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Cover Cropping and Conservation Tillage in California Processing Tomatoes

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Introduction

California tomato producers want to use production technologies that are economically viable and environmentally sustainable. The production practices that ultimately are adopted by tomato farmers ideally are profitable and at the same time preserve or improve the long-term productivity of their fields without harming the environment.

Two practices that may help producers meet both economic and sustainability goals are cover cropping and conservation tillage (CT). Though widely used in the 1940s, cover crops were not a mainstay of California production systems during much of the last half of the twentieth century. In recent years though, their attributes and potential benefits have received renewed attention from researchers and farmers alike, and there is new interest in integrating them into tomato production systems. Cover crops provide soil cover, scavenge and recycle nutrients, add crop diversity (especially in monoculture systems), and add organic matter to production fields. Cover cropping does, however, require additional expense and careful management if it is to be successfully integrated into a tomato production system.

CT practices include several tillage management approaches that reduce overall operations and costs (see sidebar) and are often associated with a number of adjunct benefits such as lower dust and diesel emissions levels, fewer pieces of farm equipment, and lower overall tractor operation hours. Like cover cropping, a CT system requires a shift in the grower's beliefs about tillage management coupled with careful planning if it is to be successful. This publication summarizes current information on and recent experiences from tomato production systems throughout the Central Valley of California that use cover crops and various CT approaches.

Glossary of tillage terminology

Like most areas of farming, tillage systems have their own specialized jargon. The UC Conservation Tillage and Cropping Systems Workgroup offers these standard terms for four general types of tillage system. You can find additional information and more complete definitions in *Classification of Conservation Tillage Practices in California Irrigated Row Crop Systems* (UC ANR Publication 8364).

Standard tillage. The sequence of operations most commonly used in a given field to prepare a seedbed and produce a given crop.

Conservation tillage. A collective, umbrella term denoting practices that have some sort of conservation goal. Broadly, the term encompasses tillage practices that reduce the volume of soil disturbed, preserve rather than incorporate surface residues, and result in the broad protection of resources while crops are grown.

Minimum tillage. This term has been adopted by the workgroup as a subcategory of conservation tillage. It refers to systems that reduce the number of tillage passes, thereby conserving fuel use for a given crop by at least 40 percent relative to conventional practices in the year 2000.

No-till. In no-till or direct-seeding systems, the soil is left undisturbed from harvest to planting, except for the injection of fertilizers.

Research Results

Cover crops in tomato production systems

To date, most cover cropping in California tomato production systems has involved the use of relatively short-season, October- or November-seeded small grain crops such as triticale *(Triticosecale)* and barley *(Secale cereale)* or the legume vetch *(Vicia sativa)*. Once they have grown, these cover crops are either managed as green manures and incorporated into planting beds (e.g., vetch) or they are chopped or burned down using herbicides and then left as a surface mulch (e.g., triticale or barley) (fig. 1). Cover crops that are used for mulch can be terminated by means of mowing or herbicide application, typically in late February or March, before tomato transplanting.

When rainfall alone is used to grow these cover crops, the volume of biomass production during the November-to-March window in the central San Joaquin Valley generally varies according to the amount of winter rain (table 1) received. For instance, a rye, triticale, and pea cover crop grown on rainfall alone produced an average of 2,824 pounds of dry matter per acre over a 10-year period in a study conducted in Five Points, California. More biomass—perhaps as much as three times this amount—can be expected when supplemental irrigation is applied or when the cover crop is allowed to grow over a longer winter season, but trade-offs with respect to water use and the timing of tomato establishment must be factored in when you decide how to manage a cover crop for a particular growing window.

Figure 1. A 25-foot Great Plains drill is used to seed winter small grain cover crops at Sano Farms in Firebaugh, California. The modified drill plants seed across the bed top without putting any seed in the furrow.

When cover crops are grown as green manure, they are typically flail-mowed and disked into the soil at least 4 weeks before tomatoes are transplanted. This gap between crops helps avoid problems with seedling pests such as seed corn maggot and the immobilization of nitrogen that can occur with a nonlegume cover crop.

Use of a legume vetch cover crop has been extensively evaluated in long-term tomato research at UC Davis and in Yolo County farm fields. Work conducted by the Sustainable Agriculture Farming Systems (SAFS) Project in Davis showed increased soil carbon of 1.33 tons per acre resulting from the incorporation of vetch cover crops, and tomato yields were comparable to fields under standard management practices (tillage with no cover crop), judged over a 12-year period (Poudel et al. 2001).

