No-Till Tomato Production

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ABSTRACT
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Tillage increases erosion rates and diminishes the quality of soils but has traditionally been a way to manage weeds and prepare a seedbed. No-till vegetable production can ameliorate the ill-effects of tillage in an economically effective way but has not been studied much in California. The objective of this thesis was to determine the viability of no-till vegetable cropping on the Central Coast of California. Tomatoes were grown in no-till and conventionally tilled treatments. Total yield, fruit weight, weed emergence, soil bulk density, soil aggregate stability, and soil organic carbon content were measured and compared. Yields and soil tests in both treatments were similar while weed emergence in the tilled plots was significantly higher than in no-till plots. The results may help vegetable producers determine how to make vegetable production on the Central Coast more sustainable.

Keywords: No-till, cover crop, soil organic matter, tillage.

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Literature Review

Introduction

No-till production in agricultural cropping systems has increased in recent years. The area of land in no-till production has increased from 4 million hectares in 1987 to about 18 million hectares in 1997 (Brady and Weil, 2004). The majority of this land is in corn and soybean production but no-till vegetable production is increasing (Groff, 2007), possibly due to the success of no-till commodity crops.

No-till as a mimicry of natural systems

Natural systems are characterized by their stability. The sun adds energy to the system and most other requirements, such as soil nutrients, are recycled. The soil is protected by plant cover, plant litter, and diverse root structures. Biota (including soil biota) is diverse and prolific. Most niches are occupied, i.e. if one plant dies another will take its place so soil will not be left bare (Woodmansee, 1984). Tillage is a very disruptive procedure that does not occur in nature on the scale that occurs in agriculture.

A definition of no-till vegetable production

No-till farming has been defined as “planting crops without prior seedbed preparation into an existing cover crop, sod, or crop residues, and eliminating subsequent tillage operations” (anonymous, 2005) or “a procedure whereby a crop is planted directly into a seedbed not tilled since harvest of the previous crop” (Brady and Weil, 2004). Plant residues cover fifty to one hundred percent of the soil surface in a no-till system. A cover crop is used to cover and protect the soil surface, especially during the winter and can be turned under by tillage as a green manure or killed and left on the surface as a mulch (Brady and Weil, 2004).

No-till vegetable production could encompass many methods but for the purposes of this paper it is described as the following. A cover crop is grown in the fall and or winter months. The cover crop can consist of legumes, non-legumes, or a mixture of both. The cover crop is then killed. It can be flail mowed (the mulch breaks down quickly to provide nutrients), rolled down by a stalk chopper or sickle-bar mower (provides a long lasting mulch for suppression of weeds and soil moisture retention), or killed by an herbicide (Carrera et al., 2004). The timing of the operation must take into account the biological characteristics of the cover crop to avoid re-growth. For example, if rye is mowed before the anthers are extended and pollen is present, it will re-grow after being mowed (Sullivan, 2003). Vegetables are then transplanted through the mulch using modified vegetable transplanters that cut through the mulch (Groff, 2007). Some examples of vegetables that have been successfully grown in this system include tomatoes (fresh market and processing), snap beans, squash, broccoli, and cucumbers (Beste 1979 in Abdul-Baki et al., 2002). Sweet corn has been successfully direct seeded through the mulch (Carrera et al., 2004).

No-Till in an Organic System

Organic certification rules do not allow the use of most herbicides. As explained below, perennial weeds are not effectively controlled by the no-till mulch. Therefore, it is unlikely that a true no-till system could be used organically. However, a modified system in which the soil is tilled occasionally, maintaining some of the benefits of the system, may be possible. Much research is needed in the area.

Benefits of cover crops

Cover crops have several benefits no matter how they are managed which include reducing soil erosion, reducing leaching losses, fixing atmospheric nitrogen (in legumes), improving the soil organic matter content (thereby increasing water infiltration rates, water holding capacity and cation exchange capacity) (Brady and Weil, 2004), and reducing weed competition (Liebman and Staver, 2001). However, legumes are more effective as mulches than as green manures in reducing weed growth, soil erosion, and water loss (Abdul-Baki and Teasdale, 1993). Legume cover crops can very effectively provide nutrients to the soil. A hairy vetch cover crop mulch in Beltsville, MD, produced 126 kg/ha of N and reduced the amount of nitrogen fertilizer needed for optimum yield of tomatoes by 101 kg/ha (Abdul-Baki et al., 1997). Forty percent of nitrogen produced by the cover crop becomes available for plants to use the first year after the cover crop is killed and left on the soil surface. About 60% is available in the same time frame when the cover crop is incorporated into the soil (Hoyt, in Sullivan, 2003).

Weed suppression in no-till vegetable production

Weeds are affected by no-till production. Mulches discourage the germination of weed seeds (Cudney et al., 2003) and tillage may bring more weeds to the surface to be germinated (Greil et al., 2003). Weed seed predation is greater in no-till systems. Scientists in North Carolina placed weed seeds on cards in tilled and no-till plots. Sixty-eight percent of the seeds were consumed in the no-till treatments compared with 27% in the tilled treatments. Carabids, ants, field mice, and crickets, in that order, were the animals most likely to consume the seeds (Brust and House, 1988). Soil cultivation has been shown to stimulate some weed seeds to germinate because of their exposure to a

flash of light (Wesson and Wareing, 1969). Lack of cultivation suppresses this reaction (Scopel et al., 1994).

Weed biomass was measured in a no-till sweet corn study using a vetch cover crop as a mulch, a cover crop mix as a mulch, and bare soil. The vetch treatment suppressed weed biomass significantly over the cover crop mixture, which suppressed weed biomass significantly over bare soil. Sweet corn yields were about 11 metric tons/ha in the vetch treatment, 8 t/ha in the cover crop mix, and 4 t/ha in the bare soil treatment (Carrera et al., 2004).

A no-till tomato experiment from 1995-1997 found different yield results. Legume/non-legume cover crop mixes produced more plant biomass than pure legume cover crops and therefore created a thicker mulch which controlled weeds more effectively. A cover crop mixture of hairy vetch, crimson clover, and rye produced 9910 kg/ha, 6620 kg/ha, and 8740 kg/ha in a three year study compared with 5180 kg/ha, 3840 kg/ha, and 6770 kg/ha of hairy vetch alone. All differences in biomass were significant except for the last year of the study. Weed biomasses in the cover crop mixture plots were 76 g/m², 299 g/m², and 161 g/m² which were significantly lower than the hairy vetch monoculture cover crop treatment weed biomasses at 204 g/m², 468 g/m², and 644 g/m². This weed biomass data are from treatments without herbicide and were collected at the first tomato harvest. The cover crop mixture treatment produced tomato yields of 106 mg/ha, 28 mg/ha, and 87 mg/ha, higher than the monoculture cover crop treatment yields of 94 mg/ha, 20 mg/ha, and 59 mg/ha. However, the only significant difference in yield was in the last year.

Of note, reduced tillage methods select for winter annuals, biennials, wind-dispersed dicots, and perennials (Greil et al., 2003). Annuals can normally survive the disturbance of tillage as seeds so they are favored in tilled systems. Perennials generally devote more energy to root growth so annuals often out-compete perennials in the first year after tillage. Those perennials will likely be more competitive than annuals in the second year after tillage due to greater reserves at the beginning of the growing season (Mohler, 2001).

No-till vegetable production and erosion

Soil erosion may be reduced in no-till agriculture. Plant growth prevents soil from being displaced by water run off (Uri, 2000) and also protects soil nutrients from leaching during storm events (Shelton, 1987: 18-23 in Abdul-Baki et al., 1993, 106). Surface litter and debris (common in no-till production) also lowers erosion rates (Woodmansee, 1984). Natural ecosystems (which no-till production partially mimics) contain larger and more numerous soil organic colloids than cultivated systems due to less oxidation and subsequent loss of organic matter. These colloids increase soil water holding capacity and water infiltration (Woodmansee, 1984). A c-value is a way to compare erosion rates of different vegetation systems in which the higher score (1 being the highest score) indicates more erosion. The c-values of no-till treatments in a corn-soybean rotation in the mid-west were 0.06 compared to the c-values of 0.53 for conventional fall plowing which removed all surface debris (Brady and Weil, 2004).

No-till production can improve soil physical properties

Soil organic matter is conserved in no-till agriculture. Organic matter is any of the carbon compounds in the soil that were formed by living organisms and are commonly

introduced into the soil by cover crops, animal residue, organic fertilizer, compost, or crop residue (Brady and Weil, 2004). Microorganisms consume the organic matter and eventually die. Their bodies form humus, which is much more resistant to further decomposition (Tan, 2003). Humus deprotonates into carboxylic acid in soils with a pH over 3.0. These anions can form ionic bonds with cation-clay molecules already in the soil (Tan, 2003). The result is a larger and more stable soil aggregate which increases pore space and subsequently increases infiltration rates of excess water, increases water absorption, gives plant roots better access to oxygen, and allows plant roots to grow more easily through the soil (Handreck, 1979). Improved soil aggregate stability can also be the result of higher microbial biomass and their by-products such as polysaccharides and proteins, which bind soil aggregates together (Stenberg, Stenberg, and Rydberg, 2000, in Stubbs et al., 2004).

