the strip-till in the 1997 trials, there were clear reasons why the loss occurred (see "Comments" section of Table 2). The increase in overall performance of the strip-till system in 1998, in spite of the excessively wet weather, could be attributed to improvements in tiller machine design as well as improvements in cover crop and weed management practices.

Soil Temperature Effects. There was no consistent pattern in tillage treatment effect on soil temperatures in these trials. At Mari-Linn Farms (Rod Chambers) the accumulated degree days (dd) over the season were similar, although slightly higher in the strip-till plot with 1,819 dd,than the growers tillage plot 1,769 dd (Fig.5). At Dickman Farms one of the data loggers failed during the second half of

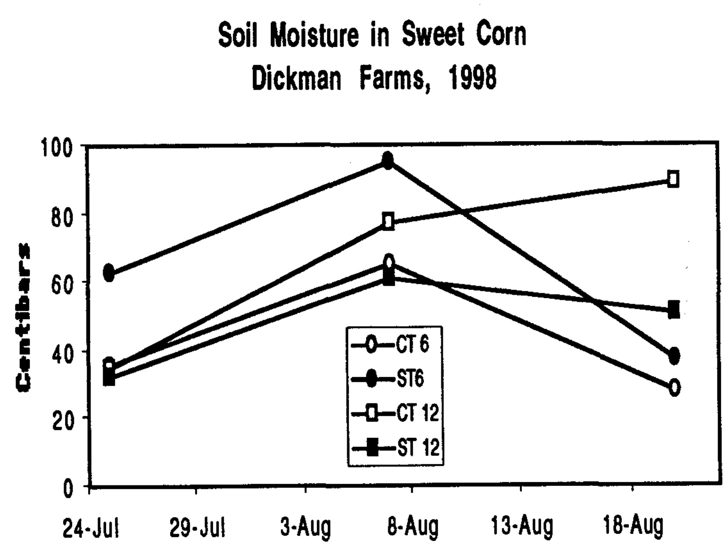

Fig. 6. Soil moisture tension in centibars at 6" and 12" in a corn field at Dickman Farms, 1998.

the season so for the first half of the growing season the strip-till plot accumulated 1,215 dd and the growers tillage received 1,320 dd.

Table 2. Graded yield, tillage cost, and comparative value of strip-till and "growers' tillage" for sweet corn and snap bean production in western Oregon, 1997-98.

Grower and field	Crop	Graded yield (tons/A)	Crop value ($/A)	Tillage savings of ST ($/A)	Comparative value of strip till ($/A)	Comments
1997						
A	Snap beans	ST: 6.2 GT: 5.2	ST: $1125 GT: $817	+$30	+$338	Different cover crops and cropping history
B	Sweet corn	ST: 8.6 GT: 8.0	ST: $750 GT: $763	-$2	-$15	Although the ST plot yielded more, field harvest was based on maturity of GT, which occupied most of the field. The ST crop matured earlier and received a lower value grade because of overmaturity at harvest.
C-1	Sweet corn	ST: 7.3 GT: 6.8	ST: $620 GT: $590	+$27	+$57	
C-2	Sweet corn	ST: 8.8 GT: 7.9	ST: $782 GT: $684	+$27	+$125	
C-3	Sweet corn	ST: 9.0 GT: 8.2	ST: $800 GT: $725	+$27	+$112	
D	Sweet corn	ST: 7.8 GT: 8.7	ST: $694 GT: $759	+$21	-$44	Cover crop sprayed out too early; poor weed control in ST
1998						
A	Sweet corn	ST: 11.4 GT: 11.0	ST: $1220 GT: $1173	+$5	+$52	
B	Snap beans	ST: 7.6 GT: 6.4	ST: $979 GT: $864	+$12*	+$127	
E-1	Sweet corn	ST: 8.8 GT: 7.9	ST: $749 GT: $637	+$19	+$131	
E-2	Sweet corn	ST: 6.9 GT: 6.9	ST: $606 GT: $606	+16	+16	Yields may be below normal because of excessive irrigation leaching nitrogen fertilizer
F	Sweet corn	ST: 9.3 GT: 8.3	ST: $807 GT: $790	+$6	+$23	

NOTES: ST= strip tillage, GT=grower's tillage;

1997 Norpac prices used for 1998, 1996 Norpac prices used for 1997.

*No actual tillage data available: this estimated value is based on the average of the other 3 farms in the 1998 trial.

Table 2. Probabilities of expected economic value associated with integrated strip-tillage systems for sweet corn production in western Oregon (n=9).