Late-summer cover crops such as an Africa-type cowpea *(Vicia unguiculata)*, whose photo-temperature reaction is very different from that of commercial California blackeyes or other legume species such as lablab *(Lablab purpureus)*, may also be useful for certain tomato rotations. However, little is currently known about management of these cover crops or about issues related to their water use or their capacity to serve as a bridge crop for tomato pests.

The warm-season grain cover crop sorghum-sudangrass (*Sorghum bicolor* [L.] Moench × *S. sudanense* [P.] Staph.) has been evaluated over a number of years in Five Points as a green manure for breaking up tomato monocultures. Unfortunately, this

Table 1. Triticale, rye, and pea cover crop biomass production (October to March), irrigation, and rainfall at Five Points, California

Biomass production, water source	Cover crop year										
	10/1999–3/2000	10/2000–3/2001	10/2001–3/2002	10/2002–3/2003	10/2003–3/2004	10/2004–3/2005	10/2005–3/2006	10/2006–3/2007	10/2007–3/2008	10/2008–3/2009	10/2009–3/2010
Cover crop biomass produced *(lb/ac)*	8,004 (± 175)	3,595 (± 115)	2,611 (± 163)	3,313 (± 359)	2,272 (± 169)	6,452 (± 251)	2,301 (± 190)	40 (± 9)	3,980 (± 409)	855 (± 40)	1,304 (± 67)
Irrigation *(in)*	4.0	—	—	—	—	—	—	—	—	—	—
Rainfall *(in)*	5.6	5.9	3.6	2.9	5.4	10.2	10.7	5.2	7.9	10.7	8.2

crop has demonstrated severe allelopathy (plant-to-plant toxicity) toward tomatoes and other vegetables if they are transplanted too soon after it is chopped (Summers et al. 2009), so it is not recommended for use as a cover crop mulch in tomato production systems. Results such as this indicate that additional research and grower experimentation are needed if cover crops are to be creatively and flexibly integrated into tomato rotations.

Tomato production with conservation tillage

Since the development and refinement of subsurface drip systems for irrigation of processing tomatoes in the early 1990s, growers have adopted more bed-preserving, minimum tillage implements. Recent estimates from UC Cooperative Extension suggest these pass-combining implements are used on 90 percent of drip-irrigated tomato acreage in the central San Joaquin Valley in order to avoid disturbing the semipermanent drip tape buried 8 to 10 inches below the soil surface. In particular, conventional deep tillage, which included a broadcast stubble disk and 30-inch-long subsoil shanks, has been eliminated. As a result, the overall use of reduced tillage in tomato production fields has gone up significantly in recent years.

In 1999, an ongoing field study was initiated to compare CT and standard tillage tomato-and-cotton rotations with and without winter cover crops at UC West Side Research and Extension Center near Five Points, California. The reduction in tillage for the CT treatments was much greater than is the current practice for commercial, minimum tillage drip-irrigated fields.

The experimental field was divided in half. Each half was rotated between a tomato crop *(Lycopersicon esculentum)* one year and a cotton crop (*Gossypium hirsutum* L.) the next, so both crops could be grown every year and be available for experimentation. Management treatments included standard tillage with no cover crop (STNO), standard tillage with cover crop (STCC), CT with no cover crop (CTNO), and CT with cover crop (CTCC). All treatments were replicated four times in a randomized complete block design on each half of the field. Each treatment plot consisted of six beds, each measuring 30 feet by 270 feet. A six-bed buffer area separated the tillage treatments to allow sufficient room for the different tractor operations that were used in each system.

A cover crop mix of Juan triticale (*Triticosecale* Wittm.), Merced rye (*Secale cereale* L.), and common vetch *(Vicia sativa)* was planted in late October at a rate of 100 pounds per acre (30% triticale, 30% rye, and 40% vetch by weight) in the appropriate plots and subsequently germinated with early winter rainfall. In the first year only, sprinkler irrigation was used to establish the cover crop; in subsequent years, no irrigation was given to establish the cover crop. The cover crops were chopped in mid-March using a Buffalo Rolling Stalk Chopper. In the STCC system, the chopped cover crop was disked into the soil to a depth of about 8 inches, and 5-foot-wide beds were reformed prior to tomato transplanting. The cover crop in the CTCC treatment was sprayed with a 2 percent solution of glyphosate, chopped, and left on the surface as a mulch.