A SARE (Sustainable Agricultural Resource and Education) soil quality research project was performed at Cedar Meadow Farm, PA (owned by Steve Groff) which showed a 44.2% increase in soil aggregate stability and a 23% increase in soil carbohydrates between fields using no-till methods compared to conventionally tilled fields in the last ten years. Soil bulk density dropped from 1.35 to 1.06 g/cm³ in thirty years.

Tillage mixes crop residues (organic matter) into the soil where the residue stays in contact with the microbial life that consumes it (Reicosky et al., 2000) and keeps the residue in a state that is easier to decompose (Wilson and Hargrove, 1986). Tillage physically breaks open the soil, releasing CO₂ that is already there. Generally, soil organic matter stays in the soil for twice as long in no-till systems than in tilled systems

(Paustian et al., 2000). Water infiltration rates in no-till systems can be higher than tilled systems because tillage can destroy macropores made by worms (Ehlers, 1975).

No-till production and soil biological properties

Generally, no-till soils have a higher diversity of microorganisms than tilled systems (Lupwayi, Rice, and Clayton, 1998) and a higher overall number of microbes. Microbial biomass increased by 47% in ten years on the SARE study mentioned above (Groff, 2007).

No-till biological activity is more intense near the soil surface and varies with depth. Conversely, tillage homogenizes biological activity throughout different soil layers (Doran, 1980, in Kennedy et al., 2004). Tilled soils are more influenced by bacterial activity and no-till soils are more influenced by fungal life and earthworm activity (Verhoef and Brussaard, 1990) because tillage tends to physically disrupt fungal hyphal strands. No-till soils have been found to have increased levels of glomalin (a glycoprotein), formed by arbuscular mycorrhizae, which increase aggregate stability (Wright et al., 1999). Larger organisms (mesofauna), such as nematodes (Jones, et al., 1969, and mites (Neave and Fox, 1998) also increase in number in no-till cropping. Mesofauna can be decomposers and are an important part of nutrient cycling. This trend continues with macrofauna: tillage decreases the numbers and diversity of arthropods (Zunino, 1991), and numbers of earthworms (Jordon et al., 1997).

Higher levels of soil organic matter, which no-till generally maintains, may provide food for beneficial micro-organisms which improve or protect crops. Organically grown rice in Japan was found to be more resistant to harmful fungi than conventionally grown rice (Andow and Hidaka, 1989). The plants themselves may be

bio-chemically different when grown on soil with higher soil organic matter. The same number of insects have been found in neighboring organic and conventional fields with much less damage encountered in the organic fields (with higher SOM) (Phelan, 2004).

No-till production and soil chemical properties

Tillage homogenizes the organic matter and nitrogen in the soil (Unger, 1991). Organic matter is higher in no-till soils, especially at the soil surface (Unger, 1991). Cation exchange capacity is generally increased in no-till systems because organic matter is conserved, and conversely, carbon can be severely depleted with tillage (Knops and Tilman, 2000). So, the CEC is increased because the organic matter has many bonding sites that can hold cations and exchange them with plant or microbial exuded H⁺ ions (Brady and Weil, 2004).

Economic analysis and yields of no-till production

The above-mentioned benefits of no-till vegetable production are of less consequence if they are not competitive economically. A hairy vetch no-till tomato production system in Maryland yielded 91.6 t/ha, 95.8 t/ha, and 93.2 t/ha compared with 46.3 t/ha, 88 t/ha, and 64.6 t/ha for a conventionally tilled, black plastic mulch treatment from 1992 to 1994 (Abdul-Baki et al., 1996). A three year economic study (involving Abdul-Baki's work) showed the no-till treatment annually returning \$18,207/ha compared with \$10,219/ha for the conventionally tilled treatment. The risk was lower for the no-till system as it had a 90% chance of returning at least \$11,858 while the conventionally tilled system had a 90% chance of returning only \$3,365. The no-till system used 50% of the nitrogen fertilizer used on conventional tillage methods and two less herbicide treatments (Kelly et al., 1995). Also, less tractor use may be needed. The

number of tractor operations may be decreased from eight in tilled tomatoes to two in no-till tomatoes (Mitchell et al., unpublished data, 2005).

Carbon Sequestration in No-Till Agriculture

Carbon dioxide levels in the Earth's atmosphere have increased in recent years due to fossil fuel use, industrial manufacturing processes, deforestation, and soil tillage. Many scientists believe that higher levels of greenhouse gases (including CO²) could have adverse effects on the Earth's climate (Brady and Weil, 2004). Soils are generally a carbon sink, however, tillage (among other agricultural practices) oxidizes soil carbon, sending it back to the atmosphere (Brady and Weil, 2004). No-till systems may sequester carbon more than tilled systems because the soil carbon is not exposed to excessive oxygen. One experiment demonstrated that conventionally tilled corn/soybean rotation crops are a source of 9.4 Tg C annually while no-till corn/soybean rotations are a sink of 2.2 Tg C annually. Therefore, if all land currently in corn/soybean rotations was converted to no-till, 21.65 Tg C could be sequestered each year, which could offset about 2% of US carbon emissions (Bernacchi et al., 2005). Systems with tillage rotation, which are more likely to be used in organic agriculture than pure no-till, may actually conserve more soil organic carbon than continuous no-till. An experiment found higher levels of C in no-till soils that had been plowed the previous year, possibly because the soil inversion stores more carbon at the 5 cm through 20 cm depth. Continuous plowing, however, had less soil organic carbon than both tillage rotations and continuous no-till (Purakayastha et al., 2008).

Drawbacks to no-till production

Drawbacks do exist in the no-till vegetable system. In one experiment, no-till tomato fruit harvests started ten days later than conventional tomatoes due to cooler soil temperatures under the green mulch and subsequent slow growth early in the growing season (Abdul-Baki and Teasdale, 1993). Cover crop re-growth is another problem in the system. Skill is needed to determine the correct time to kill the cover crop (Madden et al., unpublished data, 2005). Ammonia volatilization in alkaline soils may be a problem in no-till vegetable production. NH_4^+ reacts with OH^- to form H_2O and NH_3 gas.

Therefore, crop residues left on top of high pH soils can turn into a gas and enter the atmosphere under the right conditions (Brady and Weil, 2004). One way to prevent this from happening is to incorporate the plant matter into the soil; however, in natural conditions earthworms and other biota incorporate the plant matter into the soil (Brady and Weil, 2004). Therefore, high pH soils that successfully mimic natural conditions may not suffer greatly from ammonia volatilization. Also, some legumes are good hosts for harmful nematodes (Powell, 1990 in Abdul-Baki and Teasdale, 1993)

Plant pathogens can survive in no-till systems whereas they may not be a problem in tilled systems. Yields of beans were higher in tilled plots of one experiment, partially due to disease (Abawi and Widmer, 2000, in Kennedy et al., 2004) and wheat was affected by *Rhizoctonia* root rot in the no-till plots of another study (Weller et al., 1986). The disease seemed to survive in living weeds that were not destroyed between crops.

Conclusion

No-till vegetable production may be considered more sustainable than conventional production for many reasons. Cultivation greatly disturbs the environment, negatively impacting water infiltration rates, water run-off rates, erosion rates, leaching losses, and synchrony of plant-microorganism activity (Woodmansee, 1984). No-till methods disturb the soil much less and may mitigate some of these disturbances. New systems often have problems that need to be solved in order to become widely accepted. However, the work of the scientists and growers outlined in this paper has addressed many of those problems.

Objectives and Hypotheses

Objective – determine if no-till vegetable production differs significantly from conventional production in yield response, weed response, and soil physical characteristic response.

Hypothesis – there is no significant difference in the above responses between tilled treatments and no-till treatments.

Assumptions

The experiment, at its largest, will only encompass about 0.05 hectares. It is assumed that if a larger area were to be planted with the two treatments, similar results would be observed. It is also assumed that environmental conditions experienced in the two growing seasons will approximate future conditions on the Central Coast of California.

Methods and Materials

The first experiment was conducted on the campus of California Polytechnic State University, San Luis Obispo. It should be clearly noted that the second experiment (explained in detail below) was not conducted on the same ground as the first experiment. In other words, I conducted the same experiment twice but on different ground. The experimental plot was 12.8m by 21.34m (0.0273 ha). A cover crop was seeded in November of 2005. The cover crop, Soil Builder Mix, from Peaceful Valley Farm and Garden Supply includes 40% bell beans (*Vicia faba* L.), 20% mangus peas (*Pisum arvense*), 20% purple vetch (*Vicia sativa* ssp. *nigra*), 10% common vetch (*Vicia sativa*), and 10% cayuse oats (*Avena sativa*), by seed volume. Four samples of one square meter areas of the cover crop were cut, dried, and weighed on April 27, 2006 to determine above-ground biomass. The cover crop was mowed on May 2, 2006, after the all cover crop species had flowered to prevent regrowth.

