Effects of Cover Cropping and Conservation Tillage on Sediment and Nutrient Losses to Runoff in Conventional and Alternative Farming Systems

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OBJECTIVES

1. Quantify discharge from research plots and grower fields to compare alternative management practices with conventional ones.
2. Quantify non-point source pollutions (NPSP) concentrations and loads in discharge.
3. Inform farmers, policymakers, and the general public about the usefulness of cover crops (CC) and conservation tillage (CT) in addressing nutrients losses.

Executive Summary

Our research quantified non-point source pollution (NPSP) in discharge from conventional and alternative management practices using long-term UC Davis research plots and grower fields. We have placed a network of automated water samplers in the surrounding Sacramento Valley (Yolo County) to monitor storm season and irrigation tail water discharge. We compared the alternative practices of winter cover cropping and conservation tillage, known to reduce runoff in other areas of the US, on the amount of nutrients and sediment in agricultural runoff. Targeted constituents affecting water quality parameters (CAWQP) include total suspended sediment (TSS), turbidity, inorganic phosphate (PO_4-P) and nitrogen (NO_3-N, NH_4-N), total dissolved nitrogen and phosphorous (DON, DOP), dissolved organic carbon (DOC), and pesticides were examined. Finally, we assessed crop yields under alternative practices to provide information on the sustainability of these practices in California row crop agriculture. The following are the major findings of our research.

1. On fields prone to winter runoff cover crops significantly reduced runoff. Cover crops had little affect on fields with a tendency to produce low runoff.
2. The effect conservation tillage was not uniform and produced mixed results. The reason for mixed results is that conservation tillage was broadly defined being implemented either as leaving 30% or greater residue cover on the soil surface or a 40% reduction in tillage passes. Therefore, conservation tillage either increased or decreased winter runoff with no clear trend attributed to soil type.
3. The quality of water in runoff was generally within EPA drinking water guidelines for both winter and summer runoff except total suspended solids. Generally, less than 1% of applied fertilizers were found as inorganic or organic constituents in runoff annually.
4. Conservation tillage had comparable yields to conventional tillage using the same fertilization practices within the same farming system (i.e., conventional, organic). The main exception was for organic management where we found conservation tillage to be incompatible with manure amendments that are required to be soil incorporated to provide nitrogen to crops.
5. Conventionally managed systems generally had higher yields of corn compared to low-input or organic management. Tomatoes yields were similar among all systems regardless of source of fertilizer nitrogen, tillage or cover crop management

In conclusion, there is no universal prescription to reduce winter runoff except for the use of cover cropping on fields prone to winter runoff. We therefore recommend that a system of classification that scores fields based on runoff vulnerability be implemented to target fields prone to winter runoff. However, timing is a serious issue where planting cover crops before fall rains is generally a constraint facing farmers. In addition, farmers who cover crop may experience

significant delays in spring field entry due to managing the cover crop putting them at a competitive disadvantage compared to growers who do not cover crop.

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Introduction

Population growth, climate, and competing land uses are raising water quality concerns for Delta inflows. Agricultural activities are potential non-point sources of pollution of California's surface water. New regulations begun in January 2005 are holding California growers accountable for known pollutants draining off of their land. Conservation tillage, winter cover cropping, and post-sediment traps are alternative management practices for reducing runoff and minimizing nutrient and sediment losses. The plant canopy and residue cover in conservation tillage and cover cropped systems can lead to improved water quality through enhanced infiltration while the sediment trap's increased holding time encourages infiltration or denitrification.

This project is a three-year effort to quantify relationships between tillage, fertility management, runoff, and nutrient losses from irrigated soils farmed in Northern California using several different management strategies. To perform this task, the project has established a network of automated water samplers at the long-term UC Davis Sustainable Agricultural Farming Systems (SAFS) research plots and in grower fields in the surrounding Central Valley. SAFS is an effort created in 1988 by a multidisciplinary team of researchers, growers, and farm advisors to perform long-term comparisons of conventional, low-input, and organic farming systems. All three of these farming systems include a comparison of minimum tillage to standard tillage practices. The experiment also takes advantage of growers' interest in examining these relationships by setting up automated samplers on selected grower fields.

The network of automated samplers provide year-round monitoring of surface runoff with considerable resolution to more precisely compare the effectiveness of conservation tillage and cover cropping in minimizing runoff quantity and improving runoff quality. Runoff volume and water quality parameters including turbidity, suspended sediment, phosphate, inorganic nitrogen, total dissolved nitrogen and phosphorous, dissolved organic carbon, and pesticides were determined. Relationships of surface runoff from rainfall/irrigation and management practices will be used to develop monitoring tools for different land uses and management practices such as conservation tillage and cover cropping to minimize the export of water constituents of concern.

We have collected three years of storm runoff data from SAFS and grower fields in addition to two seasons of irrigation runoff from grower fields. Results will be discussed from both our research site and from two participating grower's fields.

Materials and Methods

Research Site - SAFS

The research sites are located in Northern California's Sacramento Valley (38º 32' N, 121 º 87' W, 18m elevation) on the former Long-term Research on Agricultural Systems (LTRAS) site of the University of California, Davis. This area is characterized by a Mediterranean climate with winter precipitation and hot, dry summers. Furrow irrigation is used for most crop production. Average annual precipitation, daily maximum and minimum temperatures from 1951 to present were 462 mm, 23.1ºC and 7.9ºC, respectively. The alluvial soils are classified as

Yolo silt loam (fine-silty, mixed nonacidic, thermic Typic Xerorthents; USDA taxonomy) and Rincon silty clay loam (fine, smectitic thermic Mollic Haploxeralfs; USDA taxonomy).

Prior to 1992, the SAFS site was farmed conventionally. In 1992 and 1993 irrigated, unfertilized sudangrass was grown and harvested for hay on the entire site to create more uniform soil fertility conditions in preparation for the LTRAS experiment. In 2003 LTRAS and SAFS merged projects and they now both coexist on the same site.

To begin, it is important to define and describe the farming systems tested in our research. The SAFS project is organized as a randomized split-plot design. First, the main factors are the conventional fallow (NCC), cover crop (CC), and organic with cover crop (OCC) systems. Secondly, each treatment is split into half to compare the effectiveness of using Standard (ST) or conservation (CT) tillage (Table 1).

All farming systems had at least a 10-year history of management under their defining criteria prior to the merging of the LTRAS and SAFS projects. However, in 2003, conservation tillage practices were imposed onto 3 treatments and thus, the NCC CT, CC CT, and OCC CT treatments began their history at the site that year.

The NCC treatment used by the SAFS team includes listing beds in the fall, leaving the field fallow over the winter, and applying synthetic fertilizer and pesticides when appropriate. The NCC treatment therefore has a bare soil surface throughout the winter storm season. It is intended to mimic the conventional practices of growers in the surrounding area and is the “control” for our experiment.

Table 1. Summary of Systems, Treatments, and Tillage practices used on the experimental plots and two grower's fields in the Sacramento Valley, California.

System	Treatment	Tillage	CIFS	Grower A	Grower B
Conventional	Fallow (NCC)	Standard (ST)	✔	✔	✔
Conventional	Fallow (NCC)	Conservatio n (CT)	✔		✔
Alternative	Cover Crop (CC)	Standard (ST)	✔	✔	✔
Alternative	Cover Crop (CC)	Conservatio n (CT)	✔		
Alternative	Organic (OCC)	Standard (ST)	✔		
Alternative	Organic (OCC)	Conservatio n (CT)	✔		

Although the CC and OCC standard tillage treatments list beds in the fall, they use a winter legume cover crop mix (WLCC) of vetch (*Vicia dasycarpa* Ten, cv Lana) and pea (*Pisum sativum L.*, cv Miranda) during the winter storm season. Therefore, the soil surface is covered throughout most of the rainy period. Currently, cover crop management accounts for less than 1% of all area farmed in the Sacramento Valley and thus, CC and OCC practices are named “alternative” in our project.

The OCC treatment meets the state of California’s standard for organic farming. Synthetic fertilizers and pesticides are prohibited and additional nutrient inputs are supplied by composted poultry manure. The CC treatment serves to test how one may transition from conventional to organic farming systems. Though fertilizer input comes from organic sources in the CC treatment, is not designed to be certified as organic. Therefore, pesticides may be used. It is important to note that the CC CT treatment uses manure and WLCC prior to tomato but only WLCC prior to corn. All other treatment and tillage systems use just WLCC prior to both tomato and corn.

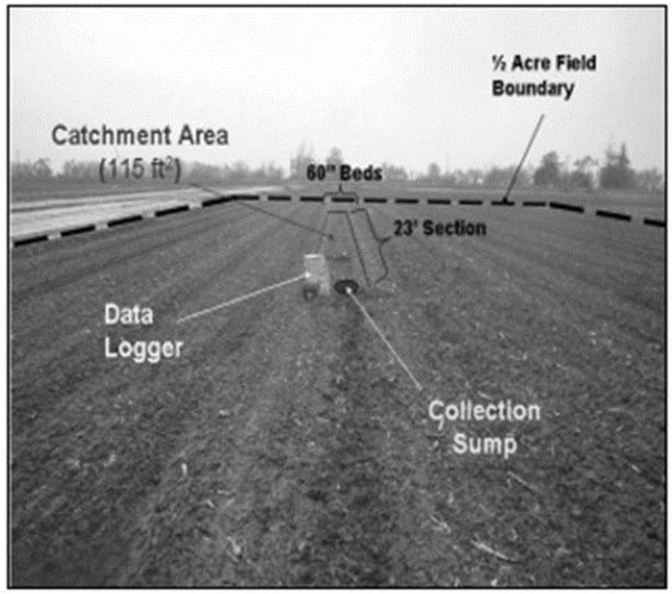


Figure 1. 2004 – 2006 experimental set-up at SAFS research facility in Yolo County, California.

CT management in all systems is defined as a tillage practice that leaves at least 30% crop residue on the soil surface and/or reduces ST practices by 40%, depending on the previous growing season’s crop. In contrast to the ST system, CT beds are not listed in the fall. However, like ST management, CT fields are left fallow in the NCC system while the CC and OCC systems use the WLCC mix.