Probability of net increase in value	Average increase ($/ac)	Probability of net decrease in value	Average decrease ($/ac)
78%	$74	22%	$30

During the critical germination stage, during the first seven days after planting, there was similar degree day accumulation in both treatments at Mari-Linn Farms (ST = 98 dd; GT = 99 dd). The growers tillage treatment was slightly higher (133 dd) than the strip-till (123 dd) at the Dickman Farms.

Soil Moisture Effects. The strip-till block was dryer than the standard tillage block at the 6" depth at all three sampling dates (Fig.

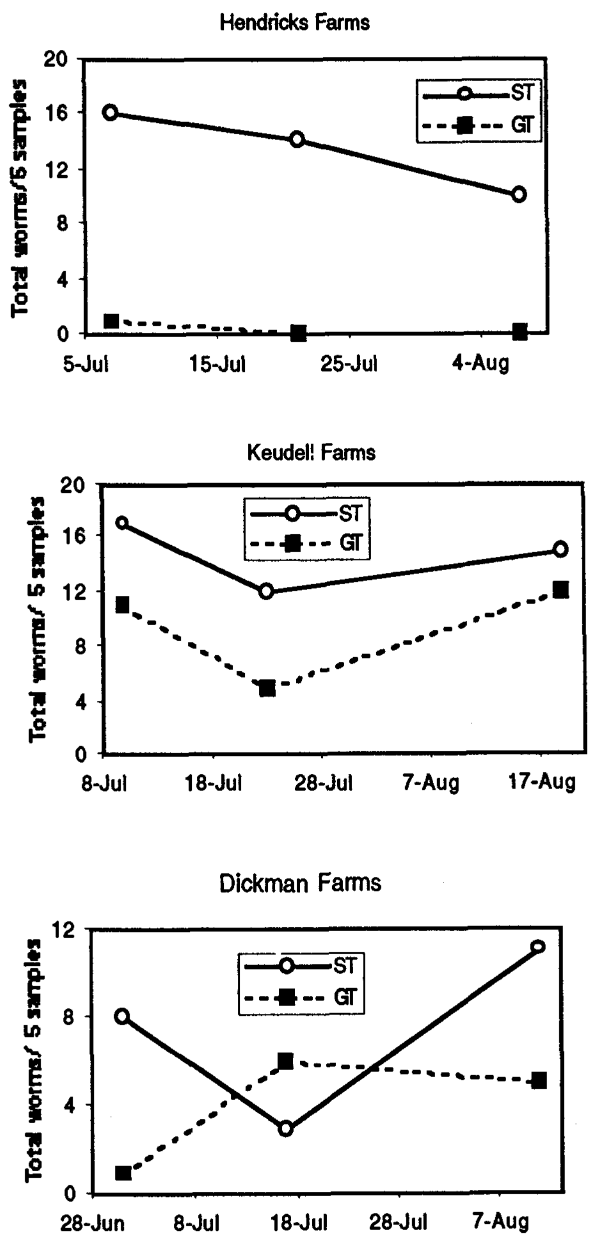

Fig. 7. Total numbers of earthworms collected using expulsion sampling.

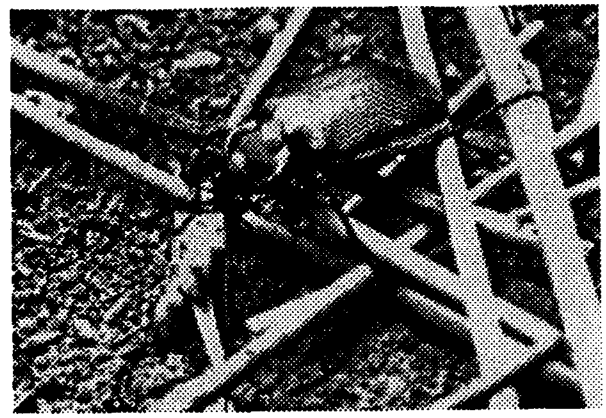

Fig. 8. Predatory ground beetles and spiders are conserved in the strip tillage system which leave cover crop residue on the soil surface.

6). At the 12" depth, however, the tillage treatments had similar moisture levels at the first sampling date (July 24), but the standard tillage block became much drier than the strip-tillage during the next two sampling dates ending on August 18.

Soil and Plant Nitrogen Effects. The PSNT tests for the tillage treatments at Dickman Farms were virtually identical, with 33 ppm for strip-till and 36 ppm for standard tillage. The "critical level" or threshold for considering N application is 18 ppm. Clearly soil nitrate was readily available to the corn crop in both tillage treatments. Plant tissue and stalk nitrate testing also revealed more than adequate N availability and similar plant tissue N concentrations of 5.4% for strip-till and 5.1% for standard tillage. Stalk nitrate levels were 9,474 ppm for strip-till and 10,683 ppm for standard till. Critically low levels are considered to be approx. 3,500 ppm, so nitrogen was clearly not lacking in the plants at time of harvest.