The two treatments were conventional tillage and no-till. In the conventional tillage method, the cover crop was mowed with a flail mower, the soil was disked, roto-tilled, pre-irrigated, and planted. In the no-till method, the cover crop was sickle-bar mowed, pre-irrigated, and planted (both treatments were irrigated with drip line). The tomatoes (*Lycopersicon esculentum* L.) used were the “New Girl” variety (indeterminate) obtained from Johnny’s Seeds. They were seeded and grown in a greenhouse and transplanted on June 19, 2006. A hand spade was used to open a large enough space in the pre-irrigated soil to insert a transplant plug. A total of 210 plants were transplanted into 6 rows (80 inches apart from center to center), or 35 plants per row, with a plant

spacing of two feet within the row. The rows were divided into three blocks of two treatments each, or six total replications.

The crop was irrigated entirely with a drip system. The plants received water as needed according to standard agricultural practices. Equal amounts of fish emulsion fertilizer (5-1-1) were injected into the drip lines for both treatments. However, including the estimated nutrients provided by the cover crop, the tilled rows received approximately 60 kg/ha N and the no-till rows received approximately 43.86 kg/ha N.

The tomato vines were trellised with tomato twine and six foot t-posts. The plot was harvested 13 times between September 9 and October 29, 2006. Only ripe, unblemished fruit were weighed.

The second, and final, experiment was very similar to the first but larger in scope. The experimental plot was 27.4 m by 18.3 m (0.05 ha) with an access road in the middle of the plot. Actual planted ground was 0.035 ha. The Soil Builder mix cover crop (described above) was planted on November 1, 2006 at a rate of 170.3 kg/ha (152 lbs/ac). The cover crop was mowed after the plants flowered to prevent re-growth (April 25). Samples of the cover crop were taken and analyzed in the laboratory for biomass and N content.

Again there were two treatments, no-till and conventional tillage. The no-till plots were sickle-bar mowed and planted. The conventionally tilled plots were flail mowed and roto-tilled. “New Girl” tomatoes were started in a greenhouse on March 15, 2007. A total of 220 plants were transplanted on May 1 with a hand spade into 22 rows of 10 plants each, with a plant spacing of 2 feet. The row spacing was 80 inches. The

twenty-two experimental units were divided into 11 blocks. The statistical design was randomized complete block design. See the appendix for an example of the field layout.

The crop was fertilized with fish emulsion, gypsum, and boron according to a soil nutrient availability test administered by Fruit Growers Lab, Santa Paula, California. Approximately 24 lbs./acre nitrogen, 15 lbs./acre phosphorus, 11 lbs./acre potassium, 13 lbs./acre calcium, 11 lbs./acre sulfur, and 0.073 lbs./acre boron were added. The tomato plants were pruned when they were 4 weeks old by removing all visible lateral shoots beneath the first flower cluster. Five main shoots were selected for each plant and all other lateral shoots were removed until week eight when pruning operations were ceased.

The fruit was harvested when ripe (50% or more colored red). Total fruit yield (weight) per row was measured 19 times throughout the season. Average fruit weight was measured twelve times throughout the harvest season. All common mallow (*malva neglecta*) and purslane (*portulaca oleracea*) weeds were picked and counted six times during the first six weeks of crop growth.

Soil bulk density tests were performed. Metal cylinders of known volume (averaging 67.41 cm³) were hammered into the soil. The soil was dried and weighed. The bulk density was obtained by dividing the weight by the volume. Four samples were taken per experimental unit both before tillage and after harvesting was complete.

An aggregate stability test was performed once the harvest was completed. A modified soil aggregate size distribution test was performed (Kemper, et al., 1986). Four samples were collected from each experimental unit. Each sample was weighed and placed in a number 5 sieve (4000 microns/0.157 inches), which was placed on an apparatus that continually dunks the sample in water for ten minutes. The sample was

then dried and weighed and compared with the original weight to see how much soil was lost in the process.

Soil organic carbon was measured before tillage and after the harvest was completed. Four samples from each experimental unit (88 total) were taken. The samples were pulverized with a mortar and pestle, weighed and analyzed by the Elementar Variomax CNS machine in the soil science laboratory of the Earth and Soil Sciences Department at the California Polytechnic State University, San Luis Obispo. The Elementar Variomax CNS machine measures total soil carbon. However, total organic carbon may be a more useful measurement when judging possible treatment effects. Total organic carbon is a part of total soil carbon so any differences measured will include total organic carbon, however, we do not know the exact percentage of total organic carbon.

Results

The tilled rows of experiment one yielded 450.97 lbs. and the untilled rows yielded 459.84 lbs. for an overall total of 910.81 lbs., with no significant difference between treatments.

Figure 1. Experiment one: tomato yield in pounds by block with till and no-till treatments.

Similar results were recorded in experiment two. The tilled rows yielded 1331.93 lbs. and the untilled rows yielded 1209.83 lbs. for an overall total of 2541.76 (figure 2) with no significant difference between treatments.

Figure 2. Experiment two: tomato yield in pounds by block with till and no-till treatments.

The average fruit weight for all the tilled replications was 0.3028 lbs. and the average for all the no-till replications was 0.2825 lbs. (figure 3), with no significant difference between treatments.

Figure 3. Average fruit weight by block with no-till and till treatments.

Weed emergence was examined in experiment two. Seven-hundred thirty nine malva plants emerged in the tilled plots (1 plant/ft.²) and 359 malva plants emerged in the no-till plots (0.49 plants/ft.²) (figure 4). The difference in malva emergence was statistically insignificant. In the tilled plots, 2472 purslane plants emerged (3.37 plants/ft.²) and 387 purslane plants emerged in the no-till plots (0.53 plants/ft.²). There was a 99% probability that the difference in purslane emergence was due to the treatment effect. The exact number of weeds per block can be viewed in the appendix.

Figure 4. Malva and purslane weed emergence in tilled and no-till plots.

The average bulk density in the no-till plots rose from 1.29 g/cm³ to 1.50 g/cm³ (0.21 g/cm³), as can be seen in figure five. The average bulk density in the conventionally tilled plots rose from 1.30 g/cm³ to 1.44 g/cm³ (0.14 g/cm³). The results were not statistically significant.

Figure 5. Change in bulk density. The first samples were taken before tillage and the compared with samples taken after harvest.

There was no significant difference in the percentage of stable aggregates between the two treatments (see figure 6). In all of the no-till replications, 82.94% of the aggregates were stable and in the tilled replications 83.12% of the aggregates were stable.

Figure 6. Percent of stable aggregates by block with no-till and tilled treatments.

In the no-till plots, total soil carbon dropped from an average of 2.6% to an average of 2.4%, for a total average drop of 0.20% (from before tillage/planting to after the harvest was complete (figure 7). In the tilled plots, total soil carbon dropped from an average of 2.62% to an average of 2.55%, for a total average drop of 0.07%. The difference in soil carbon changes was not statistically significant.

Figure 7. Change by block of the percentage of total soil carbon in no-till and conventionally tilled treatments.

Table 1. Summary of no-till and tillage treatment effects.

	Conventional Till	No-Till	Treatment Effect
Fruit Yield (total weight in lbs.) #1	450.97	459.84	No
#2	1331.93	1209.03	No
Avg. Fruit Weight (lbs.)	0.3038	0.2825	No
Total Weed Emergence (total weeds)			
Common Mallow	739	359	No
Purslane	2472	387	99% Yes
Total Change in Bulk Density (g/cm ³)	+0.1491	+0.2108	No
% of Stable Soil Aggregates	83.12	82.94	No
% Change of Soil Organic Carbon	-0.0670	-0.2037	No

Of note, the cover crop provided 8,382 kg/ha of above ground biomass and contained 80.47 kg/ha of N (Kjeldahl procedure) in year one and 6375.33 kg/ha of above ground biomass and 172.77 kg/ha of N in year two.

Economic Analysis

Weeding costs were estimated at \$100 for the tilled plots (\$2,857/ha). It took about 10 hours total to weed (all labor costs are assumed to be \$10/hour). However, all the weeds were counted and no hoe was used. This number may have been lower if a hoe had been used. The no-till plots took about 5 hours to count and weed (\$1,428/acre). Due to the cover crop mulch it would not be possible to use a hoe. Therefore, the weeding cost numbers provided here can only reflect the cost for this experiment.

The cost to sow the seeds in trays in a greenhouse and water them for 6 weeks was estimated to be about \$10 for both treatments. Transplanting took about 1 hour for each treatment (11.57 hours/acre) (anonymous, 2006). In a larger scale operation with mechanical transplanters, the planting operation would take 6.87 hours/acre). Four and one-half gallons of fish emulsion, 1.7 lbs. of gypsum, and 250 ml of 10% boron solution were applied at a cost of about \$30 per treatment (see below for per/acre costs). Using a USDA website (www.ecat.sc.usda.gov/Cost.aspx), the cost of diesel for the tilled treatment was estimated at \$2.60 while the cost for the no-till treatment was estimated at \$0.74. The cost per gallon was assumed to be \$3.