Each and every treatment and tillage system used in this study has a two-year rotation of processing tomato (*Lycopersicum esculentum*) and corn (*Zea mays*). Throughout the duration of the project, the Halley 3155 tomato variety was planted in all farming systems. In the 2003 season, an herbicide resistant variety of corn was introduced into the NCC plots to accommodate the introduction of the split plot tillage treatments. ST 7570 RR (Roundup Ready) was used in the NCC plots, while ST 7570 (non-GMO) was incorporated into the OCC and CC plots.

Bulk density measurements were taken at the LTRAS plots in 2005 (Joern Seigies, unpublished data) and in 1999 (LTRAS database - Dennis Bryant). 2005 bulk density values were averaged by system and depth. A linear regression of the 2005 and 1999 bulk density data was used to estimate 2003 and 2004 values. The estimated 2003 and 2004 values were averaged by depth and one value was used for each depth across all systems.

For the storm seasons starting in December 2004 and ending in April 2006 we compared the three treatments and two tillage combinations. There was one combination per plot, six combinations per block, and three blocks total. Each plot had an area of 0.2 ha (65 m x 32.5 m).

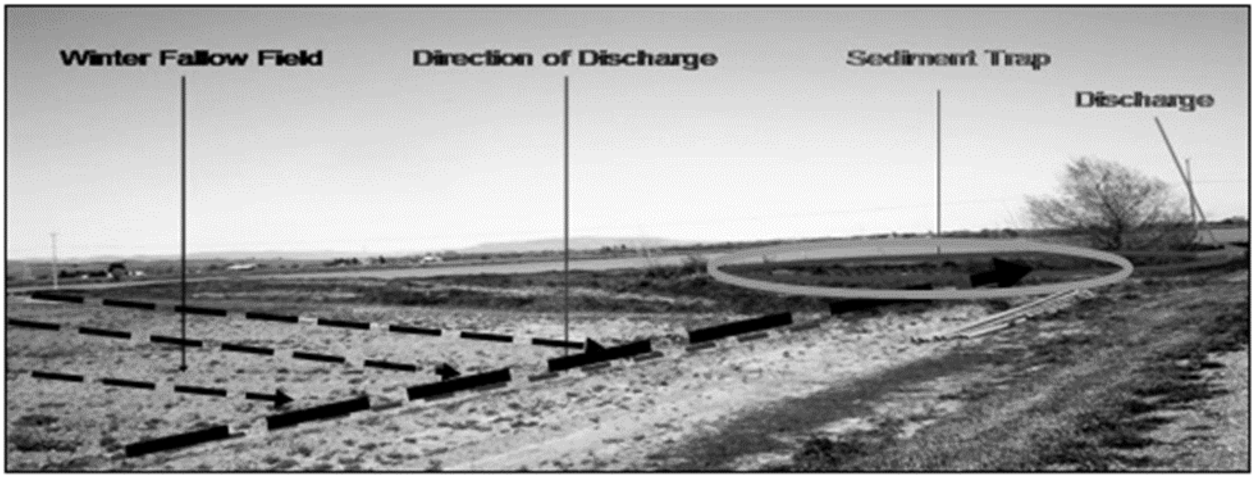


Figure 2. Runoff from the bare soiled, non-cover cropped field is channeled into a sediment trap in the northeast corner of the field. A data-logger / sampler was placed at the outflow of the

During the 2004-2005 storm season, runoff data collection at the SAFS research site used a sample catchment area of 0.001 ha (10.7 m^2) within each 0.2 ha plot. Within the catchment, discharge was channeled between 1.5 m beds, along a 0.0% slope, and down one furrow. At the end of the 7.0 m run, discharge was collected in a sump, 1 m deep and 0.3 m wide, buried at the end of the catchment area (Fig. 1). At the end of each rain event, a grab sample was taken for analysis and then the sump was emptied. The beginning of a rainfall event is defined as the first measurable rainfall and/or discharge after a minimum of 12 hours from last measurable rainfall and/or discharge. If rainfall ceases for 12 hours, but discharge doesn't during that 12-hour period, then the event still continues. The event ends as soon as discharge stops after an absence of 12 hours of measurable rainfall. For 2005 – 2006 data collection at the SAFS runoff research plots, one furrow from the same catchment size was again isolated to channel runoff along a 7.0 m run into a collection sump at the end of the catchment. However, this time a 1.0 m by 0.25m-diameter sump was installed. The sump diameter was decreased in this season to facilitate easier installation and retrieval of the sumps.

<u>Research Site – Yolo County Growers</u>

A unique aspect of SAFS research is our reliance on grower input for SAFS farming management decisions as well as data collection. As mentioned above, our project utilized three local growers to collect runoff data from farming systems similar to the research plots at SAFS (Table 1). Data from two of the growers will be presented here. Throughout the paper these growers will be referred to as Grower "A" and Grower "B". On both Grower A and B's fields, runoff was sampled by datalogger-equipped auto-samplers to assess the affects of CC ST and NCC CT in comparison to NCC ST treatments. In 2003-2004 and 2004-2005, data was also collected from a post sediment trap located at the drainage exit of the NCC ST treatment on grower "A's" field (Fig. 2). This data was collected for the project during both the storm and irrigation seasons.

In addition to the runoff quantity and quality data collected from grower fields during the 2003-2006 rain seasons, runoff was collected continuously from 2004 and 2005 growing season tail water from growers A and B. Though a determined effort was made to get crop rotation and field characteristics similar to those at the SAFS research facility, differences were unavoidable and occurred within and between all growers, fields, treatments, and tillage practices. Important differences are noted below.

Grower "A"

Grower A is located in Winters, California (38^o 59' N, 121^o 98', 42m elevation), approximately six miles Northwest of the SAFS research facility. On their farm, we sampled three years of storm discharge and two seasons of irrigation tail-water from one NCC ST treatment, one CC ST treatment and, as previously mentioned, a sediment trap created to minimize discharge leaving the NCC ST field.

The data collection for winter storm runoff was conducted on two conventional-sized fields located next to each other, facing West to East. Both fields have had similar farming history and use a typical rotation for tomato growers in this area. Grower A's NCC ST treatment for 2003-2005 was farmed on 15.86 ha of Prime Tehama loam (TaA) soil, with an area-weighted average 631 m run and a 0.32% slope. The CC ST treatment for 2003-2005 was farmed on 17.36 ha of Prime TaA and Marvin silty clay loam (Mf) soil with nearly 60% of the area classified as Mf and 40% of the area classified as TaA soil (USDA taxonomy). The CC ST field had an area-weighed average run of 468 m and a 0.17% slope. In 2005-2006, grower A switched treatments in the fields so that the CC ST treatment became NCC ST and vice versa. However the soil and field configurations remained the same so that the 2005-2006 NCC ST treatment now had 17.36 ha, for example.

In the summer of 2005 we acquired an additional NCC ST field at Grower A's farm to collect tail-water runoff data. This was done because we needed a conventionally managed tomato field to monitor discharge and be able to compare it to previous years results. The previous year's NCC ST field had been planted in tomatoes and was now in Sunflower. The Summer 2005 field was located approximately three miles Northwest of the Winter 2004-2005 Grower A NCC ST fallow treatment (38^o 63' N, 122^o 00' W, 42m elevation). Information regarding site characteristics for the summer 2005 NCC ST treatment will be forthcoming at a later date.

Grower "B"

Grower B is located in Woodland, California (38^o 71' N, 121^o 86' W, 20m elevation), approximately 20 km due North of the SAFS research facility. We sampled 2 years of storm and irrigation tail-water comparing NCC ST, CC ST, and NCC CT in 2004-2005 and NCC ST and NCC CT in 2005-2006.

On Grower B's farm, research was conducted on a total of 4 fields located within a 1 km radius next to each other. Grower B's NCC ST treatment for 2004-2005 and 2005-2006 was farmed on both Brentwood silty clay loam (BrA) and Rincon silty clay loam (Rg). Approximately 38% of the field's area consisted of BrA soils, and the rest of the field was made up of Rg (USDA). The NCC ST field was approximately 27 ha with an area weighted average run of 380 m and a 0.41% slope. The CC treatment for 2004-2005 was planted on 31 ha of mostly Prime soil. 57.6% of the field's area was over BrA soil while Rg soil comprised 37.5% of the area. The rest of the field was Clear Lake clay (Ck) (3.8%), Corning gravelly loam (CtD2) (0.7%), and Sehorn cobbley clay (SlD) (0.3%) (USDA). The field had an area-weighted average run of 603 m with a 0.34% slope. The 2004-2005 Grower B NCC CT treatment consisted of 48% BrA soil and 49% Rg soil. The rest was made up of Sehorn clay (SkD) (1%), and Sehorn-Balcom complex (SmD) (2%). The field had a area-weighted average run of 697.2 m and a 0.17% slope. We didn't use a CC ST treatment at Grower B's farm in 2005-2006. However, we did monitor a different NCC CT field to compare it to the NCC ST treatment in the same year. The 2005-2006 Grower B NCC CT field was farmed on 32.37 ha of Rg (86%) and BrA (14%) soils with an area-weighted average 621.4 m run and a 0.16% slope.

Each season discharge was measured from grower fields with an area-velocity (AV) sensor placed in the bottom of the main drainage ditch leaving the grower's field or sediment trap (Fig. 3). The data-logger / auto-sampler and connected rain gauges took readings and samples at pre-programmed intervals. Discharge was measured and sampled at regular intervals during all runoff events, collected and transported to the UC Davis campus for water quality analyses.

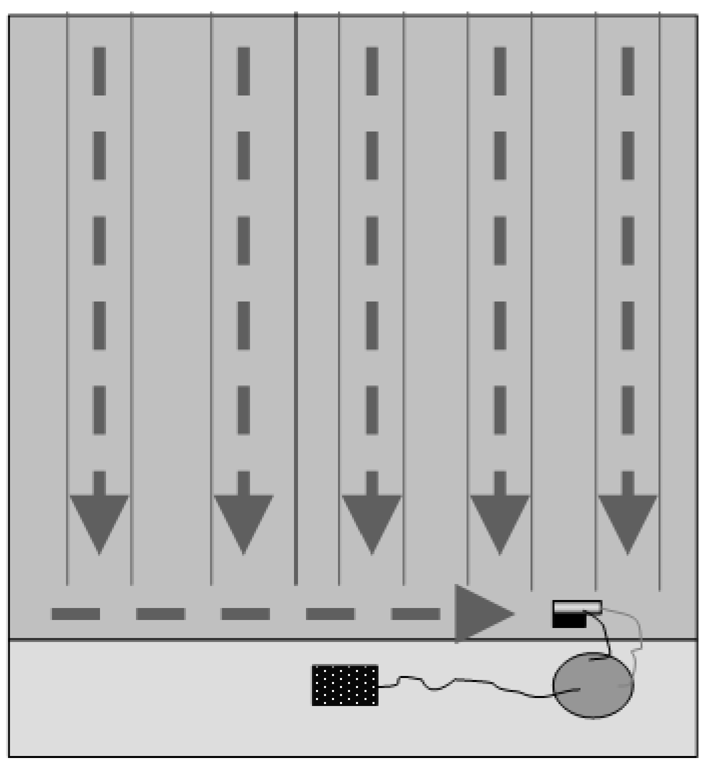


Figure 3. Diagram of grower field data collection site. The arrows represent overland flow of discharge. The circle represents the data logger / auto-sampler. The small solid black rectangle is the area-velocity (AV) sensor lying in the main drainage ditch. The slender gray rectangle next to the AV sensor is the sampling strainer. Finally the white-dotted rectangle connected to the data logger represents the rain gauge used to calculate overland flow input.

Statistical Analysis-SAFS

Data was analyzed by regression analysis comparing the impact of a number of plot characteristics on the dependent variable. The plot characteristics examined were year, block, plot, % cover from cover crop (fallow system = 0.0% cover), % residue cover on soil surface, rainfall intensity per event (mm/hr), average monthly net evapotranspiration (mm/day), soil class (Prime soil = 1, non Prime soil = 0), overall percent clay, and overall percent silt. The dependent variable for which the regression analysis was performed was the log percentage of rainfall discharged through runoff. The Tukey-Kramer HSD test was used for separation of means when significant differences were detected ($P < 0.05$).

Statistical Analysis- Grower Fields

Data from the grower fields were analyzed in a similar manner as that of the SAFS plots. Like the SAFS analysis, a regression analysis was used to compare the impact of field characteristics to the dependent variable of the log percentage of rainfall discharged as runoff. In the field trials site characteristics used in analysis were slightly different than the SAFS plots to account for differences in field length and slope of the grower fields. Therefore field characteristics examined in the grower analysis included management system (NCC, CC), tillage (ST = 0 or CT = 1), event rainfall intensity (mm/hr), average monthly net evapotranspiration (mm/day), slope (%), area-weighted average field length (m), soil class (Prime soil = 1, non Prime soil = 0), overall percent clay, and overall percent silt. Although a similar to the SAFS analysis, it is important to remember that there were limitations to the grower field statistical conclusions due to the informal design of this portion of the experiment.

All statistical analyses were performed with the SAS software (SAS Institute, Cary, NC).

Results and Conclusions

SAFS Data

As reported before, we were confronted with challenges in our first year (Winter 2003 – 2004) of data collection for runoff from the SAFS research facility. Many different modifications to the original design were attempted but in the end it was concluded that the research plots had insufficient size and slope to provide enough overland flow and transport of pollutants through our flume placed at the end of the plots. In spite of these challenges, the newly adopted method of collecting data, as stated above, was effective for the following two storm seasons (Winter 2004-2005 and Winter 2005-2006).

Results of our study from the SAFS research plots for the 2004-2005 and 2005-2006 winter storm seasons suggest that the type of crop residue left on the soil surface from CT management plays an important role in influencing discharge. In CT fields where the annual crop residue left is less than 30%, it may take years to see benefits for water quality. In addition, CC systems have great potential to provide an immediate and positive effect in minimizing load of constituents affecting water quality parameters (CAWQP). Our results also suggest that load of various CAWQP is influenced much more by the quantity of discharge than by the concentrations of CAWQP in the discharge. Finally, volume-weighted average concentrations of CAWQP for CIFS plots were below water quality standards for the City of Davis.

SAFS Storm Season Discharge

2004-2005 Discharge Following Corn

Winter 2004-2005 discharge was measured in plots that were farmed under corn in the summer of 2004. Therefore plots under CT management had at least 30% corn residue left on the soil surface. In addition, CC ST, CC CT, OCC ST, and OCC CT plots had cover from the cover crop (Fig. 4).

Under NCC management, where the plots were left fallow, CT management significantly reduced discharge as a percentage of rainfall by 41%. CT management also significantly reduced discharge under CC systems, where plots were planted with a winter cover crop, by 38%. In the OCC systems, where a cover crop was also planted, discharge was reduced by 33%, although this difference was not statistically significant. Interestingly, the cover cropped systems appeared to increase runoff as a percentage of rainfall compared to the fallow systems, regardless of tillage, although this difference was not significant. In sum, conservation tillage management with residue greater than 30% reduced total average winter discharge as a percentage of rainfall while cover cropping had no effect (Fig. 5).

The decrease in SAFS winter runoff from CT plots is expected as they reflect results from CT studies in the Midwest. These studies have demonstrated promotion of infiltration by CT management. The residue serves to reduce raindrop impact energy onto the soil surface in addtion to slowing the velocity of overland flow and thereby increasing the time water at the soil surface will have at any one place to infiltrate. The increase in runoff from the CC plots was unexpected and no explaination is available at this time. However the data will be

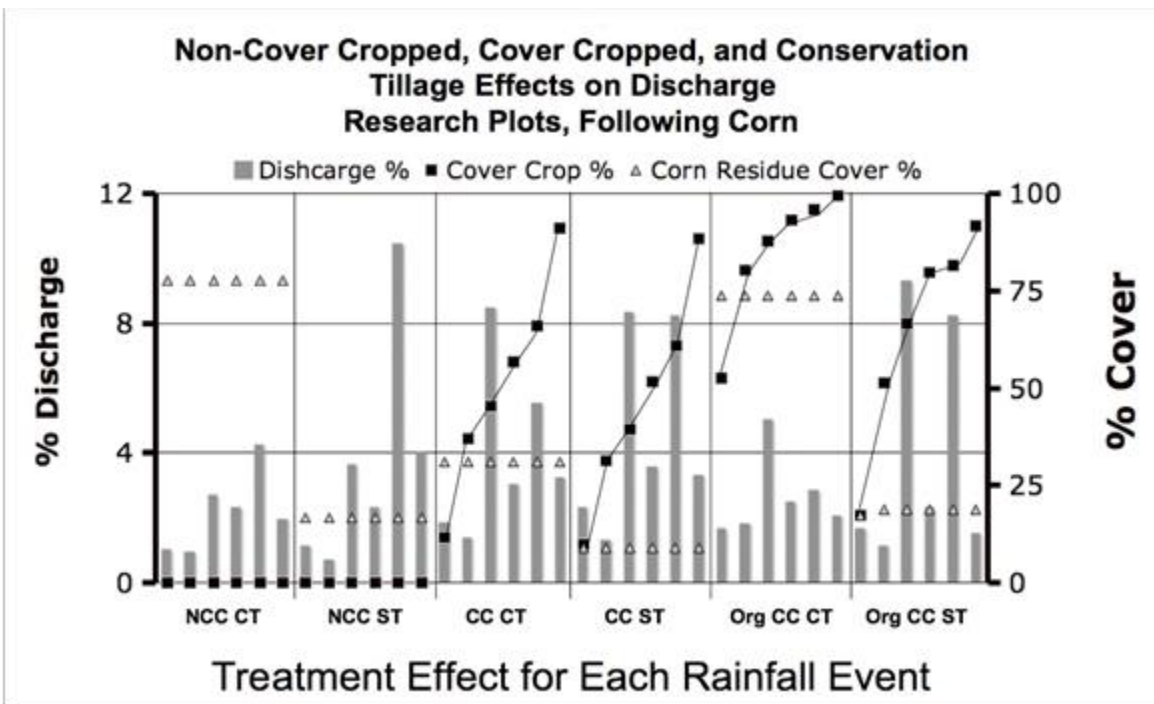
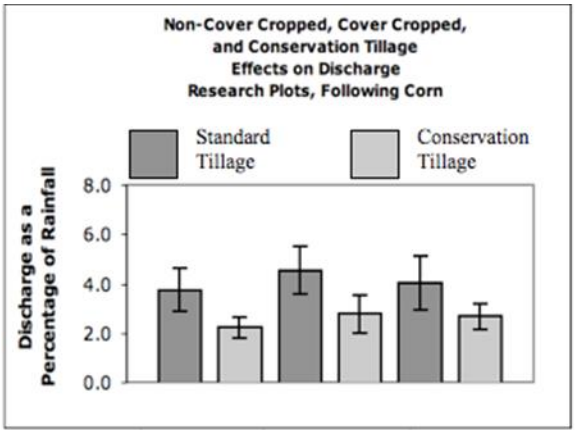


Figure 4. Mean discharge as a percentage of rainfall comparisons for 6 treatments and 6 measured rainfall events following corn. The light-colored triangles represent the mean residue cover for the each treatment. The black squares represent the mean cover from the cover crop for each treatment.

reviewed along with notes taken of field conditions at the time samples were collected to see if there will be evidence to explain the increase.



Management System	ST	CT	Change Due to CT Management
	%		%
Conventional (NCC)	3.7	2.2	-41
Cover Cropped (CC)	4.5	2.8	-38
Organic (OCC)	4.0	2.7	-33
Change Due to CC Management	+13	+20	

Figure 5. Discharge as a percentage of rainfall comparison for 6 treatments, following corn, at the SAFS research facility. The graph on the left is a seasonal volume-weighted average of runoff by treatment. The graph on the right highlights the percentage of increase or decrease in runoff due to cover cropping or conservation tillage practices.

2005-2006 Discharge Following Tomato

Winter 2005-2006 discharge was measured in the same plots as those from the 2004-2005 season. However, the 2005-2006 plots were farmed under processing tomato in the summer of 2005. Consequently, plots under CT management had tomato residue left on the soil surface. Even so, mean tomato residue on the soil surface in all plots was at or below 30%. Remember, all CC and OCC plots had the additional cover from the cover crop (Fig 6).

Both cover cropped systems (CC and OCC) significantly reduced runoff as a percentage of rainfall by 62% under ST management and 64% under CT management compared to the NCC ST and NCC CT systems, respectively. However, CT management actually increased discharge compared to ST management by 19% under the CC system and 12% under the OCC system, although these increases were not significant. In contrast, CT management increased discharge by 22% in the NCC systems and this was statistically significant when compared to the NCC ST system (Fig. 7).

As would be expected, rainfall intensity significantly impacted runoff for all events, regardless of treatment or year. All other site characteristic variables examined had no significant impact on discharge as a percentage of rainfall. This was true for both years of the study.

The decrease in discharge from the SAFS CC and OCC plots is in line with previous research on the effects of cover cropping that have been done in other climate zones. The plant cover functions to reduce raindrop impact energy as well as decreasing overland flow velocities. In addition, the extension of the plant stem penetrating into the root zone may serve as a biological plow and thereby enhance water infiltration by creating chanels for water to flow beneath the soil surface.

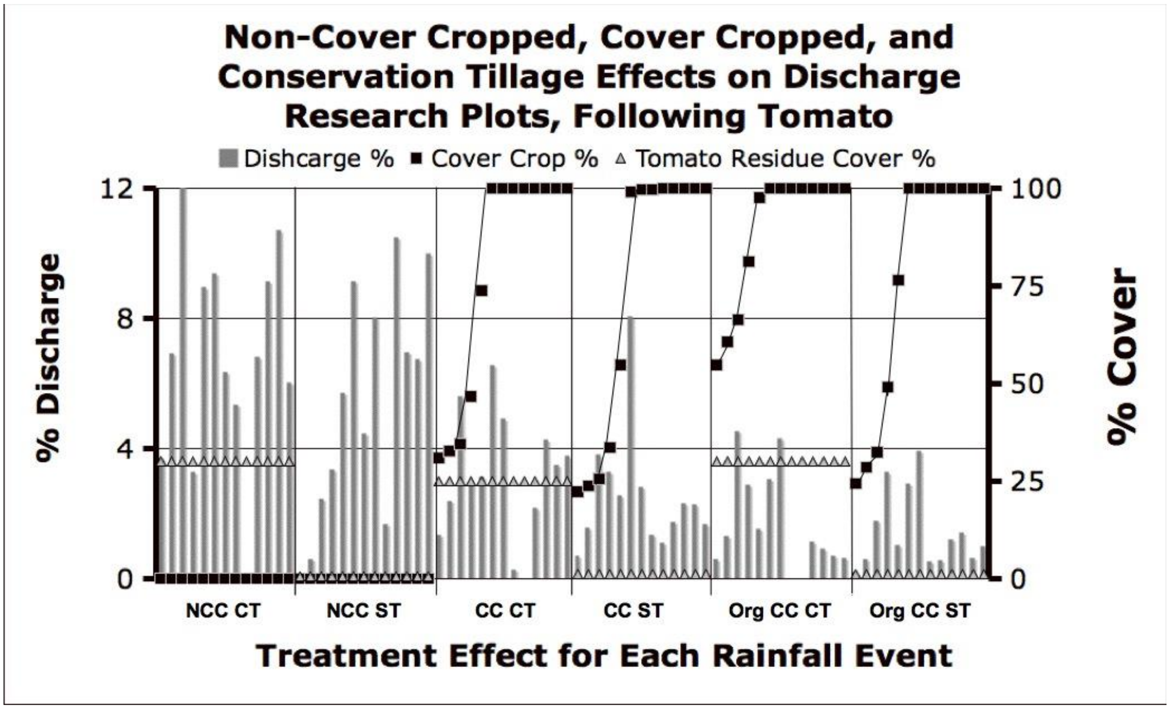


Figure 6. Mean discharge as a percentage of rainfall comparisons for 6 treatments and 13 measured rainfall events following tomato. The light-colored triangles represent the mean residue cover for the each treatment. The black squares represent the mean cover from the cover crop for each treatment. Each bar represents the discharge as a percentage of runoff for each treatment and each event.

The higher discharge from the SAFS CT plots following tomatoes may be possibley explained by the higher clay content of California soils. These soils are more likely to create a soil crust that inhibits infiltration. Unlike conventional tillage practices, CT management does not list beds prior to the winter rains and thus crusts formed from furrow irrigation in the summer remain in the furrows. In addtion the soil surface on the beds form crusts as soon as winter rains begin. Where residue cover is less than 30%, such as those in the tomato CT plots at SAFS, a large percentage of the suface remains bare and sealed and therefore raindrop impact energy and overland flow velocities will be higher than those where the soil surface is rough. Therefore water has less potential for infiltration. These combined factors likely resulted in the increase of runoff as a percentage of rainfall in the CT plots when compared to ST plots.

SAFS Storm Season Concentration

2004-2005 Following Corn

In general, concentrations of various CAWQPs were similar for all treatments. Table 2 demonstrates the effect of treatment on concentrations of 6 CAWQP. For 2004-2005 the CAWQP analyzed were total suspended solids (TSS), dissolved organic carbon (DOC), phosphate (PO_4-P), ammonium (NH_4-N), nitrate (NO_3-N), and dissolved organic nitrogen (DON). The following is a summary of the analysis based on each analyte.

<u>TSS concentrations following corn</u>

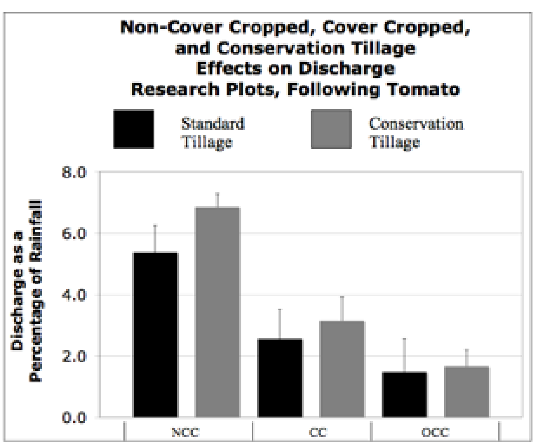
The NCC ST treatment had a significantly lower concentration when compared to the NCC CT treatment. When compared to the other two systems, the NCC ST treatment was significantly higher than CC ST and OCC ST. Overall, the NCC CT had the highest value of all the systems and tillage.

The CC ST treatment was significantly lower than the CC CT treatment. In fact, the CC ST treatment was significantly lower than all other systems and tillage treatments.

The OCC ST resulted in significantly lower concentrations of TSS compared to the OCC CT treatment. Furthermore the OCC ST treatment was significantly lower than the NCC ST treatment but significantly greater than the CC ST treatment.

In general all three systems of CT management were not significantly different from one another. However all CT management resulted in higher TSS concentrations when compared to all ST management, regardless of system. All 6 treatments resulted in TSS concentrations below 6000 mg/L (Table 2).

2005-2006 Following Tomato



Management System	ST	CT	Change Due to CT Management
	%		%
Conventional (NCC)	5.4	6.9	+22
Cover Cropped (CC)	2.6	3.2	+19
Organic (CC)	1.5	1.7	+12
Change Due to CC Management	-62	-64	

Figure 7. Discharge as a percentage of rainfall comparison for 6 treatments, following tomato at the CIFS research facility. The graph on the left is a seasonal volume weighted average of runoff by treatment. The graph on the right highlights the percentage of increase or decrease in runoff due to cover cropping or conservation tillage practices.

PO_4-P concentrations following corn

The NCC CT treatment resulted in significantly lower concentrations of phosphate when compared to the NCC ST treatment. Moreover, the NCC CT treatment had the lowest concentrations out of all 6 treatments.

The intra-system tillage comparison resulted in no significant difference of concentrations of PO_4-P under the CC treatment. In addition, CC ST was not significantly different than NCC ST but both CC ST and CC CT were significantly lower than OCC ST and OCC CT.

The intra-system tillage analysis of the OCC system resulted in CT yielding significantly lower concentrations than ST management. The OCC ST treatment resulted in significantly lower concentrations of PO_4-P compared to all other treatments.

Though there were significant differences reported between systems and tillage, overall phosphorus concentrations were below 2 mg/L (Table 2).

DOP concentrations following corn

Total dissolved organic phosphate analysis was not available for the 2004-2005 due to difficulties encountered in the laboratory analysis. Although standard methods were followed (*Standard Method*s, 20th ed., APHA/AWWA/AWF, method 4500-P B.) they did not work for our purposes. Methods were adapted from the *Standard Methods*, 20th ed. for the 2005-2006 season and this changed proved successful.

NO_3-N concentrations following corn

The intra-system tillage comparison between NCC ST and CT revealed no significant differences in NO_3-N concentrations. In addition there were no significant inter-system differences when NCC ST was compared to CC ST and

Table 2. Volume-weighted average concentrations of various constituents affecting water quality parameters (CAWQP) for the 2004-2005 storm season following a summer corn crop.

Year	Management System	Tillage	TSS	PO4-P	DOP	NO3-N	NH4-N	DON	DOC
			mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
2004-2005 Concentration With Corn Residue	Conventional (NCC)	ST	2393 (±574)	0.69 (±0.31)	.	0.61 (±0.41)	1.41 (±0.71)	3.98 (±1.79)	6.04 (±0.38)
	Conventional (NCC)	CT	5780 (±1730)	0.12 (±0.03)	.	0.56 (±0.05)	0.25 (±0.09)	1.63 (±0.62)	3.60 (±0.38)
	Cover Cropped (CC)	ST	978 (±65)	0.31 (±0.14)	.	0.27 (±0.09)	0.25 (±0.05)	1.27 (±0.58)	5.68 (±2.23)
	Cover Cropped (CC)	CT	4563 (±1190)	0.26 (±0.12)	.	0.49 (±0.12)	0.66 (±0.37)	1.56 (±0.50)	3.87 (±0.55)
	Organic (CC)	ST	1319 (±121)	0.78 (±0.27)	.	0.16 (±0.09)	1.13 (±0.24)	7.61 (±3.62)	11.12 (±0.38)
	Organic (CC)	CT	3346 (±978)	1.63 (±0.15)	.	0.23 (±0.10)	0.62 (±0.51)	2.12 (±0.84)	5.35 (±1.83)

OCC ST. However, NCC CT NO_3-N was significantly higher compared to OCC CT but not significantly different compared to CC CT.

The intra-system tillage comparison between CC ST and CT resulted in significantly lower concentrations of NO_3-N from the CC ST system.

The OCC intra-system tillage comparison showed no significant difference in NO_3-N concentrations. The OCC ST had the lowest NO_3-N concentration of all 6 treatments.

It is important to note that all NO_3-N concentration values were below 1 mg/L, regardless of system or tillage management (Table 2).

NH_4-N concentrations following corn

Intra-system tillage comparisons of the NCC system demonstrated a significantly higher concentration of NH_4-N from the ST treatment. Inter-system comparisons between NCC ST, CC ST, and OCC ST treatments resulted in no significant differences in NH_4-N among all three. The highest value of NH_4-N concentrations for all 3 ST treatments was in the NCC ST treatment.

The tillage comparison within the CC system revealed no significant differences in NH_4-N concentration. In the inter-system comparison the CC ST treatment was significantly lower than the NCC ST and OCC ST treatments. The highest value of NH_4-N for all 3 CT treatments was in the CC CT system.

The tillage comparison within the OCC system resulted in no significant differences in NH_4-N measured between the two.

In general, all NH_4-N concentration values were below 1.5 mg/L, even though significant differences among the 6 treatments as discussed (Table 2).

DON concentrations following corn

Tillage comparison between NCC ST and CT show no significant differences in total dissolved organic nitrogen concentrations. There were no inter-system ST differences in concentration when comparing NCC ST and OCC ST.

In contrast, the CC ST treatment was significantly lower in DON than the NCC ST and OCC ST treatments. However, the intra-system tillage comparison between CC ST and CC CT showed no significant difference.

The OCC intra-system tillage comparison was not significantly different for DON between OCC ST and OCC CT. The OCC ST treatment was significantly higher than all system and management practices except the NCC ST treatment and had the highest DON value of all systems and management.

There were no significant differences in DON concentrations among all CT treatments regardless of the system comparison. Finally, all DON concentrations were below 4 mg/L except for the OCC ST treatment that had a volume-weighted average of 7.6 mg/L (Table 2).

DOC concentrations following corn

The NCC CT treatment had significantly lower concentration of total dissolved organic carbon when compared to the NCC ST treatment. Furthermore, The inter-system comparison for ST management revealed that the NCC ST treatment was significantly lower than the OCC ST, but not the CC ST treatment.

Table 3. Volume-weighted average concentrations of various constituents affecting water quality parameters (CAWQP) for the 2005-2006 storm season following a summer tomato crop.

2005-2006 Concentration With Tomato Residue	Conventional (NCC)	ST	**4819** (±1259)	**0.22** (±0.04)	**0.22** (±0.07)	**0.27** (±0.04)	**0.09** (±0.02)	**0.57** (±0.04)	**4.23** (±0.43)
	Conventional (NCC)	CT	**4271** (±1343)	**0.33** (±0.05)	**0.10** (±0.01)	**0.34** (±0.11)	**0.41** (±0.29)	**0.61** (±0.10)	**4.20** (±0.06)
	Cover Cropped (CC)	ST	**4900** (±918)	**0.15** (±0.02)	**0.14** (±0.06)	**0.31** (±0.05)	**0.14** (±0.06)	**0.43** (±0.11)	**2.79** (±0.22)
	Cover Cropped (CC)	CT	**3600** (±555)	**0.15** (±0.04)	**0.12** (±0.01)	**0.33** (±0.06)	**0.14** (±0.03)	**0.51** (±0.06)	**3.57** (±0.34)
	Organic (CC)	ST	**3372** (±517)	**0.34** (±0.02)	**0.29** (±0.05)	**0.26** (±0.04)	**0.08** (±0.04)	**0.38** (±0.01)	**2.42** (±0.59)
	Organic (CC)	CT	**2102** (±409)	**0.67** (±0.26)	**0.40** (±0.18)	**0.28** (±0.12)	**0.69** (±0.35)	**0.59** (±0.20)	**3.40** (±1.07)

There was no significant difference in the DOC concentrations when comparing CC ST to CC CT. The CC ST treatment resulted in significantly lower concentrations compared to the OCC ST treatment, but was not different compared to the NCC ST treatment.

Like the NCC CT treatment, the OCC CT treatment was significantly lower than the OCC ST system and management. In addition, the OCC ST treatment was significantly higher than the NCC ST and CC ST treatments and yielded the highest overall value among all 6 treatments.

Finally, the NCC CT system had the lowest DOC value among all systems and management although CT treatment was not significantly different in an inter-system comparison. All DOC concentrations were below 6 mg/L except for the OCC ST treatment, which was 11.12 mg/L (Table 2).

In conclusion table 2 demonstrates that, although significant differences exists between systems and tillage management, the volume-weighted average concentrations of CAWQPs are below 10 mg/L in most cases, regardless of treatment (excluding TSS). These values are within drinking water quality standards for the city of Davis.

2005-2006 Following Tomato

In general, volume-weighted average concentrations of various CAWQPs were similar for all treatments in the storm season following a summer crop of processing tomatoes. Table 3 demonstrates the effect of treatment on concentrations of 7 CAWQP. For 2005-2006 the CAWQP analyzed were total suspended solids (TSS), dissolved organic carbon (DOC), phosphate (PO_4-P), dissolved organic phosphorous (DOP), ammonium (NH_4-N), nitrate (NO_3-N), and dissolved organic nitrogen (DON). The following is a summary of the analysis based on each analyte.

TSS concentrations following tomato

The NCC intra-system tillage comparison showed no significant difference between the NCC ST and NCC CT concentrations of TSS. Inter-system comparisons between NCC, CC, and OCC ST management were not significantly different among all three treatments. In fact, the NCC system and tillage management are not significantly different than all other systems and tillage except for OCC CT, which had significantly lower TSS.

The intra-system tillage comparison under the CC system revealed that CT management was not significantly different in TSS than the ST management. Inter system tillage comparisons demonstrated no significant differences between the NCC and CC systems and tillage.

CT management was significantly lower than ST management under the OCC system. The inter-system comparison demonstrated that the OCC ST treatment was not significantly different in TSS than the other ST treatments. However OCC CT treatment was significantly lower in TSS than the other two CT treatments. In fact, the OCC CT was significantly lower than all other systems and tillage management treatments.

Finally, all TSS concentrations were less than 5000 mg/L regardless of treatment (Table 3).

PO_4-P concentrations following tomato

CT management yielded significantly higher concentrations of PO_4-P compared to the ST treatment under the NCC system. The NCC ST treatment was also significantly lower in PO_4-P than the OCC ST treatment but significantly higher than the CC ST treatment.

Under the CC system, the CT treatment was not significantly different in PO_4-P than ST management. Under the inter-system comparison, the CC ST treatment was significantly lower in PO_4-P than all NCC and OCC system and tillage treatments.

Within the OCC system, the ST treatment was significantly lower in PO_4-P than the CT treatment. The inter-system comparison revealed that the OCC CT treatment was significantly higher in PO_4-P than the other 5 treatments.

Regardless of system and tillage management, all treatments yielded volume-weighted average concentrations of PO_4-P less than 0.70 mg/L (Table 3).

DOP concentrations following tomato

Within the NCC system, CT management had significantly higher concentrations of dissolved organic phosphorus than ST. There was no difference in DOP between the NCC ST and OCC ST treatments. The NCC CT treatment was significantly lower in DOP than CC CT and OCC CT management. NCC CT had the lowest DOP concentration out of all 6 treatments.

Under the CC system, there was no significant difference in DOP between tillage practices. However, the inter-system comparison demonstrated that the CC ST treatment was significantly lower in DOP than both the NCC ST and OCC ST treatments but the CC CT treatment was only significantly lower in DOP than the OCC CT treatment.

The OCC system did not provide any significant difference in DOP concentration between ST and CT management. The inter-system comparison demonstrated that the OCC CT treatment was significantly higher in DOP than both the NCC and CC CT treatments.

In sum, the ST treatments were not significantly different in DOP regardless of farming system, but the CT treatments were significantly different from one another when comparing systems. However, all DOP concentrations were below 0.50 mg/L (Table 3).

NO_3-N concentrations following tomato

There were no significant differences in NO_3-N concentrations regardless of system and/or tillage. In addition all NO_3-N concentration values were below 0.50 mg/L (Table 3).

NH_4-N concentrations following tomato

The intra-system tillage comparison of NCC management demonstrated ST treatment to have significantly lower NH_4-N concentrations than the CT treatment. In the inter-system comparison, neither ST nor CT management was significantly different in NH_4-N among the NCC, CC, and OCC systems.

The intra-system tillage comparison of CC management revealed no significant differences in NH_4-N between CC ST and CC CT treatments. The CC ST treatment was not significantly different in NH_4-N than either the NCC ST or OCC ST. The CC CT treatment was not significantly different in NH_4-N than the NCC CT treatment but was significantly lower than the OCC CT treatment.

The OCC CT treatment was significantly higher in NH_4-N than the CC CT treatment and was also significantly higher within it's own system compared to ST management. OCC CT was not significantly different in NH_4-N than the NCC CT treatment.

Overall, there were no significant differences between NCC ST, CC ST, and the OCC ST systems and tillage management. All volume-weighted average concentrations of NH_4-N were below 1.0 mg/L regardless of treatment (Table 3).

DON concentrations following tomato

The intra-system tillage comparison of dissolved organic nitrogen concentration under NCC management showed no significant differences between ST and CT. Under the inter-system comparison, the NCC ST treatment was significantly higher in DON than the OCC ST treatment, but was not significantly different than the CC ST treatment. There were no significant differences in DON when CT management was compared among the three systems.

Within the CC system, ST management was not significantly different in DON than the CT treatment. In addition, the CC ST treatment was not significantly in DON different than any other system or tillage.

Within the OCC system, CT management was significantly higher in DON than ST management.

All volume-weighted average concentration values for DON were all below 0.75 mg/L regardless of treatment (Table 3).

DOC concentrations following tomato

When comparing the NCC system to itself, CT management was not significantly different in DOC than ST. However, the NCC ST concentrations of DOC was significantly higher than the CC ST and OCC ST treatments but the NCC CT treatment was not significantly different than the CC CT or OCC CT treatments.

The intra-system tillage comparison of the CC system revealed no significant differences in DOC between ST and CT management.

When examining the OCC system, CT management was significantly higher in DOC than the ST treatment. In addition, the OCC CT treatment was significantly higher in DOC than CC CT but not significantly different than the NCC CT treatment.

There were no significant differences between the NCC ST, CC ST, and OCC ST treatments. Furthermore, the NCC ST treatment was significantly higher than CC ST and NCC ST, but the two cover cropped systems under ST management were not significantly different in DOC than each other. Finally, All DOC concentration values were below 1.0 mg/L.

In conclusion, treatment and tillage can have an effect on minimizing or increasing volume-weighted average concentrations of all CAWQP. However, these differences may not be biologically significant because, with the exception of TSS, concentrations of CAWQPs are below 1 mg/L regardless of treatment or tillage. Although TSS concentrations were high compared to the other CAWQP, they were low compared to concentration values in the literature for other farming areas of the United States. Lastly, volume-weighted average concentrations of all CAWQP were lower in discharge from the plots following tomatoes than in discharge following corn.

SAFS Storm Season Load

Seasonal load from SAFS plots were calculated as a product of discharge volumes and volume-weighted average concentrations. For the following descriptions, please refer back to Table 1 for clarification on the meaning of abbreviations.

Table 4. 2004-2005 volume-weighted average load of various constituents affecting water quality parameters (CAWQP) from the SAFS research plots following summer corn crop.

Year	Management System	Tillage	TSS	PO4-P	DOP	NO3-N	NH4-N	DON	DOC
			kg/ha	g/ha	g/ha	g/ha	g/ha	g/ha	g/ha
2004-2005 Load With Corn Residue	Conventional (NCC)	ST	**245** (±3.0)	**63** (±7.0)	.	**89** (±27)	**126** (±20)	**370** (±36)	**672** (±45)
	Conventional (NCC)	CT	**429** (±107)	**8** (±1.0)	.	**38** (±6.0)	**14** (±2.0)	**81** (±7.0)	**254** (±37)
	Cover Cropped (CC)	ST	**123** (±26)	**49** (±11)	.	**36** (±10)	**35** (±7.0)	**220** (±45)	**906** (±191)
	Cover Cropped (CC)	CT	**358** (±43)	**15** (±1.5)	.	**37** (±3.0)	**33** (±6.0)	**105** (±3.0)	**314** (±78)
	Organic (CC)	ST	**159** (±23)	**204** (±29)	.	**26** (±8.0)	**141** (±28)	**1145** (±345)	**1458** (±243)
	Organic (CC)	CT	**391** (±111)	**73** (±13)	.	**26** (±8.0)	**43** (±12)	**152** (±17)	**514** (±100)

TSS load following corn

Only one treatment was significantly different in terms of sediment load (Kg/ha). There was a significantly lower load of TSS from the CC ST treatment. None of the other treatments were significantly different from each other. All treatments were below 550 Kg/ha (0.22 tonnes per acre) in terms of cumulative load of sediment (Table 4).

PO_4-P load following corn

The NCC CT treatment produced the lowest load (g/ha) of PO_4-P and was significantly lower than the NCC ST treatment. The OCC ST produced the highest load. NCC ST and CC ST were not significantly different in PO_4-P, even though the OCC ST treatment was significantly higher than the other two. The NCC CT was significantly lower in PO_4-P than CC CT and CC CT was significantly lower than OCC ST. In general the ST treatments produced a significantly higher load of PO_4-P compared to CT treatments regardless of the system. All treatments were below 250 g/ha (1.0×10^{-4} tonnes per acre) PO_4-P and most were below 75 g/ha (3.04×10^{-5} tonnes per acre) (Table 4).

DOP load following corn

DOP load values are not available for 2004-2005 because concentration analysis for DOP encountered difficulties as explained in the SAFS concentration following corn section above.

NO_3-N load following corn

Nitrate load analysis revealed little differences between systems and tillage. The NCC ST treatment was significantly higher in NO_3-N than all other treatments. The CC and OCC treatments were not significantly different from each other, regardless of tillage and inter-system comparisons were not significantly different.

The NCC CT treatment was also not significantly different than either CC or OCC, regardless of tillage.

All NO_3-N loads were below 120 g/ha (4.86×10^{-5} tonnes per acre) regardless of system or tillage (Table 4).

NH_4-N load following corn

Significantly higher NH_4-N loads were measured for the NCC ST treatment when compared to the NCC CT treatment. The intra-system tillage comparison for the CC system was not significantly different in NH_4-N. However, like the NCC system, the OCC ST treatment was significantly higher in NH_4-N than OCC CT.

The CC ST treatment was significantly lower in NH_4-N than both the NCC ST and OCC ST treatments. NCC ST and OCC ST were not significantly different in NH_4-N than each other. The NCC CT treatment produced a significantly lower in NH_4-N volume-weighted average load than the CC CT and OCC CT treatments, which were not significantly different from each other. The NCC CT treatment had the lowest value of all loads.

All NH_4-N ST values were below 200 g/ha (8.09×10^{-5} tonnes per acre) and all CT values were below 55 g/ha (2.23×10^{-5} tonnes per acre (Table 4).

DON load following corn

In general, dissolved organic nitrogen loads were significantly higher in the ST treatments regardless of the system. The OCC ST treatment produced a significantly higher value of DON load than any of the ST (or CT) treatments. However, an inter-system comparison of CT management revealed that the NCC CT treatment was significantly lower in DON than either of the other two systems and had the lowest value of all. Under CT management, the OCC CT treatment was significantly higher in DON than either of the other two systems.

The ST treatments each produced less than 1500 g/ha of DON (6.07×10^{-4} tonnes per acre). The CT treatments each produced less than 200 g/ha (8.92×10^{-5} tonnes per acre) (Table 4).

DOC load following corn

Significantly higher loads of DOC were seen from all ST treatments when compared to CT management, regardless of system. The highest DOC load from ST management came from the OCC ST treatment and this value was significantly higher than either the NCC ST or the CC ST treatments. The lowest DOC load from ST management came from the NCC ST treatment.

NCC CT and CC CT treatments were not significantly different in DOC although the OCC CT treatment was significantly higher than the either of the two. The lowest value of DOC load under CT management was from the NCC CT treatment and the highest value came from the OCC CT treatment.

All volume-weighted averaged cumulative loads of DOC under ST management, were measured below 1750 g/ha (7.08×10^{-4} tones per acre). Under CT management DOC loads were less than 650 g/ha (2.63×10^{-4} tones per acre) (Table 4).

Table 5. Total seasonal cumulative volume-weighted average load (g/ha) comparison of conventional and alternative management practices. Various constituents affecting water quality parameters (CAWQP) were analyzed from discharge sampled from 6 different treatments over the 2005-2006 storm season. Plots were planted with tomato in the summer of 2005 and therefore CT plots had tomato residue on the soil surface.

Table 4 demonstrates the potential of conservation tillage management to minimize loads of most CAWQP from fields with substantial corn residue on the soil surface. Based on the current analysis, winter cover cropping had no significant influence on load for this sample period. In addition, due to the relatively low concentrations of CAWQP in our sampled discharge, the cumulative seasonal runoff volume largely determines load of CAWQP.

Year	Management System	Tillage	TSS kg/ha	PO4-P g/ha	DOP g/ha	NO3-N g/ha	NH4-N g/ha	DON g/ha	DOC g/ha
2005-2006 Load With Tomato Residue	Conventional (NCC)	ST	**1091** (±43)	**57** (±5.0)	**56** (±6.0)	**66** (±4.0)	**22** (±2.0)	**140** (±7.0)	**1075** (±79)
	Conventional (NCC)	CT	**1385** (±127)	**108** (±4.0)	**34** (±2.0)	**110** (±10.0)	**132** (±0.4)	**201** (±8.0)	**1387** (±15)
	Cover Cropped (CC)	ST	**706** (±47)	**21** (±0.5)	**19** (±2.0)	**43** (±1.0)	**22** (±1.0)	**65** (±7.0)	**399** (±16)
	Cover Cropped (CC)	CT	**591** (±44)	**22** (±0.6)	**21** (±10)	**51** (±2.0)	**19** (±2.0)	**97** (±12.0)	**662** (±78)
	Organic (CC)	ST	**322** (±71)	**32** (±2.0)	**29** (±3.0)	**30** (±1.5)	**14** (±1.0)	**37** (±3.0)	**258** (±33)
	Organic (CC)	CT	**230** (±73)	**73** (±8.5)	**42** (±6.0)	**32** (±5.0)	**72** (±10.5)	**66** (±8.0)	**385** (±40)

TSS load following tomato

Intra system tillage comparisons of TSS load were mixed. The NCC ST treatment was significantly lower in TSS than the NCC CT treatment while the CC ST treatment was significantly higher than the CC CT treatment. There was no significant difference in TSS between OCC ST and OCC CT loads. All Three systems were significantly different from one another, regardless of tillage. As mentioned, the NCC system produced the greatest TSS load, and the OCC system produced the lowest, regardless of tillage. The inter-system, intra tillage comparison revealed the NCC system to be significantly highest and OCC to be significantly lowest in TSS, regardless of tillage. All treatments were below 1600 kg/ha (0.65 tonnes per acre) TSS in terms of cumulative load of sediment (Table 5, Fig 6).

PO_4-P load following tomato

The NCC intra-system tillage comparison demonstrated significantly higher PO_4-P loads for CT management. The same was true for the intra-system tillage comparison for the OCC CT treatment. The CC system showed no significant differences in PO_4-P in terms of tillage.

Inter system comparisons showed NCC ST to produce the significantly highest PO_4-P load compared to the other two ST systems. All three ST systems were significantly different than each other. The CC ST system produced the smallest PO_4-P load out of the three ST systems.

Inter-system CT management mimicked the ST inter-system comparisons. In general, CT management produced significantly higher loads of PO_4-P across all three systems.

All PO_4-P treatments were below 115 g/ha (4.65×10^{-5} tonnes per acre) (Table 6, Fig. 8).

DOP load following tomato

Dissolved organic phosphorus lab analysis methods were modified for the 2005-2006 storm season. As a result of changes made, our team was able to to calculate DOP load.

Intra-system NCC comparison of DOP load demonstrated a significant reduction from CT management. However, there was no significant difference between ST and CT management in the CC system and CT management produced a significantly higher load in the OCC system.

Inter-system comparisons were mixed. Under the NCC system, ST management produced higher DOP loads. Under the CC system, results were insignificantly different between tillage management. In contrast, the OCC CT treatment demonstrated significantly higher DOP loads when compared to the OCC ST treatment.

The CC system produced the lowest loads of DOP regardless of tillage. Overall, loads of DOP were below 65 g/ha (2.63×10^{-5} tonnes per acre) (Table 6, Fig. 8).

NO_3-N load following tomato

Nitrate load analysis revealed significant differences between systems and tillage. The NCC CT treatment was significantly higher in NO_3-N than the NCC ST treatment. In fact, the NCC CT treatment had the significantly highest NO_3-N value of all 6 treatments. Overall CT management produced higher NO_3-N loads than ST management, regardless of the system although under the OCC system the difference was not significant than all other treatments.

In addition, inter-system comparisons revealed that the NCC system had significantly higher NO_3-N loads compared to the other two systems, regardless of tillage. Furthermore, the OCC system significantly reduced NO_3-N loads and had the lowest values for load, regardless of tillage.

All NO_3-N loads were below 120 g/ha (4.86×10^{-5} tonnes per acre) regardless of system or tillage (Table 5, Fig. 8).

NH_4-N load following tomato

In general, CT management produced significantly higher loads of NH_4-N than ST management, regardless of system. Inter-system comparisons of ST management revealed little differences. NCC ST and CC ST were not significantly different. OCC ST was significantly lower NH_4-N than the other two ST treatments.

Under CT management results were mixed. The NCC CT treatment was significantly higher than the NCC ST treatment and produced the highest load of NH_4-N in all treatments. Likewise, The OCC CT treatment was significantly higher NH_4-N than the OCC ST treatment. The exception was the CC system, where tillage management was not significantly different. In addition, the CC system produced the significantly lowest NH_4-N load, regardless of tillage.

Load values of NH_4-N were all below 135 g/ha, (5.46×10^{-5} tonnes per acre) regardless of system or tillage management (Table 5, Fig. 8).

DON load following tomato

In general intra-system tillage comparisons revealed significantly higher DON loads in the CT treatments compared to ST treatments, regardless of the system. The OCC ST treatment produced a significantly lower value of DON load than any of the ST (or CT) treatments. The NCC CT treatment was significantly higher in DON than either of the other two systems and had the highest value of all.

In terms of significant differences, ST and CT management mimicked each other through all three systems. CT management DON was consistently higher than ST management throughout all three systems and the NCC system was significantly higher in both ST and CT inter-system comparisons. Likewise, the OCC system was significantly lower in DON than the other two systems under both tillage comparisons.

All treatments produced less than 210 g/ha (8.50×10^{-5} tonnes per acre) DON (Table 5, Fig 8).

DOC load following tomato

Significantly higher loads of DOC were seen from all CT treatments when compared to ST management, regardless of system. The highest DOC load from ST management came from the NCC ST treatment and this value was significantly higher than either the CC ST or the OCC ST treatments. The lowest DOC load from ST management came from the OCC ST treatment. Once again, CT management mimicked ST management throughout the three systems.

In sum CT management produced significantly higher loads of DOC compared to ST management. CT management was significantly higher than ST management in all three systems. However, both CC systems (CC and OCC) water significantly lower in DOC than NCC system regardless of tillage.

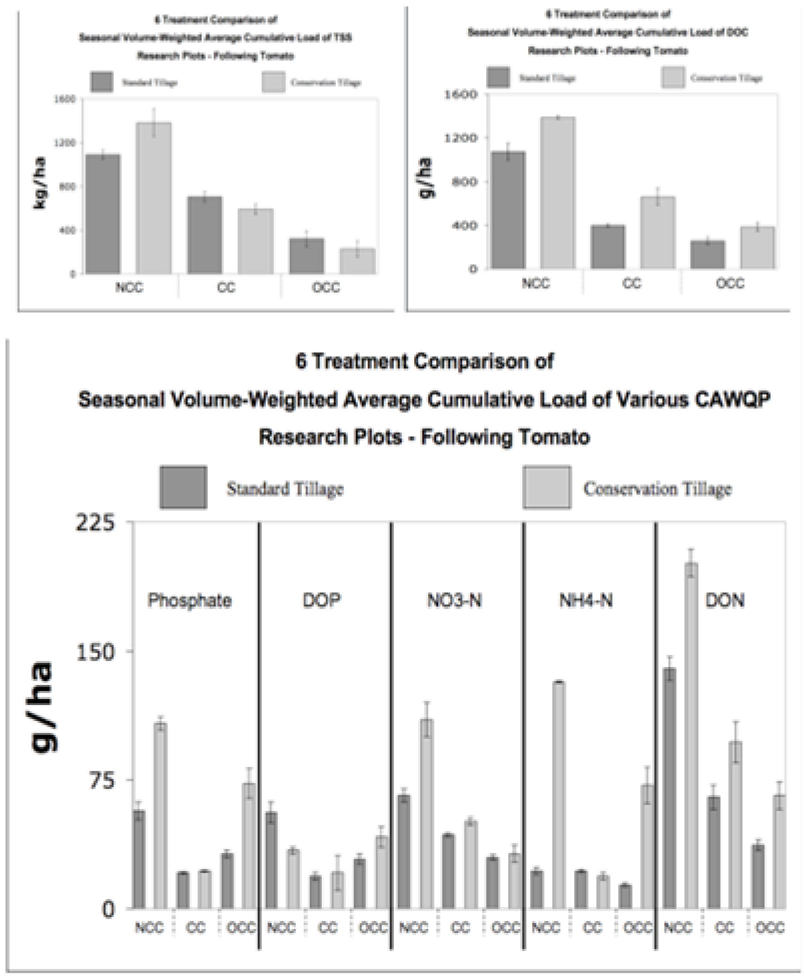


Figure 8. 6 treatment comparison of seasonal volume-weighted average cumulative load for the 2005-2006 storm season following tomato. The graph shows comparisons between systems (NCC, CC, and OCC), tillage (ST, CT) and Inter-system, intra-tillage comparisons. Standard error shown.

All seasonal volume-weighted averaged cumulative loads of DOC were measured 1600 g/ha (6.50 x 10^{-4} tones per acre). (Table 5, Fig. 8).

Table 5 and figure 8 demonstrate the potential of cover cropping systems to minimize loads of most CAWQP from fields with minimal crop residue on the soil surface. Based on the current analysis, winter cover cropping systems (CC and OCC) significantly minimized load in this sample period. However, under CT management where crop residue is less than 30% during the storm season, load of various CAWQP may actually increased compared to ST.

As with the 2004-2005 data, cumulative seasonal runoff volume largely determines load of CAWQP as opposed to volume-weighted average concentrations. This is due to the relatively low concentrations of CAWQP, regardless of system or tillage and the significant differences of discharge between systems and tillage management.

In summary, conservation tillage management significantly influenced discharge and load when crop residue was greater than 30%. Under our experimental management, which strives to mimic grower practices, cover cropping did not influence discharge or load of CAWQP. However, when crop residues under CT management were below 30%,

such as following processing tomato, cover cropping played a significant roll in reducing discharge and load. However, following tomato (residue in CT managemet < 30%) CT plots demonstrated significantly higher discharge and load of CAWQP.

Concentrations of CAWPQs provided mixed results and no clear trends have yet been determined. However it is clear that regardless of system, tillage, or summer crop, concentrations are relatively low and do don't play an important roll in determining load of CAWP.

Finally, the SAFS results for discharge, concentration, and load told a similar story as the grower field experiments, though the grower field results were more dramatic when examining the effects of cover cropping. Further research and analysis is needed in order to examine co-variables that could have accounted for scale differences.

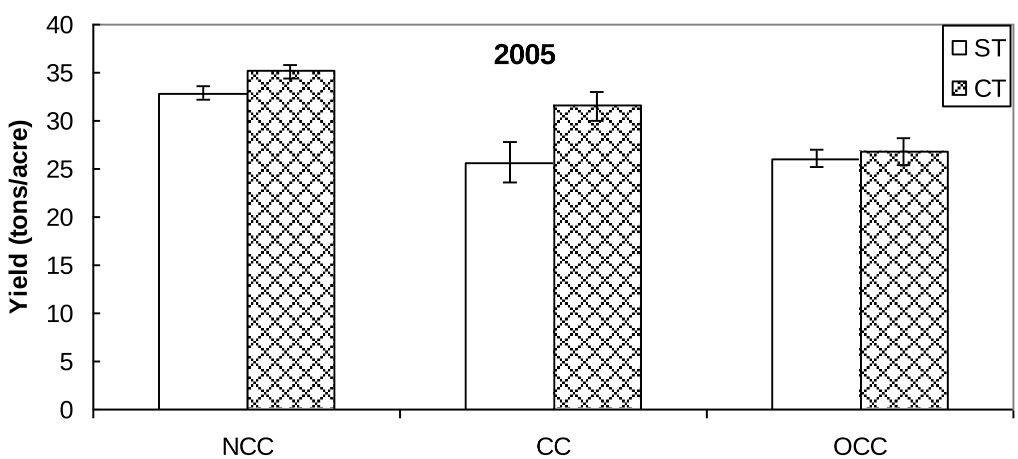


Figure. 9. Tomato yields in conventional (NCC), cover cropped (CC) and organic (OCC, also cover cropped) farming systems under standard tillage (ST) and conservation tillage (CT). Error bars are ± standard error of mean.