Standard intercrop tillage practices that knock beds down and establish new beds following harvest were used in the ST systems (table 2). The CT systems were managed based on the general intention of trying to reduce primary intercrop tillage to the greatest extent possible. Zone production practices that restrict tractor traffic to furrows were used in the CT systems. Planting beds have not been moved or destroyed in these systems at any time during the 11 years of the study.

Table 2. Comparison of standard tillage (ST) and conservation tillage (CT) system operations with and without cover crops in tomato study; each "X" indicates a separate instance of each operation

Operations (chronological order)	With cover crop		Without cover crop	
	STCC	CTCC	STNO	CTNO
Shred cotton	X		X	
Undercut cotton	X		X	
Disk	XXXX		XX	
Chisel	X		X	
Level (triplane)	X		X	
List beds	XX		X	
Incorporate/shape beds	X		X	
Clean furrows		X		X
Shred bed		X		X
Spray herbicide: Treflan	X		X	
Incorporate Treflan (Lilliston)	X		X	
Spray herbicide: Roundup			X	X
Spray herbicide: Shadeout	X	X	X	X
Cultivate: Sled cultivator	XXX		XXX	
Cultivate: High-residue cultivator		XXX		XXX
Plant tomatoes	X	X	X	X
Fertilize	XX	XX	XX	XX
Plant cover crop	X	X		
Mow cover crop	X	X		
Harvest (custom)	X	X	X	X
Times over field	23	12	19	11

In the tomato-planted half of the field, plants of a common commercial processing variety were transplanted each year in the center of beds at an in-row spacing of 12 inches during the first week of April using a modified three-row commercial transplanter fitted with a large (20-in) coulter ahead of each transplanter shoe. Treatments received the same fertilizer applications, with dry fertilizer (11-52-0 NPK) applied preplant at 100 pounds per acre. Additional N (urea) was sidedress-applied at 125 pounds of N per acre in two lines about 7 inches from the transplants and about 6 inches deep, around 4 weeks after transplanting. Furrow irrigation was used on the tomatoes over the duration of the test.

When averaged over the entire 2001–2010 period, tomato yields were higher in the two systems without cover crops (NO) than in the cover crop (CC) systems, and yields were higher for the CT systems than for the ST systems. Results were comparable to those of typical yields in Fresno County during these years. When measured after 8 years, soil carbon in the 0-to-12-inch depth was highest in the CC systems, second highest in the CTNO system, and lowest in the STNO system (table 3).

Using information generated by this study, we have evaluated two indicators of sustainability developed by the USDA Natural Resources Conservation Service (NRCS). The Soil Conditioning Index (SCI) is a predictor of the consequences of management actions on soil carbon. The computed SCI values in table 4 seem to be closely associated with the field operations used in the tillage systems. SCI values were negative for the two ST systems, suggesting a tendency for degrading soil carbon stocks, and positive for the CT systems, indicating upgrading carbon stocks. The soil tillage intensity rating (STIR) is calculated as a function of the speed of tillage equipment, the type of equipment used, the depth of tillage, and the percentage of the soil surface that is disturbed. As a point of reference, no-till requires a STIR value of 30 or less. Values in the NRCS national database typically range from 0 to 200. A low score is preferable. The STIR values for ST are very high, well over 200, while both of the CT values are under 40, indicating excellent soil quality preservation and residue retention (table 4).

Our long-term study points to a number of important outcomes and implications for California tomato producers. Yields of the CTNO system were generally stable, fluctuating less than those of the other systems over the course of the study when the preceding cotton crop had been followed only by aboveground shredding and root pulling. Soil carbon in the top foot of soil was significantly greater in the STCC, CTCC, and CTNO systems than in the STNO system after 8 years. Finally, estimated fuel costs for the CT systems were about 28 percent of those for the ST systems.

Table 3. Soil carbon weight in tons per acre for tillage treatments across two soil depth ranges

	Soil carbon weight (T/ac)			
Depth	**STNO***	**STCC**	**CTNO**	**CTCC**
0–6 in	4.35	5.50	5.86	6.54
6–12 in	4.69	5.53	4.72	5.20
Total†	9.04 c	11.06 b	10.58 b	11.65 a

* STNO = Standard tillage no cover crop, STCC = Standard tillage with cover crop, CTNO = Conservation tillage no cover crop, CTCC = Conservation tillage with cover crop.
† Letters represent significant differences among treatments using a one-way ANOVA analysis with Tukey HSD means comparison.

Table 4. Tillage and cover crop system soil condition index (SCI), soil tillage intensity rating (STIR), and estimated diesel fuel use

Cropping system*	SCI	STIR (average annual)	Diesel fuel use (gal/ac)
STNO	– 0.71	261	24
STCC	– 0.96	390	31
CTNO	0.43	30.6	9.3
CTCC	0.52	37.1	11

* STNO = Standard tillage no cover crop, STCC = Standard tillage with cover crop, CTNO = Conservation tillage no cover crop, CTCC = Conservation tillage with cover crop.

UC Davis research trials

CT studies were also conducted on the UC Davis campus from 2007 to 2009, comparing standard broadcast (full field) fall-timed tillage (ST) and a minimum tillage system (CT). The comparisons were restricted to the fall-timed tillage period. The standard tillage system included broadcast disking, subsoiling, land planing, and rebedding. The reduced tillage system conserved the beds with two passes of a Wilcox Performer. Additionally, each tillage comparison included either (1) a fall-planted triticale cover crop, (2) a single-chisel shank in the center of the bed after the beds were reformed in the fall, or (3) clean fallow with no additional fall tillage. Tomatoes were transplanted in the spring, and all preplant and growing-season tillage operations were conducted according to conventional cultivation practices in both systems. Tomato was the sole cash crop produced.

Each year, irrigation started with sprinklers to establish the tomato transplants and then switched to furrow, which is common practice in the Sacramento Valley. A furrow bottom–located drip tape was used to finish the second season and then utilized fully in the third year to mimic furrow irrigation, but with greater control. Before the CT project, the 4-acre experimental area was planted to wheat, and it was not tilled prior to the initiation of our experiment in the fall of 2006.

A factorial design was employed with the main plots either (1) ST or (2) CT with cover crop or fallow subplots within the main plots. Treatments were replicated four times. Main plots were in blocks of 18 beds on 5-foot centers (90 feet total width) and 220 feet long. The location of the plot remained fixed over the 3 years of the test.

The field was transplanted every year. We used the common commercial variety AB 2 the first 2 years and then changed to HM 6898 because of a small area of nematode infestation detected at the end of year 2. For harvest, we used a mechanical harvest every year. A tractor-mounted, hydraulically operated cone penetrometer measured soil compaction differences to a depth of 18 inches prior to spring tillage. In year 2 of the experiment, water infiltration rate was evaluated using blocked furrow methods.

Table 5. Yield comparisons in standard tillage and conservation (bed) tillage treatments, canning tomato production trial, UC Davis, 2007–2009

Tillage treatment	2007 marketable yield	2008 marketable yield	2009 marketable yield
		T/ac	
1. Standard tillage	25.9	32.3	33.3
2. Conservation (bed) tillage	24.3	32.9	33.6
probability	*NS*	*NS*	*NS*
a) Chisel bed center	24.2	36.8	34.1
b) Triticale cover crop	—	29.9	33.7
c) Fallow, no chisel	24.6	31.0	32.6
probability	*NS*	—	*NS*
Standard tillage, chisel center	23.8	33.5	32.7
Standard tillage, triticale	—	32.4	34.0
Standard tillage, fallow	25.2	30.9	33.2
Conservation (bed) tillage, chisel center	24.5	40.1	35.4
Conservation (bed) tillage, triticale	—	27.5	33.4
Conservation (bed) tillage, fallow	24.1	31.1	31.9
interaction probability	*NS*	*0.03*	*NS*
LSD @ 5%	—	*5.6*	—
% CV	*11*	*11*	*10*

Table 6. Effects of reduced fall tillage on water infiltration rate from furrow irrigation of processing tomatoes, UC Davis, 2008

Tillage	Infiltration in 90 min	Infiltration in 60 min
	liters/foot	
1. Standard tillage	7.4	4.1
2. Conservation (bed) tillage	6.5	3.8
probability	*NS*	*NS*
a) Fallow	6.7	3.9
b) Triticale cover crop	7.2	4.1
probability	*0.17*	*NS*
LSD @5%	*NS*	*NS*
Standard tillage, fallow	7.1	4.0
Standard tillage, triticale	7.6	4.3
Conservation (bed) tillage, fallow	6.3	3.7
Conservation (bed) tillage, triticale	6.7	3.9
interaction	*NS*	*NS*
LSD @ 5%	*NS*	*NS*
% CV	*8*	*13*

Tomato fruit yields for ST and CT treatments were similar in all 3 years, with one exception (table 5). In 2008, yields in the CT treatment were substantially greater (40.1 T/ac compared to 33.5 T/ac) when the center of the bed was chiseled with a single shank in the fall to a depth of 15 inches. In 2008, the water infiltration rate in the furrow area within the crop season was similar for both tillage systems and for the split-plot treatments (table 6).

Measurement with a mechanical cone penetrometer indicated no difference in soil compaction (resistance measured as psi) between the ST and the CT systems. The central bed chisel treatment had the lowest resistance level (65 psi), followed by the fallow treatment (133 psi), and that difference may be partially due to soil moisture levels rather than compaction. The triticale cover crop dried the soil the most and influenced the resistance measurement substantially (216 psi). Regardless, the CT and ST penetrometer readings were comparable.

To sum up, the results of this study indicate that there was no loss in tomato production with the fall tillage reduction associated with CT as compared to standard broadcast tillage. The measurements of water infiltration and compaction were also similar for ST and CT. In one year, we saw a substantial yield increase for the CT system when additional chisel tillage was performed in the fall as the last step before the beds were left to overwinter. Use of a grass cover crop did not increase tomato crop yield in either of the tillage systems.

Case study

During the past 6 years, Sano Farms in Firebaugh, California, has refined a production system for processing tomatoes that makes use of cover crops, subsurface drip irrigation, and CT practices. Sano Farms is a 4,000-acre farm in the Westlands Water District of western Fresno County. The farm has a history of producing a variety of crops, including cotton, melons, and tomatoes, but for about the past 4 years, the only crop on its annual cropland has been tomatoes, primarily for processing.

The overall system that co-owner Alan Sano and farm manager Jesse Sanchez developed reduced the number of tractor operations (thus saving fuel), cut fertilizer inputs, reduced labor hours, improved soil condition, reduced overall variations in yield, and increased tomato yields by 12 to 15 percent over the yields with standard practices that were previously used. Considerable planning was required to successfully manage the integrated production system used at Sano Farms. This program integrated a winter-grown cover crop, strip tillage and row crop equipment modified for CT use, and fertility and weed management adjustments.

Winter cover crops

An important component of the integrated tomato production system at Sano Farms is the use of small grain cover crops in winter. These cover crops are typically seeded in late October or early November, sprinkle irrigated as part of the farm's pre-irrigation program for the following year's crop, and then terminated with herbicide applications, typically in early February before their aboveground growth becomes too unwieldy and difficult to manage. The cover crops, which for a number of years have consisted of a single species of triticale, are seeded at a rate of about 110 pounds per acre.

Sano Farms experimented with seeding rates as low as 45 pounds per acre, but they found that the current rate of 110 pounds per acre can achieve the desired level of cover and growth. The cover crop characteristics that Sano Farms now seeks include high amounts of root biomass, quick surface cover, and quick meltdown following herbicide application to allow ease of transplanting. They used a modified 27.5-foot Great Plains drill for seeding (fig. 1). The drill was modified to plant only the bed top and not the furrow (fig. 2).

The tomato harvesters used at Sano Farms include an on-board shredder to chop vines into small pieces as a way to facilitate the reduced tillage program. Typically, the only fall tillage employed by Sano Farms after the harvest of one tomato crop and before the next season's planting consists of three tillage passes. The first of these is a furrow-chiseling pass to break up compacted zones. The second pass is with a conventional disk pulled in line with the beds. The third pass employs a Wilcox Agriproducts Performer bed-conditioning implement that accomplishes a shallow mixing of residues, loosens the soil in the bed, and reshapes

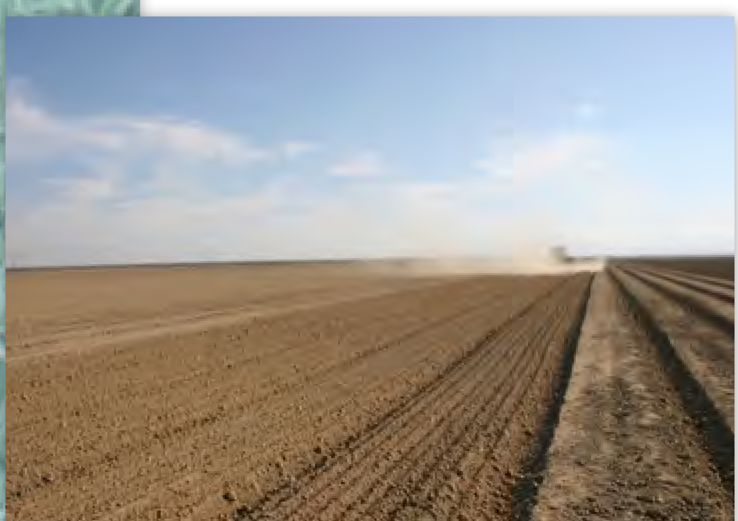

Figure 2. The Great Plains 25-foot drill in action, seeding winter cover crops with seed lines every 7.5 inches on 40-inch-wide tomato bed tops at Sano Farms.

Figure 3. Winter triticale cover crop growth in early February 2008 at Sano Farms.

Figure 4. A triticale cover crop just before it was terminated with an herbicide application, Sano Farms, 2008. This photo shows the cover crop height at the time of termination, giving an idea of how much biomass was produced.

Figure 5. An herbicide-treated triticale cover crop dying, or burning down, at Sano Farms, 2007.

Figure 6. An herbicide-terminated triticale cover crop at Sano Farms prior to transplanting of the tomato crop, 2007.

the planting beds for the subsequent season. For these three passes the grower relies on GPS guidance to preserve essentially undisturbed crop growth zones in the center of beds over long-term buried drip tape, and thus performs zone tillage on permanent tomato planting beds.

The winter small grain cover crop at Sano Farms is typically terminated with an herbicide application before it can grow more than about 12 inches tall, usually in early February (figs. 3, 4, 5, and 6). The cover crop provides winter weed suppression. Sanchez and Sano believe their cover crop, combined with the overall CT approach, results in lower weed populations during the tomato season. However, in recent years, in-season bindweed *(Convolvulus arvensis)* has become more problematic. Control measures include Roundup (glyphosate) applications in fall, before planting the cover crop.

Conservation tillage

Before transplanting processing tomatoes in the spring, Sano Farms uses a ground-driven strip-till implement to loosen the soil, mix in cover crop residues, and incorporate herbicide into the soil in the center of beds where transplants will be established. This strip-till operation works the soil to a depth of about 8 inches and then leaves a firmed zone of soil into which the transplants will be placed (fig. 7). In prior years, Sano Farms used a PTO-powered tiller-mulcher to accomplish this strip tillage function, but now they use row units, an Orthman model 1tRIPr (figs. 8, 9, and 10). The

Figure 7. Sixty-inch tomato beds after herbicide burn down of the cover crop and bed-center strip tillage prior to tomato transplanting, Sano Farms, 2009.

Figure 8. A modified Orthman 1tRIPr five-row strip-till implement tilling in the cover crop residue and incorporating preplant herbicide prior to tomato transplanting, Sano Farms, 2009.

Figure 9. A ground-driven strip tiller used to prepare bed centers prior to tomato transplanting, Sano Farms, 2009.

Figure 10. Close-up view of modified Orthman 1tRIPr strip-till row units at Sano Farms, showing the residue-cutting depth wheel and coulter, subsoiling shank, wavy coulters, and clod-busting rolling baskets.

Figure 11. A conventional five-row tomato Checci Magli transplanter used to establish tomato seedlings in cover crop residues at Sano Farms, 2009.

Figure 12. A conventional five-row tomato transplanter used at Sano Farms, 2009.

strip tiller also applies starter fertilizer ahead of transplanting. The single ground-driven implement can be run faster and with less maintenance than the two slower PTO-driven tillers. A tractor-drawn roller is used to firm the bed after the strip tiller and before transplanting.

Sano Farms uses a conventional five-row transplanter (figs. 11 and 12). This transplanter requires no CT modifications and performs well in the minimal surface cover crop residue that typically is present at the time of transplanting, after strip tillage.

The integrated production techniques that are now used successfully at Sano Farms are the products of considerable planning as well as rigorous and detailed trial-and-error investigations. Both Sano and Sanchez see it as management of their entire system, not just a series of distinct practices. They have found, for example, that the benefits of the cover crops increase if they are left in place on the bed tops as mulch rather than incorporated as green manure. They observed better weed control during the winter and summer as well as better overall soil tilth. Improvements in soil quality, such as greater friability and the presence of earthworms, are now observed in fields that have used this system for a number of years. Through years of innovation and adjustments and refinements to their system, their goal at Sano Farms has been to create an entire cropping system that is profitable from year to year and also sustainable and self-improving over the long haul.

While changes in soil carbon have not been monitored at Sano Farms, recent long-term research with CT and cover crops at the UC West Side Research and Extension Center in Five Points (table 3) indicates that it is reasonable to expect that soil carbon levels will have increased due to the cover crop inputs at Sano Farms.