It took about 50 hours to harvest each treatment. Although the no-till treatment yielded slightly less, it took an equal amount of time to harvest as a person has to

examine each tomato plant for fruit even if it is not there. The cost was \$500 per treatment.

Pruning and trellising costs were equal for both treatments at \$35 and \$220 respectively.

Miscellaneous work took about 5 hours (\$50) for the tilled treatment and 5.5 hours (\$55) for the no-till treatment. This estimate mostly accounts for turning on the irrigation system, fixing drip tape, applying fertilizer, and setting gopher traps. Of note, gopher holes were only encountered in the no-till treatment. Three gophers were eventually trapped, but only after three plants were killed in the no-till treatment.

Table 2. Summary of Economic Analysis of conventionally tilled and no-till tomatoes*

Costs

	(\$ Conventional Tillage		(\$ No-Till	
(Cost per acre in parenthesis)				
Weeding	100	(1,157)	50	(578)
Seed/Greenhouse	10	(116)	10	(116)
Transplant	10	(116)	10	(116)
Fertilizer (5 gal. fish)	30	(347)	300	(116)
Diesel** (tillage/mowing)	2.6	(30)	.74	(9)
Pruning	35	(404)	35	(404)
Trellising	220	(2544)	220	(2544)
Harvest/Boxing	500	(5784)	500	(5784)
Miscellaneous	50	(578)	55	(636)
Total	957.60	(11076)	910.74	(10535)
Sales \$2/lb***	2663.86			2418.06
Total Profit (2663.86 – 957.60)	1706.26	(2418.06 – 910.74)		1507.32
Total Profit/Acre ((1706.26/.035 ha)/2.47))		((1507.32/.035 ha)/2.47))		
	19,736.96			17,435.74

*There was no cost for irrigation water. The same amount was applied on both treatments.

**USDA Energy Estimator (www.ecat.sc.usda.gov/Cost.aspx)

*** \$2/lb is an approximate price for direct market sales, or in the case of these tomatoes, the price per pound for a community supported agriculture program. The cost for marketing is not reflected in this analysis.

Discussion

There was no appreciable difference in yield between the treatments in the first experiment. Much of the literature suggests that lack of tillage does not decrease yields so the results were expected (Abdul-Baki and Teasdale, 1993, Abdul-Baki et al., 1996). The slightly higher yield in the tilled areas of the second experiment could be due to the treatment. If indeed a difference exists, there are several possibilities as to why. Soil tests confirmed sufficient plant nutrients on both treatments. However, differences in soil biota in the no-till treatment may have sequestered some nutrients, making them unavailable to the tomato plants. Another possibility may be the soil structure. Soil structure should generally improve under no-till conditions. However, improvements would be minimal after less than a year without tillage. In fact, the bulk density in this experiment increased in the no-till plots, indicating a decrease in soil aggregate size. Plant roots would likely have been smaller and the plant might have captured fewer nutrients. However, the yield difference was small so it probably would not affect the viability of the system on the central coast of California.

There was no statistical difference in the average fruit weight, therefore, there seems to be no treatment effect on the weight of each tomato.

Total purslane emergence was significantly greater in the tilled treatment. The cover crop mulch in the no-till treatment probably prevented the germination of some weeds by preventing sunlight from reaching the soil. The lack of tillage in general

probably also stopped some weed seed germination because the weed seeds in the no-till plots were not brought to the surface by tillage.

Soil bulk density increased in both treatments. A bulk density increase in the tilled treatment would seem possible. Tillage can be associated with the loss of organic matter, decreasing pore size, which would make the soil more compact or dense. However, a substantial amount of organic matter was incorporated into the soil which should have at least partially offset the loss due to tillage.

The bulk density increased in the no-till treatment also. The increase was difficult to understand because, as mentioned above, the lack of tillage should conserve organic matter, keeping pores sizes static or increasing them, which would not change the bulk density or decrease it. The organic matter from the cover crop was not incorporated but, again, the bulk density at worst should stay static. Unfortunately, the methodology may have been the problem. The soil tested has many gravel-sized particles that may skew the results of the test. I had hoped that the high number of tests would account for a few skewed results, but, ultimately, I am not confident in the results of this test. A different method for determining bulk density would be recommended for future testing. Another possibility for the increase in bulk density may be compaction. Changes in bulk density during the transition to no-till will most likely vary by location, and are dependent on such variables as soil type, OM content, cropping system, and climate (Kettler et al., 2000). Franzleubbers has reported that after the adoption of no-till, surface soil can become temporarily compacted (Franzluebbbers, 2004).

Total soil carbon decreased in the conventionally tilled treatment. Again, tillage encourages the loss of carbon stored in the soil so a loss could be explained. However,

the incorporation of the cover crop (containing large amounts of carbon) should have mitigated the loss somewhat.

More perplexing is the larger loss of total soil carbon in the no-till treatment. There is no obvious pathway for soil carbon to be lost to the atmosphere without tillage. Granted, the cover crop was not incorporated and much of it was still intact on the soil surface when the tests were performed. Therefore, no gain of carbon could be expected. Shrink/swell properties of soil could explain some loss, however, the samples were taken from the drip line zone (i.e. irrigated) and that soil was kept at near full water capacity and should not have exhibited cracks.

Judging by the data recorded in this experiment, incorporating the cover crop into the soil may improve the soil more than leaving the cover crop on the soil surface for one cropping period.

A cursory look at the estimated costs of producing these fresh market tomatoes shows that labor is by far the biggest concern. All of those costs are almost identical in both treatments except for weeding. No-till production methods could save the farmer money in this area. Almost no weed growth was observed in both treatments outside of the drip tape zone (probably due to the Mediterranean climate with zero rainfall in the summer) so mechanical weeding with a tractor would not be an advantage in the tilled treatment. The only ways to get rid of the weeds was by hand-pulling or with a hoe. As mentioned above, the hoe is not practical in the no-till treatment because of the cover crop mulch. Logically, using a hoe is more efficient, however, we have shown that there are more weeds to be destroyed and the weeds closest to the tomato plants would have to be hand-pulled in the conventionally tilled treatment anyway. So, the real question is

which method takes more labor. An experiment that can more precisely answer that question would help greatly in determining the efficacy of no-till vegetable production, especially under organic certification standards.

Another question that is difficult to answer is the cost of soil erosion. Erosion is not something that often shows up on budgetary spreadsheets but could certainly cost a farmer dearly in the long term. No attempt is made here to put a dollar amount on soil lost due to agriculture, but all can agree that less is better. Both treatments were treated equally until the cover crop was tilled under in the conventional treatment and the soil was left uncovered except for the tomato plants. No rainfall was measured during the growing season of the tomatoes so water erosion was not a factor. Wind erosion was not studied but, due to the protection of the cover crop mulch on the no-till treatment, wind erosion should be less likely. Again, a study on the amount of wind erosion from both treatments would help determine if no-till vegetable production is viable.

Conclusion

The two years of yield data suggest that there is no significant yield loss for no-till tomato production on the Central Coast of California. Purslane weed seeds are much less likely to germinate in no-till conditions. Soil bulk density and soil aggregate stability are not affected by no-till methods during one tomato cropping period. Soil carbon did not increase by eliminating tillage.

During the course of this study, some questions were raised that may be interesting to answer to better understand no-till methods. Annual weeds were less likely to germinate but does that mean less work for a farmer? Is wind erosion decreased by the

lack of tillage and cover crop mulch over conventional tillage? Does the no-till system require less water to keep the soil close to field capacity? Future studies might answer these questions.

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Appendix

Timetable

Experiment 1

Nov. 15, 2005 – Cover crop planted

April 4, 2006 – Tomato seeds planted in trays in greenhouse

April 4, 2006 – Cover crop samples harvested

May 2, 2006 – Flail mowed areas to be disked

May 4, 2006 – More cover crop samples harvested

May 5, 2006 – Sickle-bar mowed appropriate areas

May 6, 2006 – Disked appropriate areas

June 18, 2006 – Pre-irrigated

June 19, 2006 – Roto-tilled appropriate areas

- Tomatoes transplanted

Summer, 2006 – Tomato crop fertilized and irrigated as needed.

Sept. 12 – Nov. 5, 2006 – Harvested tomatoes

Experiment 2

Nov. 1, 2006 – Cover crop planted

March 15, 2007 – Plant tomato seeds in flats in greenhouse

April 1, 2007 – Plant back-up tomatoes in greenhouse

April 25, 2007 – Harvest cover crop samples

April 25, 2007 – Flail mow and sickle-bar mow appropriate areas, collect soil samples

May 9, 2007 – Knifed and roto-tilled appropriate areas

May 14, 2007 – Set up irrigation system, pre-irrigate

May 15, 2007 – Transplant tomatoes

Summer, 2007 – Collect weed samples

Summer, 2007 – Fertilize and irrigate as needed

August 11 – October 4, 2007 – Harvest tomatoes

October, 2007 – Collect soil samples

Raw Data

Total Yield – Experiment One

Block	Date	Tillage	Yield (lbs.)
1	12-Sep	Till	1.06
1	12-Sep	No-Till	0.34
2	12-Sep	Till	1.07
2	12-Sep	No-Till	0.12
3	12-Sep	Till	0
3	12-Sep	No-Till	1.13
1	15-Sep	Till	0.8
1	15-Sep	No-Till	0.77
2	15-Sep	Till	0.42
2	15-Sep	No-Till	0.44
3	15-Sep	Till	0
3	15-Sep	No-Till	1.42
1	19-Sep	Till	0.28
1	19-Sep	No-Till	0.57
2	19-Sep	Till	0.65
2	19-Sep	No-Till	0.4
3	19-Sep	Till	0.45
3	19-Sep	No-Till	0.55
1	21-Sep	Till	2.54
1	21-Sep	No-Till	1.18
2	21-Sep	Till	1.25
2	21-Sep	No-Till	1.16
3	21-Sep	Till	0.56
3	21-Sep	No-Till	1.37
1	25-Sep	Till	6.66
1	25-Sep	No-Till	3.64
2	25-Sep	Till	7.04
2	25-Sep	No-Till	7.43
3	25-Sep	Till	3.67
3	25-Sep	No-Till	3.97
1	29-Sep	Till	6.45
1	29-Sep	No-Till	3.62
2	29-Sep	Till	6.56
2	29-Sep	No-Till	10.16
3	29-Sep	Till	2.65
3	29-Sep	No-Till	2.63
1	2-Oct	Till	13.29
1	2-Oct	No-Till	11.36
2	2-Oct	Till	18.73
2	2-Oct	No-Till	18.75
3	2-Oct	Till	8.94
3	2-Oct	No-Till	14.39
1	6-Oct	Till	22.85
1	6-Oct	No-Till	9.66

2	6-Oct	Till	11.4
2	6-Oct	No-Till	26.74
3	6-Oct	Till	9.65
3	6-Oct	No-Till	7.33
1	10-Oct	Till	14.85
1	10-Oct	No-Till	13.09
2	10-Oct	Till	17.09
2	10-Oct	No-Till	25
3	10-Oct	Till	12.31
3	10-Oct	No-Till	15.6
1	14-Oct	Till	25.64
1	14-Oct	No-Till	16.92
2	14-Oct	Till	24.59
2	14-Oct	No-Till	18.96
3	14-Oct	Till	20.37
3	14-Oct	No-Till	27.3
1	17-Oct	Till	4.27
1	17-Oct	No-Till	7.15
2	17-Oct	Till	14.63
2	17-Oct	No-Till	17.69
3	17-Oct	Till	13.25
3	17-Oct	No-Till	10.91
1	22-Oct	Till	14.75
1	22-Oct	No-Till	19.01
2	22-Oct	Till	20.12
2	22-Oct	No-Till	21
3	22-Oct	Till	9.32
3	22-Oct	No-Till	15.1
1	29-Oct	Till	18.64
1	29-Oct	No-Till	19.18
2	29-Oct	Till	23.01
2	29-Oct	No-Till	20.16
3	29-Oct	Till	19.32
3	29-Oct	No-Till	16.15
1	5-Nov	Till	24.94
1	5-Nov	No-Till	20.42
2	5-Nov	Till	17.27
2	5-Nov	No-Till	21.53
3	5-Nov	Till	29.63
3	5-Nov	No-Till	25.54

Total Yield – Experiment 2

Block	Date	Tillage	Yield (lbs.)	Avg. Weight
1	11-Aug	Till	0	
1	11-Aug	No-Till	0.76	0.25
2	11-Aug	Till	0	0
2	11-Aug	No-Till	0	0
3	11-Aug	Till	0	0
3	11-Aug	No-Till	0	0
4	11-Aug	Till	0	0
4	11-Aug	No-Till	0.24	0.24
5	11-Aug	Till	0	0
5	11-Aug	No-Till	0.49	0.25
6	11-Aug	Till	0	0
6	11-Aug	No-Till	0	0
7	11-Aug	Till	0	0
7	11-Aug	No-Till	0	0
8	11-Aug	Till	0	0
8	11-Aug	No-Till	0	0
9	11-Aug	Till	0	0
9	11-Aug	No-Till	0	0
10	11-Aug	Till	0	0
10	11-Aug	No-Till	0	0
11	11-Aug	Till	0	0
11	11-Aug	No-Till	0	0
1	14-Aug	Till	0	0
1	14-Aug	No-Till	0.71	0.24
2	14-Aug	Till	0	0
2	14-Aug	No-Till	0.34	0.34
3	14-Aug	Till	0	0
3	14-Aug	No-Till	0	0
4	14-Aug	Till	0	0
4	14-Aug	No-Till	0	0
5	14-Aug	Till	0.3	0.3
5	14-Aug	No-Till	0.71	0.36
6	14-Aug	Till	0	0
6	14-Aug	No-Till	0.99	0.33
7	14-Aug	Till	0.3	0.30
7	14-Aug	No-Till	0	0
8	14-Aug	Till	0	0
8	14-Aug	No-Till	0	0
9	14-Aug	Till	0	0
9	14-Aug	No-Till	0	0
10	14-Aug	Till	0	0
10	14-Aug	No-Till	0	0
11	14-Aug	Till	0	0
11	14-Aug	No-Till	0.89	0.30
1	16-Aug	Till	0.29	0.29
1	16-Aug	No-Till	1.77	0.35

2	16-Aug	Till	0	0
2	16-Aug	No-Till	1.41	0.28
3	16-Aug	Till	0.27	0.27
3	16-Aug	No-Till	0.6	0.3
4	16-Aug	Till	0.46	0.46
4	16-Aug	No-Till	0.58	0.29
5	16-Aug	Till	0.88	0.29
5	16-Aug	No-Till	0.92	0.31
6	16-Aug	Till	0.29	0.29
6	16-Aug	No-Till	0	0
7	16-Aug	Till	0.64	0.32
7	16-Aug	No-Till	1.07	0.27
8	16-Aug	Till	0.21	0.21
8	16-Aug	No-Till	0.21	0.21
9	16-Aug	Till	0	0
9	16-Aug	No-Till	0.94	0.31
10	16-Aug	Till	0.16	0.16
10	16-Aug	No-Till	0	0
11	16-Aug	Till	0	0
11	16-Aug	No-Till	0.59	0.30
1	19-Aug	Till	0.38	0.38
1	19-Aug	No-Till	1.98	0.33
2	19-Aug	Till	0	0
2	19-Aug	No-Till	1.19	0.30
3	19-Aug	Till	0	0
3	19-Aug	No-Till	1.1	0.28
4	19-Aug	Till	1.02	0.34
4	19-Aug	No-Till	1.81	0.30
5	19-Aug	Till	0.38	0.19
5	19-Aug	No-Till	1.18	0.30
6	19-Aug	Till	0.63	0.63
6	19-Aug	No-Till	1.62	0.32
7	19-Aug	Till	1.08	0.36
7	19-Aug	No-Till	0.93	0.31
8	19-Aug	Till	0	0
8	19-Aug	No-Till	0.66	0.22
9	19-Aug	Till	0	0
9	19-Aug	No-Till	0.87	0.29
10	19-Aug	Till	0.23	0.23
10	19-Aug	No-Till	0.5	0.50
11	19-Aug	Till	0	0
11	19-Aug	No-Till	0	0
1	22-Aug	Till	0.86	0.43
1	22-Aug	No-Till	1.8	0.30
2	22-Aug	Till	1.4	0.35
2	22-Aug	No-Till	2.22	0.32
3	22-Aug	Till	3.13	0.39
3	22-Aug	No-Till	2.39	0.34
4	22-Aug	Till	0.99	0.33

4	22-Aug	No-Till	0.36	0.36
5	22-Aug	Till	1.39	0.35
5	22-Aug	No-Till	1.99	0.28
6	22-Aug	Till	1.44	0.48
6	22-Aug	No-Till	0.31	0.31
7	22-Aug	Till	1.31	0.33
7	22-Aug	No-Till	1.08	0.36
8	22-Aug	Till	0.7	0.35
8	22-Aug	No-Till	1.94	0.32
9	22-Aug	Till	0.66	0.33
9	22-Aug	No-Till	0.17	0.17
10	22-Aug	Till	0	0
10	22-Aug	No-Till	0.49	0.25
11	22-Aug	Till	0	0
11	22-Aug	No-Till	0.71	0.24
1	24-Aug	Till	2.33	0.47
1	24-Aug	No-Till	3.24	0.46
2	24-Aug	Till	3.41	0.43
2	24-Aug	No-Till	4.28	0.36
3	24-Aug	Till	2.79	0.35
3	24-Aug	No-Till	2	0.40
4	24-Aug	Till	1.29	0.43
4	24-Aug	No-Till	2.96	0.30
5	24-Aug	Till	2.03	0.34
5	24-Aug	No-Till	2.87	0.32
6	24-Aug	Till	1.66	0.42
6	24-Aug	No-Till	0.96	0.32
7	24-Aug	Till	0.98	0.33
7	24-Aug	No-Till	0.9	0.30
8	24-Aug	Till	1.9	0.32
8	24-Aug	No-Till	0.98	0.25
9	24-Aug	Till	0.47	0.24
9	24-Aug	No-Till	1.39	0.23
10	24-Aug	Till	0.87	0.44
10	24-Aug	No-Till	0	0
11	24-Aug	Till	0	0
11	24-Aug	No-Till	0.75	0.25
1	25-Aug	Till	1.58	0.32
1	25-Aug	No-Till	2.7	0.30
2	25-Aug	Till	2.22	0.37
2	25-Aug	No-Till	2.09	0.35
3	25-Aug	Till	4.13	0.34
3	25-Aug	No-Till	5.17	0.34
4	25-Aug	Till	1.38	0.28
4	25-Aug	No-Till	2.1	0.35
5	25-Aug	Till	2.9	0.32
5	25-Aug	No-Till	2.12	0.27
6	25-Aug	Till	0.57	0.29
6	25-Aug	No-Till	1.13	0.28