Earthworm Abundance Effects. Earthworms are known to improve soil fertility by incorporating organic matter into the soil and increasing nutrient turnover. Tillage can reduce earthworm populations by mechanical damage, exposure to predation or weather, destruction of burrows, or reduction in food source. At both the Hendricks Farms and Keudell Farms fields there were significantly higher worm populations in the strip till compared to grower tillage treatments (Fig. 7). At the Dickman Farm field, the results were less clear on two of the three sampling dates, the strip till plot had more earthworms, but one date the growers tillage plot contained a higher number of worms. Two of the three sampling dates the strip till plot had more worms at Dickman Farms (Fig. 7).

Soil Arthropod Activity. A major generalist predator that colonizes agricultural fields are the carabid beetles. These beetles prey upon a wide array of hosts, including important crops pests such as cutworm and slugs. More adult carabids were found over the trapping season in the strip-tillage block compared to the standard tillage block, and most of this difference occurred early in the season when the beetles could prey upon pests that could damage the young corn plants (Fig. 9). More spiders were found in the standard tillage treatment early in the growing season than in the strip-till block.

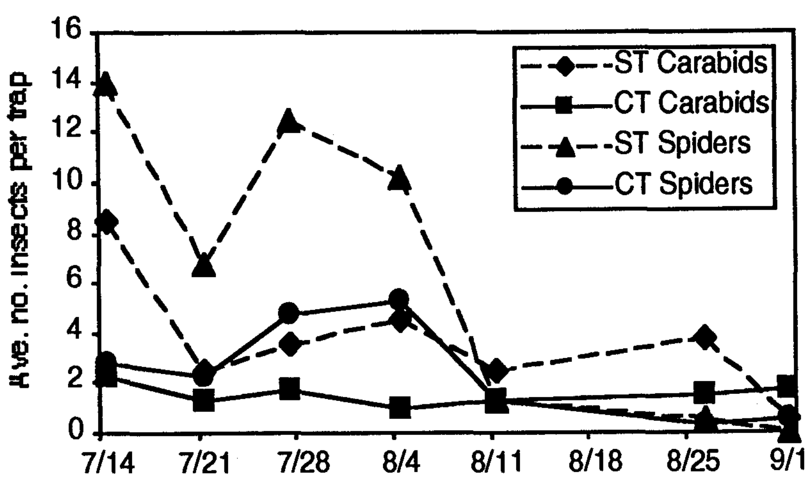

Fig. 9. Mean nNumber of spiders and ground beetles captured in pitfall trps in strip-till and standard tillage blocks in a on-farm trial near Stayton, Or., 1998.

Future Directions

Clearly, this strip tillage vegetable production system offers the potential to increase net profit, enhance soil quality through conservation of soil organic matter and biological diversity, and improve water quality through reduction of leaching and surface runoff. Reduced tillage dramatically reduces weed germination and cover crop mulches help suppress weed growth. Integrated with band-applied herbicides and high-residue cultivation, these systems offer the potential to reduce herbicide inputs. Fertilizer inputs can be dramatically reduced by the use of legume cover crops and from the enhanced nutrient capture and recycling from cereal cover crops.

For this system to be adopted a large number of vegetable growers, however, a reliable, reasonably-priced strip-tillage machine must be available. The machine must also be capable of working relatively wet soil and able to be used at 5-6 mph on a moderate-sized tractor. The growers who have been collaborating on this project met in early December, 1998, with Bill Chambers and Rob Heater of Stahlbush Island Farms to discuss future collaborative efforts to build a new strip-till machine. A decision was made to form a "Farm Improvement Club" to build a new prototype machine based on technology developed in the Midwest which will be much less expensive, lighter weight with lower horsepower requirements, and can be used at higher field speeds. This machine, to be manufactured at Stahlbush Island Farm, will use a small chisel plow and fluted coulters rather than a PTO-powered tiller to till the strips. A second pass with additional fluted coulters and clod crushers (all within narrow tilled strips) may be necessary to prepare an adequate seed bed. These changes, if they can produce high yielding crops, will greatly accelerate the adoption of this system by other vegetable growers.

Many management improvements still need to be made in this strip-till system in addition to the changes of the tiller itself, including cover crop selection and management, fertilization, and integrated pest management techniques to manage weeds and insect and pathogen pests. More effort is needed to maximize the legume component of the cover crop mixture for sweet corn production.

Acknowledgements

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Signatures of Principle Investigators: