CALIFORNIA DEPARTMENT OF FOOD AND AGRICULTURE
FERTILIZER RESEARCH AND EDUCATION PROGRAM (FREP)
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Project Title: **Fertilization technologies for conservation tillage production systems in California**

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Period Covered by Report: **2002 - 2008**

Introduction:

California producers face a wide range of economic and environmental resource conservation pressures. Creating efficient and inexpensive production systems that preserve air, water and soil quality is a mounting imperative in all agricultural regions. A potentially very significant means for achieving these goals in annual crop systems may result from a variety of what have historically been termed “conservation tillage” production practices. These techniques minimize the number of tractor and soil disturbance operations within a given cropping systems, thereby saving fuel, reducing labor, and in theory, decreasing the risk of soil loss through erosion and dust emissions. While adoption of CT systems has increased in a number of regions in the US and in South America particularly during the past three decades, their use in CA is quite limited and currently accounts for less than 2% of cultivated acreage in the State. In this FREP study, we conducted what has now turned out to be a six-year evaluation of a CT corn and tomato rotation that has compared traditional (ST) and conservation tillage (CT) practices for these crops with (CC) and without (NO) the use of winter cover crops.

This study has pursued two general lines of work. First, we conducted a detailed assessment of the fate of both fertilizer and cover crop nitrogen in standard and conservation tillage systems. Then, we have tracked the longer-term performance of CT vs ST in terms of productivity.

Justification:

Despite a 300% increase in conservation tillage (CT) production in the Midwest during the past decade, less than 0.3% of the acreage in California's Central Valley (CV) is currently farmed using CT practices. Preplant tillage operations typically account for 18 – 24% of overall production costs for annual crops grown in this region. An average of 9 to 11 tillage-related passes are routinely done during the fall-spring period to *prepare* the soil for summer cropping. These passes represent not only considerable energy, equipment and labor costs, but recent research indicates that tillage reduces soil organic matter (SOM) and emits considerable respirable dust as well. Because SOM is widely regarded as an important attribute of good soil quality and long-term productivity, interest has been growing over the last several years, in developing alternative production systems that reduce costs while at the same time improve the soil resource through greater carbon sequestration.

Recent pioneering studies by Reicosky and Lindstrom (1993) involving a variety of tillage methods indicate major gaseous losses of carbon (C) immediately following tillage, but point to the potential for reducing soil C loss and enhancing soil C management through the use of conservation tillage (CT) crop production systems. Though these practices have been developed over the past several decades primarily for erosion control in other parts of the US, recent concerns regarding the need to sustain soil quality and profitability have prompted an examination of CT practices in California.

Tillage in most annual cropping systems in California's Central Valley is typically done in a "broadcast" manner through a field, without deliberate regard to preserving dedicated crop growth or traffic zones. Studies by Carter (1991a, b) over the last several decades, however, have confirmed the potential to eliminate deep tillage, decrease the number of soil preparation operations by as much as 60%, reduce unit production costs, lower soil impedance and maintain productivity in a number of CV cropping contexts using reduced, precision or zone tillage practices that limit traffic to permanent paths throughout a field thereby reducing soil compaction and preserving an optimum soil volume for root exploration and growth. No systematic studies have been conducted in California, however, that evaluate optimal fertilization strategies for these reduced tillage systems. Horwath *et al*., (1999) has shown that changes in fertilizer use efficiency occur when soils are managed for C sequestration in California. Additional work in other regions of the US has shown that the selection of nitrogen fertilizer rates, source and application methods requires management decisions in CT systems that differ from those used in conventionally tilled systems (Touchton *et al*., 1995). Factors such as the type or quality of surface residue, residual soil fertility levels, soil temperatures, planting dates, crop variety and soil moisture (Touchton *et al*., 1995) determine optimal fertilization programs in CT systems. Soils in conservation tillage tend to be cooler, wetter, more firm and higher in organic matter near the surface than in conventional tillage (Denton, 1993). The likelihood of obtaining a yield response to starter fertilizer increased rapidly as tillage operations decrease (Touchton *et al*., 1995).

Project Objectives:

The objectives of this research are:

1. to evaluate the effectiveness of various fertilization practices in conservation tillage tomato, corn, and cotton production systems

2. to determine the fertilizer use efficiency in conservation tillage production systems transitioning to CT, and
3. to extend information developed by the project widely to Central Valley row crop producers via field days, equipment demonstrations and written project outcome summaries

Project Methods:

This project was conducted in a 5 acre field at the Department of Plant Sciences Field Headquarters on the UC Davis campus where a corn/tomato/corn/tomato rotation was being pursued. There have been two major components of this work: the detailed ^{15}N fertilizer and cover crop labeling study and a broader, more agronomic study that has evaluated the productive performance of different tillage and cover crop management systems. For ease of understanding how these two experimental components were conducted, we report them here separately.

^{15}N Labelled Fertilizer and Cover Crop Microplot Study:

Four experimental treatments (standard tillage no cover crop, STNO, standard tillage with incorporated cover crop, STCC, conservation tillage no cover crop, CTNO, and conservation tillage with cover crop, CTCC) were established in the fall of 2000 in nine-bed (60"each) field plots that are replicated 4 times in a randomized complete block design. In 2001, a uniform field corn crop was produced across the entire field. Following corn harvest in September 2001, common vetch cover crops were seeded in each of the CC plots. Forty ^{15}N microplots (4.57m wide band 3m long) were then established during the 2001 – 2002 winter as indicated below.

STNO	**STCC**	**CTNO**	**CTCC**
Zero N Labeled fertilizer	Zero N Labeled fertilizer + vetch Labeled vetch + fertilizer	Zero N Labeled fertilizer	Zero N Labeled fertilizer + vetch Labeled vetch + fertilizer

These microplots are being used to track the amount of ^{15}N-labelled fertilizer and vetch cover crop that is taken up by each of the main summer crops during the course of the study. GPS coordinates of the center of each microplot were recorded so that the microplots would be able to be relocated at any time in the future. Soil samples were taken annually in each plot. Three random cores from 30 – 60 and 60 – 90 cm, and 15 – 20 cores form 0 – 15 and 15 – 30 cm were taken throughout each plot. Composited samples were homogenized by passing them through a 4 mm sieve. A subsample of each core was air dried for total carbon and nitrogen content, another subsample was taken for moisture content, and a third subsample was extracted for determination of nitrate.

The main plots and microplots were fertilized each year following planting at a rate of 125 lb N / acre for tomatoes and 150 lb N / acre for corn. The main fertilizer applicator was shut off when passing through microplots, but the shank line remained in the soil. In the microplots, these shank bands (2 per bed) were opened with a shovel to 3 – 4” so that fertilizer could be applied close to where the normal application was.

Crop management for each system is shown below.

Tomato

STNO	STCC	CTNO	CTCC
• Flail mow / chop corn residue	• Flail mow / chop corn residue	• Flail mow / chop corn residue	• Flail mow / chop corn residue
• Stubble disk (2X)	• Stubble disk (2X)	• Winter herbicide applicatoin	• Plant cover crop
• Finishing disk	• Finishing disk		• Chop cover crop
• Moldboard plow	• Moldboard plow		• Herbicide application
• Rip / subsoil	• Rip / subsoil		
• Landplane	• Landplane		
• List beds	• List beds		
• Winter herbicide application	• Plant cover crop		
• Bed cultivator	• Flail chop cover crop		
• Herbicide application and bed mulching	• Bed disk (2X)		
• Roll beds flat	• Herbicide application and bed mulching		
	• Roll beds flat		

Corn

STNO

- Stubble disk (2X)
- Landplane
- List beds
- Winter herbicide application
- Bed cultivator

STCC

- Stubble disk (2X)
- Landplane
- List beds
- Plant cover crop
- Disk cover crop
- List beds

CTNO

- Winter herbicide application

CTCC

- Winter herbicide application

Yields in each year were determined by machine harvesting the main plots and by hand harvesting and weighing fruit and vegetative biomass in each microplot. ^{15}N in crop tissue and in the surface soil were determined. Crop yields for 2002 - 2007in main plots are shown below.

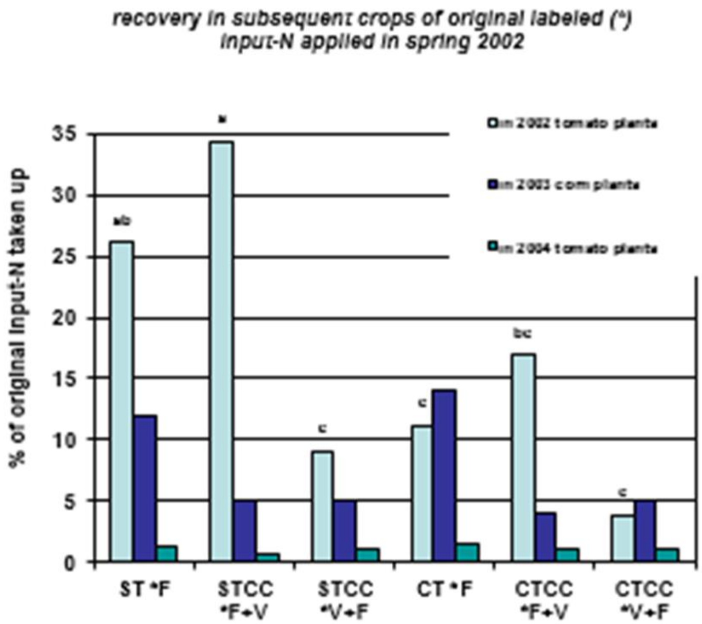
System	2002	2003	2004	2005	2006	2007
	Tomatoes	*Corn*	*Tomatoes*	*Corn*	*Tomatoes*	*Corn*
STNO	51.8 ± 2.3	5.68 ± 0.68	39.0 ± 2.4	5.56 ± 0.69	43.7 ± 3.2	4.2 ± 1.7
STCC	51.8 ± 2.7	6.19 ± 0.67	40.5 ± 2.8	6.39 ± 0.17	35.9 ± 2.8	3.9 ± 0.8
CTNO	38.5 ± 1.6	4.04 ± 0.35	26.7 ± 2.9	6.34 ± 0.38	24.7 ± 4.8	3.8 ± 1.2
CTCC	50.3 ± 3.2	4.69 ± 0.35	23.1 ± 2.8	6.26 ± 0.29	33.3 ± 0.5	5.0 ± 0.4

Results, Discussion and Conclusions:

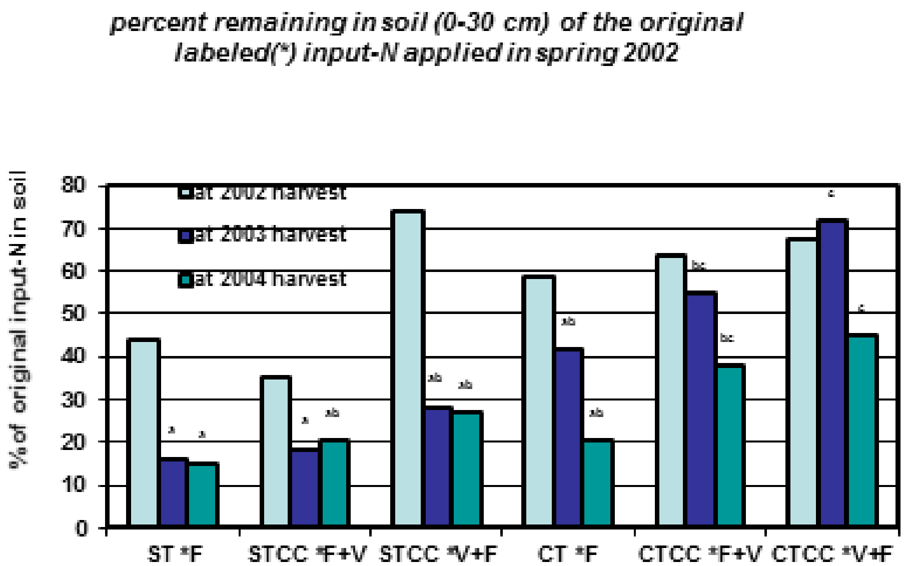
An average of 1010 g / m^2 of corn residue (± 286 std dev) was left on the soil surface in each CT plot following the 2001 corn harvest. This corresponded to nearly 100% of the soil surface being covered by corn residue in the fall of 2001. An average of about 2800 kg / ha of vetch dry matter was produced from November 2001 – April 2, 2002 in the CC plots.

On average, both for tomato and corn, the ST systems performed better than both of the CT systems. The CTCC tomato system provided the lowest tomato yields of the four systems for both 2002 and 2004, due, we believe, to difficulties transplanting the crop into the heavy crop and cover crop residue and reduced early season growth and vigor. Corn yields were reduced 30% and 18% by CTNO and CTCC.

The figure below presents the recovery of original labeled ^{15}N to tomato, corn and tomato crops in 2002, 2003 and 2004, respectively. These data suggest higher N uptake in the first year under ST than CT, and much lower levels in the following years. In this figure, the "*" refers to whether either fertilizer (F), or vetch (V) were labeled.

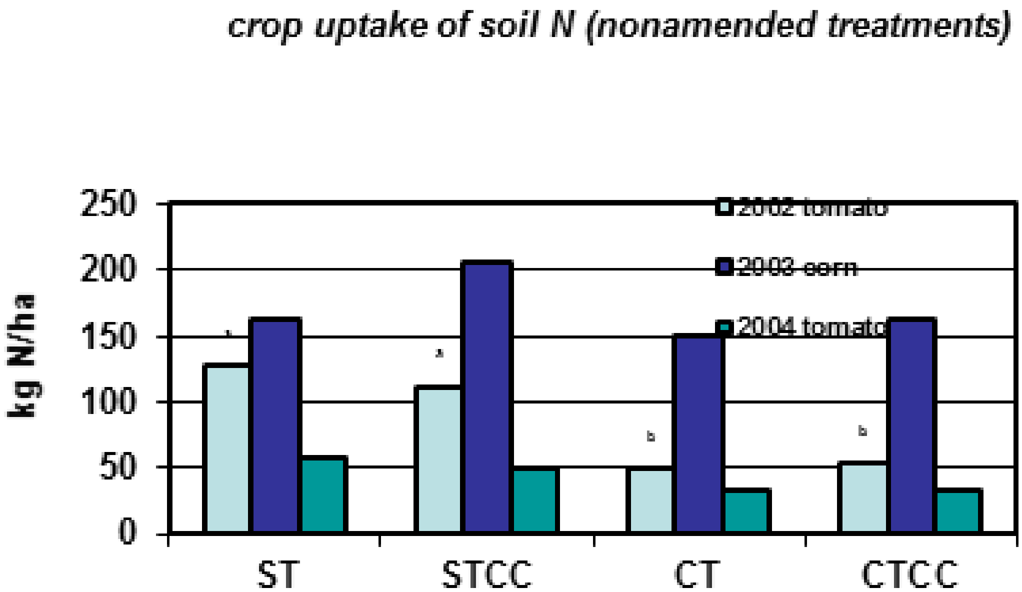


Less [15]N was taken up by CT crops compared to ST and there was a correspondingly greater amount of N remaining in the soil under CT. (See figure below).

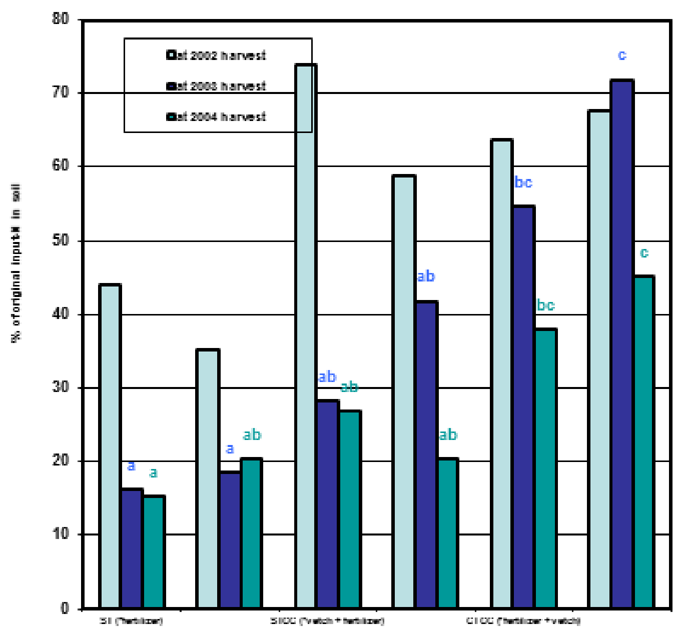


This may be due to a number of factors including the possibility that the fertilizer N somehow was more mobile in the ST systems because of greater overall soil disturbance in these systems or perhaps the fact that the ST soils did not appear to “consolidate” and harden as much as the CT soils. This is merely speculation, however, and will be monitored as these and other related studies proceed.

Finally, evidence of this last observation may perhaps be seen in the figure below in which total N uptake in the unamended plots is presented. This graph presents a trend toward higher N input from the zero N plots under ST in both of the first two years.



The percent remaining in soil (0-30 cm) of the original labeled input-N applied in spring 2002 is shown below. By the end of the second season, more of the original input ^{15}N, whether fertilizer or vetch, was found in the soil under CT management. This is likely related to greater crop uptake and removal of input-N during the first season under ST management.



A manuscript summarizing the ^{15}N labeling fertilizer and cover crop work has been prepared and will be submitted for consideration for publication in a peer-reviewed scientific journal in 2008.

Practical Recommendations:

These preliminary findings point to a number of tentative considerations. First, from a productivity perspective, considerable improvements in CT production techniques are needed in order for yields to match those of ST systems. Yields in the CT systems tended to be significantly lower than those of the ST systems in four out of six years. Nitrogen availability may be a yield-limiting factor in the CT systems as we've implemented them here. However, there are also other management issues affecting CT crop performance: that have been documented in this work that may account for the poor performance of the CT corn and tomato systems in this study. A general lack of soil mixing, problems of stand establishment for both crops, transplant pests and cloddy weed cultivation conditions for tomato were major obstacles to better agronomic performance of the CT crops.

Based on considerable work with CT production systems in other regions and a survey of results from studies that have compared benefits of "starter" fertilizers in CT and ST production systems (personal communication, Dwayne Beck, South Dakota State University), there are generally-recognized benefits of "starter" fertilizer materials in CT relative to ST environments. In neither the tomatoes, nor the corn in this study did we use such materials. For CT to become and remain successful in CA, greater refinement and better of understanding of fertilizer applications, rates, timing, and placement in reduced disturbance systems will be needed. If this work is not done, then it may be quite difficult for the full potential of CT approaches to be realized.

Extension of information

While it is somewhat difficult to separate this project from other ongoing CT studies that we have underway, aspects of this project have been presented at a very wide variety of venues during the course of this project in addition to the two formal presentations that PI Mitchell made at Annual FREP conferences. Several of these outreach activities are listed below. A Powerpoint file of one such presentation accompanies this report to FREP. Any photographs in this presentation may be used for subsequent outreach by FREP.

October 5, 2003. Expansion of conservation tillage production practices in California's Central Valley. Poster presentation. ASHS Centennial Conference. Providence, RI.

October 6, 2003. Transitioning tomato and cotton production to conservation tillage in California's San Joaquin Valley. Oral presentation. ASHS Centennial Conference. Providence, RI.

October 7, 2003. Introduction to CT2003. Oral welcome and introduction to Conservation Tillage 2003: The California Experience. CT Workgroup Annual Conference, Tulare, CA. 80 participants.

October 7, 2003. Reduced tillage cotton and tomato rotation study in Five Points, CA: An evaluation after four years. CT Workgroup Annual Conference, Tulare, CA. 80 participants.

October 8, 2003. Introduction to CT2003. Oral welcome and introduction to Conservation Tillage 2003: The California Experience. CT Workgroup Annual Conference, Five Points, CA. 90 participants.

October 8, 2003. Reduced tillage cotton and tomato rotation study in Five Points, CA: An evaluation after four years. CT Workgroup Annual Conference, Five Points, CA. 90 participants.

October 9, 2003. Introduction to CT2003. Oral welcome and introduction to Conservation Tillage 2003: The California Experience. CT Workgroup Annual Conference, Davis, CA. 60 participants.

October 9, 2003. Reduced tillage cotton and tomato rotation study in Five Points, CA: An evaluation after four years. CT Workgroup Annual Conference, Davis, CA. 60 participants.

November 3, 2003. California's Conservation Tillage Workgroup: Research, Demonstrations and Extension Education. Poster presentation at the 2003 Annual Meetings of the American Society of Agronomy, Crop Science Society of America and the Soil Science Society of America. Changing Sciences for a Changing World: Building a Broader Vision. Denver, CO.

November 5, 2003. Reduced tillage cotton production systems in California's San Joaquin Valley. Poster presentation at the 2003 Annual Meetings of the American Society of Agronomy, Crop Science Society of America and the Soil Science Society of America. Changing Sciences for a Changing World: Building a Broader Vision. Denver, CO.

November 6, 2003. Productivity and profitability of reduced tillage cotton and processing tomato production systems in California's San Joaquin Valley. Oral presentation at the 2003 Annual Meetings of the American Society of Agronomy, Crop Science Society of America and the Soil Science Society of America. Changing Sciences for a Changing World: Building a Broader Vision. Denver, CO.

January 9, 2003. Reduced tillage cotton and tomato production systems evaluations in California. JPM prepared 38-slide Powerpoint presentation for Dan Munk to present). 2004 Beltwide Cotton Conferences. Marriott River Center, San Antonio, TX.

January 8, 2004. Conservation tillage and environmental protection. Invited presentation. 96th Tomato Day. University of California, Davis. Buehler Alumni Center. 70 participants.

January 21, 2004. What is conservation tillage and why might it be an important means for improving San Joaquin Valley air quality? Invited presentation to USDA Natural Resources Conservation Service San Joaquin Valley Air Quality Coordinators. Fresno County Farm Bureau. Fresno, CA.

February 4, 2004. Sustainable tomato production in California. Introductory discussion for Liz Mann, Australian Tomato Commission and Chuck Rivara, California Tomato Research Institute. Walnut Grove, CA.

February 4, 2004. Conservation tillage corn production. CT Corn Production Meeting. Western Farm Service. Wimpy's Restaurant. Walnut Grove, CA. 60 participants.

February 18, 2004. Annual Address. CT Workgroup Annual Meeting, Davis, CA. 45 participants.

April 2004. Conservation tillage. Oral presentation to USDA NRCS, Western Farm Service in NRCS office, Sacramento County. Invited by Christian Davis.

April 21, 2004. Presentation and tour for Steve Werblow. Writer for *California Farmer* and *The Furrow*.

May 27, 2004. Research and extension education related to conservation tillage in Califonria. Field tour and oral presentation to 19 students of Denmark agricultural science university. Five Points, CA.

June 15, 2004. Conservation tillage in intensive California agriculture. Invited presentation at the USDA Natural Resources Conservation Service National Agronomists' Conference. Lied Conference Center. Nebraska City, NE. 45 particpants.

July 1, 2004. Conservation tillage in California: An overview. Presentation for Intern of USDA Associate Director, Mack Gray, John Beyer and Johnnie Siliznoff. Five Points, CA.

July 14, 2004. Reduced tillage tomato production. 2004 Warm season vegetable field day. UC West Side Research and Extension Center. Five Points, CA. 150 participants.

July 17, 2004. Farm research networks to create new conservation tillage systems. Invited oral presentation in ASHS Workshop "Serving organic growers through innovative outreach and on-farm research. Austin, TX.

September 8 and 9, 2004. Conservation tillage in California. Oral plenary session presentation at CT2004: Western States Conservation Tillage Conference. Five Points, CA. 270 participants.

October 14, 2004. Fertilization technologies for conservation tillage production systems in California. Interpretive Summary Report. California Department of Food and Agriculture, Fertilizer Research and Education Program. Sacramento, CA

November 2, 2004. Conservation tillage wheat and tomato rotations in California. J.P. Mitchell, L.F. Jackson, A. Shrestha and J.J. Jackson. ASA/CSSA/SSSA Annual Meetings. Seattle, WA. p. 187 of Program. Oral presentation. 25 participants.

November 3, 2004. Capacity building for the adoption of conservation tillage in Califonria. J.P. Mitchell, A. Shrestha, R. Fry, J. Beyer and R.B. Hutmacher. ASA/CSSA/SSSA. Annual Meetings. Seattle, WA. p. 284 of Program. Oral presentation. 12 participants.

November 5, 2004. Reduced tillage in California vegetable crop systems. Oral presentation to UC Davis AMR110C student tour. UC West Side Research and Extension Center, Five Points, CA. 9 participants.

November 9, 2004. Fertilization technologies for conservation tillage production systems in

California. California Department of Food and Agriculture Fertilizer Research and Education Program. 12th Annual Fertilizer Research and Education Program Conference Proceedings. Edison AgTAC. Tulare, CA. Proceedings article. P. 34-37.

November 9, 2004. Fertilization technologies for conservation tillage production systems in California. California Department of Food and Agriculture Fertilizer Research and Education Program. 12th Annual Fertilizer Research and Education Program Conference Presentation. Edison AgTAC. Tulare, CA. 60 participants.

November 17, 2004. Recent advances in tomato production systems management in California. Invited presentation in “Farming Systems” Session of the 9th ISHS Symposium on the Processing Tomato. 30 participants.

January 5, 2005. Conservation tillage: Making it happen in California. 2005 Beltwide Cotton Conference: Innovation and Application – The Competitive Edge. Invited Plenary Session Speaker. New Orleans, LA. 1200 participants in audience.

January 28, 2005. Fertilization technologies for conservation tillage production systems in California. Annual Report to the California Department of Food and Agriculture’s Fertilizer Research and Education Program.

June 28, 2005. Conservation tillage cotton, corn and tomato systems in California. The 27th Annual Southern Conservation Tillage Systems Conference. June 27 – 29, 2005. Florence, SC. Oral presentation and abstract. 100 participants.

July 13, 2005. Conservation tillage in California. Invited presentation for PAPA (Pesticide Applicators Association). Kerman Community Center, Kerman, CA. 100 participants.

July 13, 2005. No-till production in California. Invited presentation at Cotton Production Meeting. Dos Palos, CA. 40 participants.

July 19, 2005. Oral presentation. Tomato yield stability during five-year transition to conservation tillage and cover cropping. J.P. Mitchell, W.R. Horwath, K.K. Klonsky, R.J. Southard, R. DeMoura, D.S. Munk, and K.J. Hembree. Annual Meetings American Society for Horticultural Science, Las Vegas, NV. 40 participants.

July 19, 2005. Tomato yield stability during five-year transition to conservation tillage and cover cropping. J.P. Mitchell, W.R. Horwath, K.K. Klonsky, R.J. Southard, R. DeMoura, D.S. Munk, and K.J. Hembree. Annual Meetings American Society for Horticultural Science, Las Vegas, NV. HortScience Abstract 40(4):1111.

August 10, 2005. Growing tomatoes with less tillage. 3rd Annual LeGrand Tomato Day, LeGrand, CA. Prepared posters and handout materials. 50 participannts