Economic Evaluation

To further evaluate the performance of tomato production systems that use cover crops and CT, we compared the production costs of the Sano Farms strip-till cover crop system, the current bed-preserving minimum tillage system without cover crops that is common in subsurface drip-irrigated tomato fields, a generic no-till system, and the standard tillage approach that has been in common use in California tomato fields for decades. The minimum tillage system uses many standard tillage practices but eliminates deep subsoil tillage to protect the buried drip tape. For the standard tillage system, we used practices from the most recent UCCE cost study for processing tomatoes in the San Joaquin Valley (Valencia et al. 2002).

Calendars of intercrop operations from just after harvest of the crop that preceded tomatoes up to the transplanting of tomatoes into the field were generated for the Sano model and the minimum tillage system. We made a record of the equipment used and applications of materials and water. The cost of each operation for each system was estimated, using a model of a hypothetical 1,000-acre farm managed under each of the four systems. We used agricultural engineering equations to generate figures for the time required for each operation, plus the costs of fuel, lube, and repairs. Input costs for fertilizer and pesticides were obtained from local input suppliers and entered into the model. The production cost and resource use for each of the systems were then compared. The model summary contains costs for the labor requirements for both tractor operators and irrigation laborers as well as fuel use. From this, we estimated the economic feasibility of each system and determined relative costs.

An overall comparison of the itemized costs is shown in table 7, and a summary of the calendars and costs associated with each of the four systems is provided in table 8. In these comparisons, we included a winter sprinkler pre-irrigation with each of the four systems, as this is conventional practice through much of the San Joaquin Valley's tomato-growing regions, primarily for salt management and to provide about 6 inches of soil water ahead of transplanting. Our cost comparisons indicate that the no-till system is the least expensive of the four systems: about $137 lower than the Standard systems, $120 lower than the Sano CT cover crop approach, and $59 lower than the Minimum tillage system. Savings are realized in the no-till, minimum tillage, and Sano (CT) systems because of their lower machinery-associated costs.

After the no-till system, the Sano Farms system is the next-least-expensive system with respect to tillage operations. It is more expensive than the minimum till system, however, because of the added expenses for cover cropping and herbicides for bindweed control, which total $76 per acre (table 7). The Sano system employs wider and generally larger implements for the series of intercrop tillage passes than does the standard tillage system. With the exception of the three-bed (16.5 ft) Performer bed shaper and the 22-foot furrow chisel used by Sano, all implements are five-row or 27.5-foot configurations. These implements—particularly the self-propelled sprayer with its 100-foot boom, the cover crop drill, and the strip tiller—can be operated at relatively high speeds so they cover ground more quickly than most implements that are used in the standard tillage system.

The larger, higher-speed implements that Sano Farms uses represent higher initial capital investment costs associated with the farm's large-scale conversion to both CT and cover cropping. Because other farms generally used smaller equipment for standard tillage systems, they probably had to use additional, duplicate implements for certain operations in order to get the work done in a timely fashion, a factor that was not considered in this study. The standard tillage system model was generally based on 2002 practices and equipment. Changes in conventional tillage management in more recent years may,

Table 7. Comparative preplant tomato production costs per acre and resource use per acre for standard tillage, minimum tillage, Sano Farms CT, and no-till systems

Operation	Standard	Minimum	Sano Farms CT	No-till
Machine labor *(hr)*	1.89	0.95	0.55	0.05
Machine labor costs *($)*	25.93	12.95	7.59	0.71
Nonmachine labor *(hr)*	1.00	1.00	1.00	1.00
Nonmachine labor costs *($)*	10.96	10.96	10.96	10.96
Diesel *(gal)*	24.58	10.69	5.55	0.30
Diesel costs *($)*	50.15	21.80	11.32	0.62
Lube *($)*	7.52	3.27	1.70	0.09
Repair *($)*	17.84	7.81	8.19	0.14
Interest *($)*	8.97	6.06	9.74	3.66
Total operation costs *($)*	121.37	62.85	49.50	16.18
Cash overhead *($)*	2.75	1.09	1.72	0.07
Noncash overhead *($)*	29.36	11.65	17.42	0.01
Total per-acre costs (excluding materials)	**$153.48**	**$75.59**	**$68.64**	**$16.26**
Materials	**Standard**	**Minimum**	**Sano Farms CT**	**No-till**
Water *($)*	75.00	75.00	75.00	75.00
Roundup *($)*	8.07	8.07	48.42	8.07
Cover crop *($)*	0.00	0.00	28.00	0.00
Total per-acre materials	**$83.07**	**$83.07**	**$151.42**	**$83.07**
Total per-acre costs (including materials)	**$236.55**	**$158.66**	**$220.06**	**$99.33**

Table 8. Preplant operations and equipment used in standard tillage, minimum tillage, Sano Farms CT, and no-till systems

Season	Operation	Tractor	Implement	Materials	$/ac
Standard tillage					
Fall	Disk	225HP 4WD	Disk 18′		7.39
Fall	Subsoil 2×	325HP 4WD	Subsoil 16′		40.13
Fall	Triplane 2×	225HP 4WD	Triplane 16′		18.30
Fall	Disk 2×	225HP 4WD	Disk 18′		14.77
Fall	List/fertilize (fertilizer not included)	225HP 4WD		Lister 15′	6.51
Fall	Shape/mulch beds	150HP MFWD	Mulcher 15′		6.39
Spring	Pre-irrigate, sprinkler (spring)			Water (6.0 ac-in)	85.96
Spring	Weed: spray beds (spring)	110HP MFWD	Boom sprayer 45′	Roundup (1 pt)	9.63
Spring	Mulch bare beds	150HP MFWD	Mulcher 15′		6.39
	Total cultural costs (prior to planting)				195.47
Minimum tillage					
Fall	Rip furrows	250HP 4WD	Rip lister 22′		4.95
Fall	Disk 2×	225HP 4WD	Disk 18′		14.77
Fall	Level: triplane	225HP 4WD	Triplane 16′		9.15
Fall	List/rebed	250HP 4WD	Lister-bedder 30′		3.32
Spring	Pre-irrigate, sprinkler			Water (6.0 ac-in)	85.96
Spring	Weed: spray beds (spring)	110HP 4WD	Boom sprayer 45′	Roundup (1 pt)	9.63
Spring	Spring tooth	250HP 4WD	Perfecta II 15′		5.70
Spring	Power incorporator	150HP MFWD	Cultimulcher 15′		6.39
	Total cultural costs (prior to planting)				139.87
Sano Farms conservation tillage					
Fall	Chisel furrows (4 furrows)	250HP 4WD	Furrow chisel 22′		4.96
Fall	Disk	250HP 4WD	Disk tandem 27.5′		3.60
Fall	Rebed	250HP 4WD	Performer 16.5′		6.95
Fall	Pre-irrigate, sprinkler			Water (6.0 ac-in)	85.96
Fall	Weed: spray beds (bindweed control)	SP Sprayer	Boom 100′	Roundup (4 pt)	33.80
Fall	Drill cover crop	160HP MFWD	Drill 27.5′	Triticale (100 lb)	33.25
Spring	Weed: spray beds (spring)	SP Sprayer	Boom 100′	Roundup (2 pt)	17.66
Spring	Strip till (cover crop)	150HP MFWD	Strip tiller 27.5′		2.97
Spring	Roll	80HP MFWD	Flat roller 27.5′		2.03
	Total cultural costs (prior to planting)				191.18
No-till					
Spring	Pre-irrigate, sprinkler (spring)			Water (6.0 ac-in)	85.96
Spring	Weed: spray beds (spring)	110HP MFWD	Boom sprayer 45′	Roundup (1 pt)	9.63
	Total cultural costs (prior to planting)				95.59

however, tend toward the use of larger multiple-row equipment.

Conclusion and Discussion

The multi-year field research studies indicate that when tomato crops are produced under reduced tillage systems, yields are equivalent to those produced under standard practices, but with a savings in tractor operation hours and fuel. Cover crops may provide long-term benefits to soil health, such as improved tilth due to increased soil organic matter, but they do not improve tomato yields over those of systems without cover crops.

Before cover cropping and CT can be widely adopted in California, these practices will have to meet the cost and production goals of individual farmers. The tipping point for each farmer will ultimately depend upon how the perceived benefits of adopting the new practice match up with the farmer's goals, both

immediate and longer term. The research and farmers' experience summarized in this publication show both the economic and resource conservation benefits of these practices. The conversion of a tomato production operation to CT and cover cropping techniques is not a trivial endeavor, and because such a conversion entails risk, producers would do well to experiment first on a small scale before attempting a wholesale, farm-scale transformation.

The UC Conservation Agriculture Systems Innovation Group provides a considerable database and a variety of networking opportunities for farmers who are interested in transitioning to CT. There is a growing experience and knowledge base that includes CT farmers, UC advisors, private sector consultants, and NRCS conservationists in California's processing tomato production areas. Although much local experience in CT right now is more directly related to dairy silage crop production, there is good practical information and guidance from these successes that may be useful to tomato farmers. For access to these resources, contact the UC Conservation Agriculture Innovation Group at ucanr.org/sites/ct.

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