7	25-Aug	Till	2.2	0.28
7	25-Aug	No-Till	1.5	0.30
8	25-Aug	Till	1.5	0.30
8	25-Aug	No-Till	1.52	0.25
9	25-Aug	Till	1.5	0.30
9	25-Aug	No-Till	4.05	0.27
10	25-Aug	Till	3.17	0.35
10	25-Aug	No-Till	0.82	0.27
11	25-Aug	Till	0	0
11	25-Aug	No-Till	2.9	0.29
1	28-Aug	Till	4.88	0.31
1	28-Aug	No-Till	1.61	0.27
2	28-Aug	Till	5.28	0.41
2	28-Aug	No-Till	5.49	0.29
3	28-Aug	Till	3.67	0.31
3	28-Aug	No-Till	4.24	0.27
4	28-Aug	Till	3.6	0.28
4	28-Aug	No-Till	3.6	0.28
5	28-Aug	Till	4.36	0.29
5	28-Aug	No-Till	3.27	0.25
6	28-Aug	Till	0.62	0.21
6	28-Aug	No-Till	2.25	0.28
7	28-Aug	Till	2.83	0.26
7	28-Aug	No-Till	2.6	0.26
8	28-Aug	Till	2.81	0.35
8	28-Aug	No-Till	3.33	0.26
9	28-Aug	Till	4.56	0.25
9	28-Aug	No-Till	2.9	0.29
10	28-Aug	Till	2.97	0.30
10	28-Aug	No-Till	1.63	0.20
11	28-Aug	Till	0	0
11	28-Aug	No-Till	4.53	0.25
1	1-Sep	Till	6.12	0.31
1	1-Sep	No-Till	4.48	0.28
2	1-Sep	Till	6.52	0.30
2	1-Sep	No-Till	7.86	0.28
3	1-Sep	Till	4.83	0.35
3	1-Sep	No-Till	4.19	0.26
4	1-Sep	Till	2.96	0.30
4	1-Sep	No-Till	4.25	0.30
5	1-Sep	Till	5.15	0.29
5	1-Sep	No-Till	3.66	0.31
6	1-Sep	Till	5.2	0.37
6	1-Sep	No-Till	4.39	0.31
7	1-Sep	Till	4.17	0.30
7	1-Sep	No-Till	3.16	0.29
8	1-Sep	Till	8.77	0.31
8	1-Sep	No-Till	4.16	0.24
9	1-Sep	Till	2.3	0.26

9	1-Sep	No-Till	6.62	0.26
10	1-Sep	Till	3.76	0.31
10	1-Sep	No-Till	2.48	0.23
11	1-Sep	Till	0	0
11	1-Sep	No-Till	3.41	0.28
1	3-Sep	Till	5.71	0.27
1	3-Sep	No-Till	8.96	0.26
2	3-Sep	Till	13.07	0.30
2	3-Sep	No-Till	11.68	0.27
3	3-Sep	Till	16.62	0.29
3	3-Sep	No-Till	15.9	0.28
4	3-Sep	Till	11.1	0.28
4	3-Sep	No-Till	11.2	0.23
5	3-Sep	Till	9.4	0.28
5	3-Sep	No-Till	11.6	0.29
6	3-Sep	Till	7.5	0.31
6	3-Sep	No-Till	5.6	0.29
7	3-Sep	Till	9.8	0.26
7	3-Sep	No-Till	8.8	0.24
8	3-Sep	Till	7	0.28
8	3-Sep	No-Till	5.7	0.25
9	3-Sep	Till	6.7	0.24
9	3-Sep	No-Till	8.5	0.28
10	3-Sep	Till	8.3	0.28
10	3-Sep	No-Till	2.7	0.23
11	3-Sep	Till	1.65	0.21
11	3-Sep	No-Till	6.7	0.25
1	5-Sep	Till	4.4	0.26
1	5-Sep	No-Till	3.4	0.26
2	5-Sep	Till	3.9	0.28
2	5-Sep	No-Till	2.6	0.26
3	5-Sep	Till	2.1	0.30
3	5-Sep	No-Till	4.4	0.29
4	5-Sep	Till	3.9	0.23
4	5-Sep	No-Till	3.3	0.24
5	5-Sep	Till	3.2	0.23
5	5-Sep	No-Till	4.2	0.35
6	5-Sep	Till	2.35	0.29
6	5-Sep	No-Till	2.4	0.30
7	5-Sep	Till	2.8	0.25
7	5-Sep	No-Till	4	0.29
8	5-Sep	Till	3.67	0.24
8	5-Sep	No-Till	2.7	0.27
9	5-Sep	Till	2.9	0.26
9	5-Sep	No-Till	4.4	0.28
10	5-Sep	Till	0.93	0.23
10	5-Sep	No-Till	1.35	0.23
11	5-Sep	Till	1.45	0.24
11	5-Sep	No-Till	1.75	0.22

1	6-Sep	Till	10.3
1	6-Sep	No-Till	10.96
2	6-Sep	Till	15.22
2	6-Sep	No-Till	12.91
3	6-Sep	Till	10.35
3	6-Sep	No-Till	16.31
4	6-Sep	Till	11.55
4	6-Sep	No-Till	12.35
5	6-Sep	Till	14.14
5	6-Sep	No-Till	11.81
6	6-Sep	Till	6.88
6	6-Sep	No-Till	10.33
7	6-Sep	Till	12.73
7	6-Sep	No-Till	11.37
8	6-Sep	Till	15.14
8	6-Sep	No-Till	12.46
9	6-Sep	Till	14.65
9	6-Sep	No-Till	15.9
10	6-Sep	Till	15.42
10	6-Sep	No-Till	5.21
11	6-Sep	Till	5.06
11	6-Sep	No-Till	10.41
1	10-Sep	Till	35.18
1	10-Sep	No-Till	22.23
2	10-Sep	Till	19.39
2	10-Sep	No-Till	14.56
3	10-Sep	Till	13.84
3	10-Sep	No-Till	17.67
4	10-Sep	Till	23.53
4	10-Sep	No-Till	12.08
5	10-Sep	Till	18.48
5	10-Sep	No-Till	17.58
6	10-Sep	Till	12.64
6	10-Sep	No-Till	14.62
7	10-Sep	Till	9.63
7	10-Sep	No-Till	9.4
8	10-Sep	Till	14.89
8	10-Sep	No-Till	9.93
9	10-Sep	Till	16.22
9	10-Sep	No-Till	17.53
10	10-Sep	Till	12.95
10	10-Sep	No-Till	16.48
11	10-Sep	Till	11.71
11	10-Sep	No-Till	18.09
1	13-Sep	Till	4.8
1	13-Sep	No-Till	13.34
2	13-Sep	Till	24.17
2	13-Sep	No-Till	12.63
3	13-Sep	Till	19.22

3	13-Sep	No-Till	23.17	
4	13-Sep	Till	18.84	
4	13-Sep	No-Till	15.42	
5	13-Sep	Till	13.35	
5	13-Sep	No-Till	17.89	
6	13-Sep	Till	15.74	
6	13-Sep	No-Till	14.99	
7	13-Sep	Till	17.6	
7	13-Sep	No-Till	19.29	
8	13-Sep	Till	12.16	
8	13-Sep	No-Till	11.45	
9	13-Sep	Till	18	
9	13-Sep	No-Till	9.73	
10	13-Sep	Till	9.7	
10	13-Sep	No-Till	3.56	
11	13-Sep	Till	8.94	
11	13-Sep	No-Till	7.15	
1	17-Sep	Till	22.76	
1	17-Sep	No-Till	9	
2	17-Sep	Till	9.13	
2	17-Sep	No-Till	18.43	
3	17-Sep	Till	27.29	
3	17-Sep	No-Till	10.1	
4	17-Sep	Till	14.37	
4	17-Sep	No-Till	11.73	
5	17-Sep	Till	24.36	
5	17-Sep	No-Till	18.66	
6	17-Sep	Till	8.17	
6	17-Sep	No-Till	13.2	
7	17-Sep	Till	18.75	
7	17-Sep	No-Till	8.64	
8	17-Sep	Till	12.32	
8	17-Sep	No-Till	5.78	
9	17-Sep	Till	9.85	
9	17-Sep	No-Till	19.82	
10	17-Sep	Till	20.49	
10	17-Sep	No-Till	5.4	
11	17-Sep	Till	11.12	
11	17-Sep	No-Till	8.66	
1	22-Sep	Till	4.72	0.15
1	22-Sep	No-Till	9.41	0.18
2	22-Sep	Till	8.28	0.17
2	22-Sep	No-Till	8.3	0.18
3	22-Sep	Till	10.67	0.16
3	22-Sep	No-Till	10.28	0.18
4	22-Sep	Till	9.09	0.17
4	22-Sep	No-Till	7.05	0.20
5	22-Sep	Till	8.65	0.18
5	22-Sep	No-Till	10.82	0.20

6	22-Sep	Till	12.11	0.23
6	22-Sep	No-Till	9	0.23
7	22-Sep	Till	5.15	0.17
7	22-Sep	No-Till	6.22	0.19
8	22-Sep	Till	4.78	0.14
8	22-Sep	No-Till	7.82	0.22
9	22-Sep	Till	10.09	0.21
9	22-Sep	No-Till	6.09	0.17
10	22-Sep	Till	4.7	0.17
10	22-Sep	No-Till	4.6	0.20
11	22-Sep	Till	10.8	0.18
11	22-Sep	No-Till	8.93	0.24
1	27-Sep	Till	7.92	
1	27-Sep	No-Till	7.97	
2	27-Sep	Till	8.65	
2	27-Sep	No-Till	7.98	
3	27-Sep	Till	10.53	
3	27-Sep	No-Till	18.6	
4	27-Sep	Till	17.75	
4	27-Sep	No-Till	10.2	
5	27-Sep	Till	14.53	
5	27-Sep	No-Till	19.5	
6	27-Sep	Till	13.53	
6	27-Sep	No-Till	6.51	
7	27-Sep	Till	16.17	
7	27-Sep	No-Till	10.36	
8	27-Sep	Till	15.97	
8	27-Sep	No-Till	10.15	
9	27-Sep	Till	10.23	
9	27-Sep	No-Till	9.55	
10	27-Sep	Till	14.5	
10	27-Sep	No-Till	8.93	
11	27-Sep	Till	23.85	
11	27-Sep	No-Till	5.9	
1	1-Oct	Till	4.15	
1	1-Oct	No-Till	2.8	
2	1-Oct	Till	5.7	
2	1-Oct	No-Till	4.83	
3	1-Oct	Till	7.18	
3	1-Oct	No-Till	4.6	
4	1-Oct	Till	9.36	
4	1-Oct	No-Till	4.5	
5	1-Oct	Till	11	
5	1-Oct	No-Till	9	
6	1-Oct	Till	14	
6	1-Oct	No-Till	9.54	
7	1-Oct	Till	6	
7	1-Oct	No-Till	8.3	
8	1-Oct	Till	7.92	

8	1-Oct	No-Till	9.33
9	1-Oct	Till	12.68
9	1-Oct	No-Till	8.3
10	1-Oct	Till	6.4
10	1-Oct	No-Till	4.32
11	1-Oct	Till	13.5
11	1-Oct	No-Till	3.82
1	4-Oct	Till	5.35
1	4-Oct	No-Till	4.07
2	4-Oct	Till	2.64
2	4-Oct	No-Till	7.05
3	4-Oct	Till	12.03
3	4-Oct	No-Till	5.24
4	4-Oct	Till	2.97
4	4-Oct	No-Till	1.2
5	4-Oct	Till	7.78
5	4-Oct	No-Till	3.32
6	4-Oct	Till	3.52
6	4-Oct	No-Till	13.33
7	4-Oct	Till	10.47
7	4-Oct	No-Till	2.5
8	4-Oct	Till	2.47
8	4-Oct	No-Till	5.06
9	4-Oct	Till	2.5
9	4-Oct	No-Till	6.63
10	4-Oct	Till	3.93
10	4-Oct	No-Till	3.58
11	4-Oct	Till	4.32
11	4-Oct	No-Till	5.48

Weed Emergence – Common Mallow, Purslane

Block	Date	Tillage	Malva	Purslane	Total
1	5-Jun	Till	19	67	86
1	5-Jun	No-till	11	7	18
2	5-Jun	Till	25	353	378
2	5-Jun	No-till	0	0	0
3	5-Jun	Till	30	39	69
3	5-Jun	No-till	25	3	28
4	5-Jun	Till	11	249	260
4	5-Jun	No-till	31	11	42
5	5-Jun	Till	6	64	70
5	5-Jun	No-till	6	1	7
6	5-Jun	Till	47	141	188
6	5-Jun	No-till	0	2	2
7	5-Jun	Till	26	423	449
7	5-Jun	No-till	3	1	4
8	5-Jun	Till	10	124	134
8	5-Jun	No-till	21	11	32
9	5-Jun	Till	29	95	124
9	5-Jun	No-till	2	73	75
10	5-Jun	Till	17	285	302
10	5-Jun	No-till	10	6	16
11	5-Jun	Till	6	50	56
11	5-Jun	No-till	1	25	26
1	12-Jun	Till	6	13	19
1	12-Jun	No-till	1	0	1
2	12-Jun	Till	55	68	123
2	12-Jun	No-till	0	0	0
3	12-Jun	Till	9	7	16
3	12-Jun	No-till	4	2	6
4	12-Jun	Till	4	15	19
4	12-Jun	No-till	9	1	10
5	12-Jun	Till	1	10	11
5	12-Jun	No-till	5	2	7
6	12-Jun	Till	31	17	48
6	12-Jun	No-till	0	0	0
7	12-Jun	Till	7	34	41
7	12-Jun	No-till	1	0	1
8	12-Jun	Till	3	23	26
8	12-Jun	No-till	3	2	5
9	12-Jun	Till	18	19	37
9	12-Jun	No-till	1	24	25
10	12-Jun	Till	24	55	79
10	12-Jun	No-till	0	0	0
11	12-Jun	Till	1	31	32
11	12-Jun	No-till	3	10	13

1	19-Jun	Till	2	13	15
1	19-Jun	No-till	0	0	0
2	19-Jun	Till	14	29	43
2	19-Jun	No-till	0	1	1
3	19-Jun	Till	0	0	0
3	19-Jun	No-till	2	4	6
4	19-Jun	Till	2	13	15
4	19-Jun	No-till	5	7	12
5	19-Jun	Till	0	8	8
5	19-Jun	No-till	3	1	4
6	19-Jun	Till	9	18	27
6	19-Jun	No-till	1	1	2
7	19-Jun	Till	4	31	35
7	19-Jun	No-till	3	2	5
8	19-Jun	Till	1	13	14
8	19-Jun	No-till	1	1	2
9	19-Jun	Till	3	4	7
9	19-Jun	No-till	3	38	41
10	19-Jun	Till	9	25	34
10	19-Jun	No-till	4	8	12
11	19-Jun	Till	0	2	2
11	19-Jun	No-till	2	9	11
1	26-Jun	Till	2	1	3
1	26-Jun	No-till	2	7	9
2	26-Jun	Till	15	9	24
2	26-Jun	No-till	1	2	3
3	26-Jun	Till	4	4	8
3	26-Jun	No-till	7	1	8
4	26-Jun	Till	0	2	2
4	26-Jun	No-till	2	4	6
5	26-Jun	Till	1	1	2
5	26-Jun	No-till	0	2	2
6	26-Jun	Till	3	3	6
6	26-Jun	No-till	0	0	0
7	26-Jun	Till	3	1	4
7	26-Jun	No-till	1	0	1
8	26-Jun	Till	1	3	4
8	26-Jun	No-till	1	0	1
9	26-Jun	Till	1	3	4
9	26-Jun	No-till	4	3	7
10	26-Jun	Till	3	3	6
10	26-Jun	No-till	0	0	0
11	26-Jun	Till	4	22	26
11	26-Jun	No-till	3	12	15
1	11-Jul	Till	9	0	9
1	11-Jul	No-till	10	4	14
2	11-Jul	Till	39	6	45
2	11-Jul	No-till	6	0	6
3	11-Jul	Till	12	2	14

3	11-Jul	No-till	13	0	13
4	11-Jul	Till	9	2	11
4	11-Jul	No-till	23	6	29
5	11-Jul	Till	6	11	17
5	11-Jul	No-till	4	5	9
6	11-Jul	Till	11	1	12
6	11-Jul	No-till	2	0	2
7	11-Jul	Till	18	13	31
7	11-Jul	No-till	0	0	0
8	11-Jul	Till	1	3	4
8	11-Jul	No-till	12	8	20
9	11-Jul	Till	28	6	34
9	11-Jul	No-till	11	38	49
10	11-Jul	Till	6	9	15
10	11-Jul	No-till	6	2	8
11	11-Jul	Till	9	5	14
11	11-Jul	No-till	1	7	8
1	8-Aug	Till	11	0	11
1	8-Aug	No-till	11	5	16
2	8-Aug	Till	6	4	10
2	8-Aug	No-till	2	0	2
3	8-Aug	Till	8	0	8
3	8-Aug	No-till	17	1	18
4	8-Aug	Till	6	4	10
4	8-Aug	No-till	9	3	12
5	8-Aug	Till	10	0	10
5	8-Aug	No-till	3	2	5
6	8-Aug	Till	25	2	27
6	8-Aug	No-till	5	0	5
7	8-Aug	Till	12	2	14
7	8-Aug	No-till	7	2	9
8	8-Aug	Till	7	3	10
8	8-Aug	No-till	9	0	9
9	8-Aug	Till	7	2	9
9	8-Aug	No-till	12	5	17
10	8-Aug	Till	30	4	34
10	8-Aug	No-till	6	1	7
11	8-Aug	Till	3	3	6
11	8-Aug	No-till	8	14	22

Bulk Density

Block	1st Data NT	2nd Data NT	Difference	1st Data Till	2nd Data Till	Difference
1	1.23	1.58	0.35	1.12	1.62	0.50
1	1.33	1.65	0.32	1.36	1.45	0.09
1	1.22	1.31	0.09	1.17	1.23	0.06
1	1.38	1.64	0.26	1.34	1.51	0.17
2	1.32	1.41	0.10	1.20	1.38	0.18
2	1.45	1.44	-0.01	1.24	1.44	0.21
2	1.25	1.47	0.22	1.17	1.47	0.29
2	1.17	1.52	0.35	1.25	1.47	0.22
3	1.34	1.56	0.22	1.20	1.37	0.17
3	1.14	1.53	0.40	1.38	1.62	0.23
3	1.38	1.44	0.06	1.20	1.54	0.34
3	1.29	1.46	0.17	1.33	1.54	0.22
4	1.42	1.47	0.05	1.30	1.38	0.09
4	1.24	1.43	0.19	1.52	1.33	-0.18
4	1.19	1.69	0.51	1.48	1.34	-0.14
4	1.29	1.43	0.15	1.44	1.32	-0.12
5	1.30	1.46	0.16	1.16	1.28	0.12
5	1.32	1.36	0.04	1.32	1.56	0.24
5	1.38	1.41	0.02	1.30	1.42	0.12
5	1.16	1.60	0.44	1.21	1.33	0.13
6	1.33	1.61	0.28	1.32	1.46	0.14
6	1.27	1.59	0.32	1.34	1.52	0.18
6	1.06	1.58	0.53	1.27	1.58	0.31
6	1.13	1.37	0.24	1.35	1.37	0.02
7	1.23	1.44	0.21	1.30	1.58	0.28
7	1.28	1.62	0.34	1.22	1.60	0.38
7	1.46	1.29	-0.17	1.33	1.46	0.13
7	1.31	1.46	0.15	1.27	1.39	0.12
8	1.25	1.64	0.39	1.35	1.42	0.07
8	1.34	1.47	0.13	1.05	1.53	0.48
8	1.21	1.57	0.36	1.30	1.54	0.23
8	1.20	1.46	0.27	1.42	1.26	-0.16
9	1.07	1.55	0.49	1.41	1.42	0.01
9	1.48	1.34	-0.14	1.28	1.43	0.16
9	1.40	1.63	0.23	1.34	1.28	-0.06
9	1.31	1.61	0.31	1.19	1.37	0.18
10	1.40	1.46	0.06	1.34	1.51	0.17
10	1.19	1.39	0.19	1.34	1.41	0.07
10	1.29	1.33	0.04	1.36	1.48	0.13
10	1.53	1.47	-0.06	1.21	1.55	0.34
11	1.07	1.59	0.53	1.27	1.40	0.14
11	1.28	1.63	0.35	1.33	1.48	0.15
11	1.44	1.44	-0.01	1.55	1.50	-0.05
11	1.26	1.43	0.17	1.15	1.37	0.21

% of Stable Aggregates

Block	Till	No-till
1	90.5	88.55
1	82.65	91.08
1	91.53	88.55
1	87.84	91.08
2	76.68	81.68
2	83.32	87.1
2	59.07	85.47
2	73.94	87.64
3	87.19	91.45
3	83.54	79.13
3	85.29	75.54
3	85.24	72.28
4	87.85	83.04
4	64.32	79.62
4	86.76	60.11
4	85.16	76.19
5	81.5	78.49
5	75.42	84.06
5	77.18	88.53
5	80.96	82.9
6	84.91	91.49
6	82.8	91.27
6	69.43	84.77
6	87.87	82.93
7	87.45	78.51
7	89.59	84.83
7	74.01	76.35
7	90.33	82.04
8	84.99	67.05
8	84.77	66.87
8	91.74	75.67
8	88.81	87.02
9	81.08	88.3
9	90.88	89.44
9	73.97	73.9
9	86.27	85.66
10	84.18	84.04
10	88.04	87.03
10	80.6	87.05
10	89.95	83.73
11	78.78	92.2
11	88.43	79.84
11	83.35	88.28
11	89.16	88.42
Total Soil Carbon		

Conventional Tillage Data

9/8/07			1/29/08		
Sample	Carbon	Average	Sample		Average
1t#1	2.602		1t#1	2.685	
1t#2	2.564		1t#2	2.745	
			1t#3	2.094	
			1t#4	2.736	
		2.583			2.565
2t#1	2.951		2t#1	2.837	
2t#2	2.772		2t#2	2.745	
			2t#3	2.094	
			2t#4	2.736	
		2.8615			2.603
3t#1	2.787		3t#1	2.682	
3t#2	2.654		3t#2	3.05	
			3t#3	2.605	
			3t#4	2.811	
		2.7205			2.787
4t#1	2.503		4t#1	2.798	
4t#2	2.158		4t#2	2.838	
			4t#3	2.779	
			4t#4	2.638	
		2.3305			2.76325
5t#1	2.704		5t#1	2.613	
5t#2	2.685		5t#2	2.418	
			5t#3	2.548	
			5t#4	2.63	
		2.6945			2.55225
6t#1	2.733		6t#1	2.645	
6t#2	2.777		6t#2	2.639	
			6t#3	2.522	
			6t#4	2.472	
		2.755			2.5695
7t#1	2.684		7t#1	2.525	
7t#2	2.639		7t#2	2.762	
			7t#3	2.552	
			7t#4	2.638	
		2.6615			2.61925
8t#1	2.662		8t#1	2.921	
8t#2	2.639		8t#2	2.119	
			8t#3	2.681	
			8t#4	2.237	
		2.6505			2.4895
9t#1	2.272		9t#1	2.074	
9t#2	2.198		9t#2	2.285	
			9t#3	2.211	
			9t#4	2.197	
		2.235			2.19175

10t#1	2.885		10t#1	2.807	
10t#2	2.867		10t#2	2.555	
			10t#3	2.635	
			10t#4	2.592	
		2.876			2.64725
11t#1	2.446		11t#1	2.208	
11#2	2.407		11t#2	2.313	
			11t#3	2.221	
			11t#4	2.338	
		2.4265			2.27
No-Till Data					
1nt#1	2.826		1nt#1	2.652	
1nt#2	2.633		1nt#2	2.029	
			1nt#3	2.55	
			1nt#4	2.524	
		2.7295			2.43875
2nt#1	2.562		2nt#1	2.55	
2nt#2	2.525		2nt#2	2.568	
			2nt#3	2.491	
			2nt#4	2.556	
		2.5435			2.54125
3nt#1	2.841		3nt#1	2.461	
3nt#2	2.756		3nt#2	2.371	
			3nt#3	2.844	
			3nt#4	2.523	
		2.7985			2.54975
4nt#1	2.824		4nt#1	2.574	
4nt#2	2.618		4nt#2	2.568	
			4nt#3	2.535	
			4nt#4	2.63	
		2.721			2.57675
5nt#1	2.46		5nt#1	2.647	
5nt#2	2.634		5nt#2	2.575	
			5nt#3	2.676	
			5nt#4	2.434	
		2.547			2.583
6nt#1	2.585		6nt#1	2.486	
6nt#2	2.749		6nt#2	2.448	
			6nt#3	2.191	
			6nt#4	2.55	
		2.667			2.41875
7nt#1	2.397		7nt#1	2.167	
7nt#2	2.489		7nt#2	2.047	
			7nt#3	2.159	
			7nt#4	2.183	
		2.443			2.139
8nt#1	2.332		8nt#1	2.131	

8nt#2	2.568		8nt#2	2.335	
			8nt#3	2.254	
			8nt#4	2.226	
		2.45			2.2365
9nt#1	2.71		9nt#1	1.993	
9nt#2	2.682		9nt#2	1.997	
			9nt#3	2.346	
			9nt#4	2.409	
		2.696			2.18625
10nt#1	2.349		10nt#1	2.218	
10nt#2	2.331		10nt#2	2.11	
			10nt#3	2.223	
			10nt#4	1.807	
		2.34			2.0895
11nt#1	2.698		11nt#1	2.372	
11nt#2	2.647		11nt#2	2.908	
			11nt#3	2.561	
			11nt#4	2.592	
		2.6725			2.60825