SAFS Crop Yield

SAFS tomato yield

In 2005, tomatoes were harvested in the conventional (NCC), low-input and Organic (OCC) farming systems on August 22-25 and in 2006 tomatoes were harvested on September 28. Hand harvest samples were taken one week earlier and were generally consistent with the machine harvest yields. At the time of machine harvest most of the fruits became red across treatments. Tomato yields ranged from 25.68 to 35.11 tons acre^{-1} in 2005, however, in 2006 tomato yields ranged from 24.17 to 37.16 tons acre^{-1} across all farming system. Tomato yields were significantly higher in NCC systems compared to the Low-input (CC) and OCC systems (Fig. 10). In the NCC and Low-input plots yields were significantly greater under conservation tillage (CT) than under the standard tillage (ST). However, yields were not significantly difference between the ST and CT in the OCC systems. In 2005, greater yields of tomato in the CT were associated with the better growth of cover crop that increased the N availability in the CT soils. In 2006, tomato yield was not differing in two tillage practices in conventional (NCC) and winter legume CC systems. However, in the organic systems (OCC) standard tillage produced a significantly greater yield than conservation tillage. It has been showed that weed competition with the tomato plants was a distinct problem in the conservation tillage plots that may limit N and other nutrients uptake in this practices resulting in the reduction of yield. Weed control remains a great challenge in the CT systems. It is important to develop effective strategies and new management systems in CT practices.

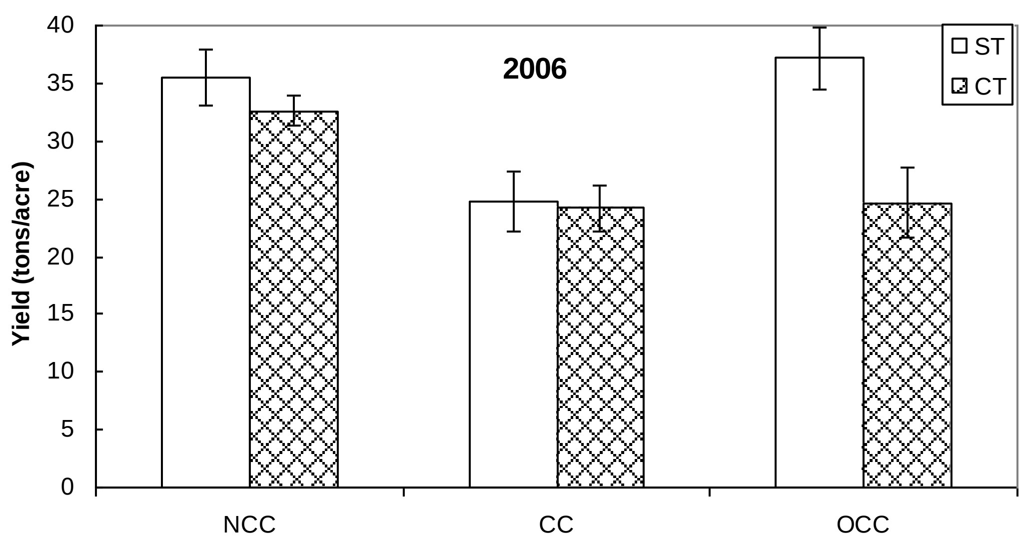


Figure 10. Tomato yield in conventional (NCC), winter legume cover cropped (CC) and organic (OCC, also cover cropped) under standard and conservation tillage systems. Error bars represent the standard error of the mean.

SAFS corn yield

In 2005, corns were harvested on October 18, however, in 2006, corn were harvested on October 24. The hand harvest samples indicated similar yields that were found with the machine harvest samples. Corn yields across all farming systems ranged from 1,959 to 12,421 lbs ac^{-1} in 2005, but in 2006, corn yields ranged from 4417 to 9328 lbs ac^{-1}. In 2005, corn yields in the conventional farming were significantly greater than the winter legume cover crops (CC), and OCC farming system produced the lowest yield (Fig. 11). However, grain yields were not different between the tillage practices (ST vs. CT). In 2006, corn yields were significantly highest in NCC, intermediate OCC and lowest in the CC (Low-input) farming systems. Tillage practices (CT vs. ST) did not have any influence on corn yield in NCC and CC systems but in OCC system, CT practices significantly increased corn yield compared to ST practices (Fig 12).

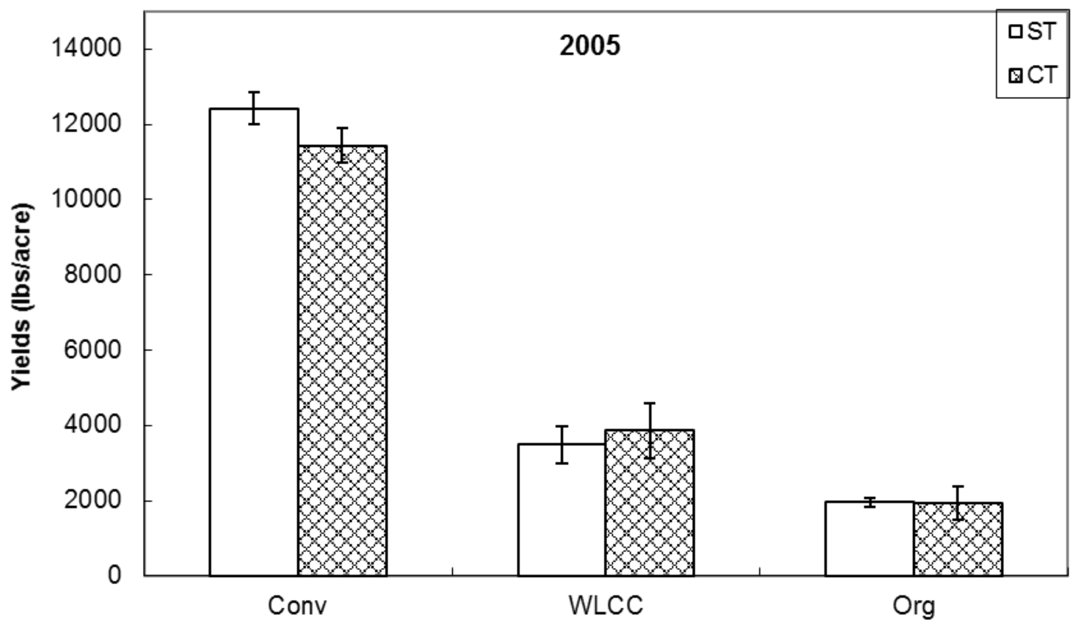


Figure 11. Corn yield in conventional (NCC), winter legume cover cropped (CC) and organic (OCC, also cover cropped) under standard and conservation tillage systems. Error bars represent the standard error of the mean.

Differences in corn yields in different farming systems may be attributed to the variation in timing of corn planting (NCC corn planting 5-6 weeks earlier than CC and OCC systems) among systems. Soil nitrate was consistently quite high in the OCC and CC (Low-input) plots throughout the season, suggesting that the low plant N status of these two systems observed at maturity might not have been due to a lack of available N, but instead to some kind of physiological impediment to uptake in the later part of the season resulting in reduced yield. It is also possible the lack of synchronization between N mineralization and corn N demand in these two farming systems. Additional study showed that fertilizing the

CC systems with the 6 weeks later planting date has increased corn yield equivalent to that of the conventional system. The reduction of corn yield may be due to disease or weeds pressure in the CC and OCC farming systems. Recent study showed that corn smut was significantly greater in the CC and OCC systems compared to NCC system.

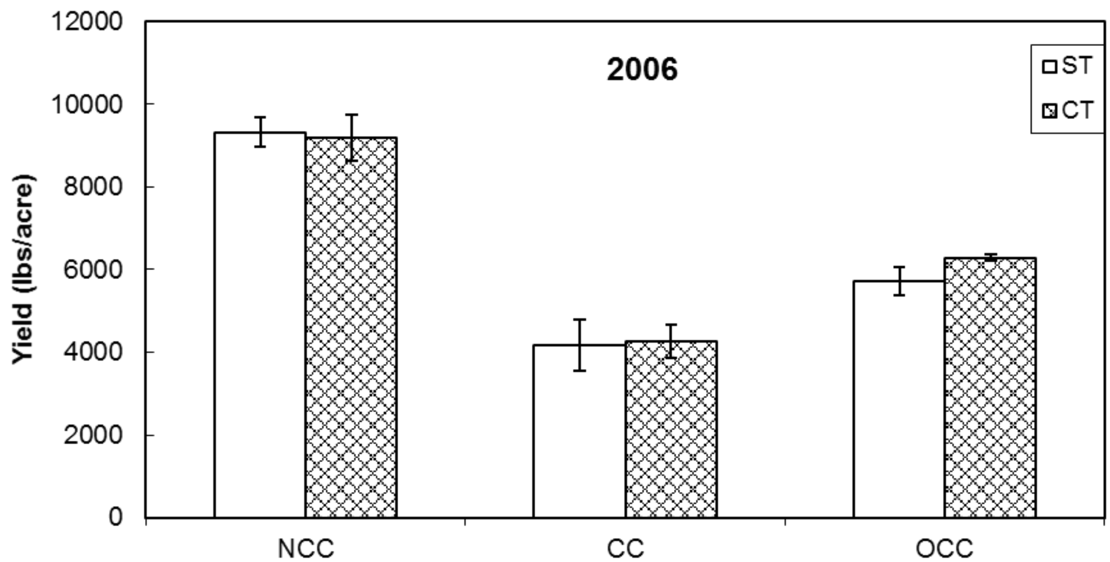


Figure 12. Corn yield in conventional (NCC), winter legume cover cropped (CC) and organic (OCC, also cover cropped) under standard and conservation tillage systems. Error bars represent the standard error of the mean.

Grower Field Storm Season Discharge

As previously mentioned, the SAFS project utilizes grower input to guide plot research. The water quality portion of the SAFS project engaged three growers in Yolo and Solano Counties (Only two farm results are presented here). On ST fields of "Grower A" and "Grower B" we compared a winter leguminous cover cropped field (CC ST)) to conventional treatments (NCC ST) for several seasons. In addition we compared conventional conservation tillage management (NCC CT) to conventional standard tillage management (NCC CT) for 2 seasons on Grower B's farm.

Preliminary analyses of growers' field data illustrate the effectiveness of CC at substantially minimizing winter discharge and NPSP loads (Fig. 4). Although, with the possible exception of sediment discharges, seasonal NPSP loading from winter fallow fields is not dramatic, suggesting that other field scale strategies (e.g., reconfiguring drainage patterns) may also be effective at meeting agricultural water quality goals.

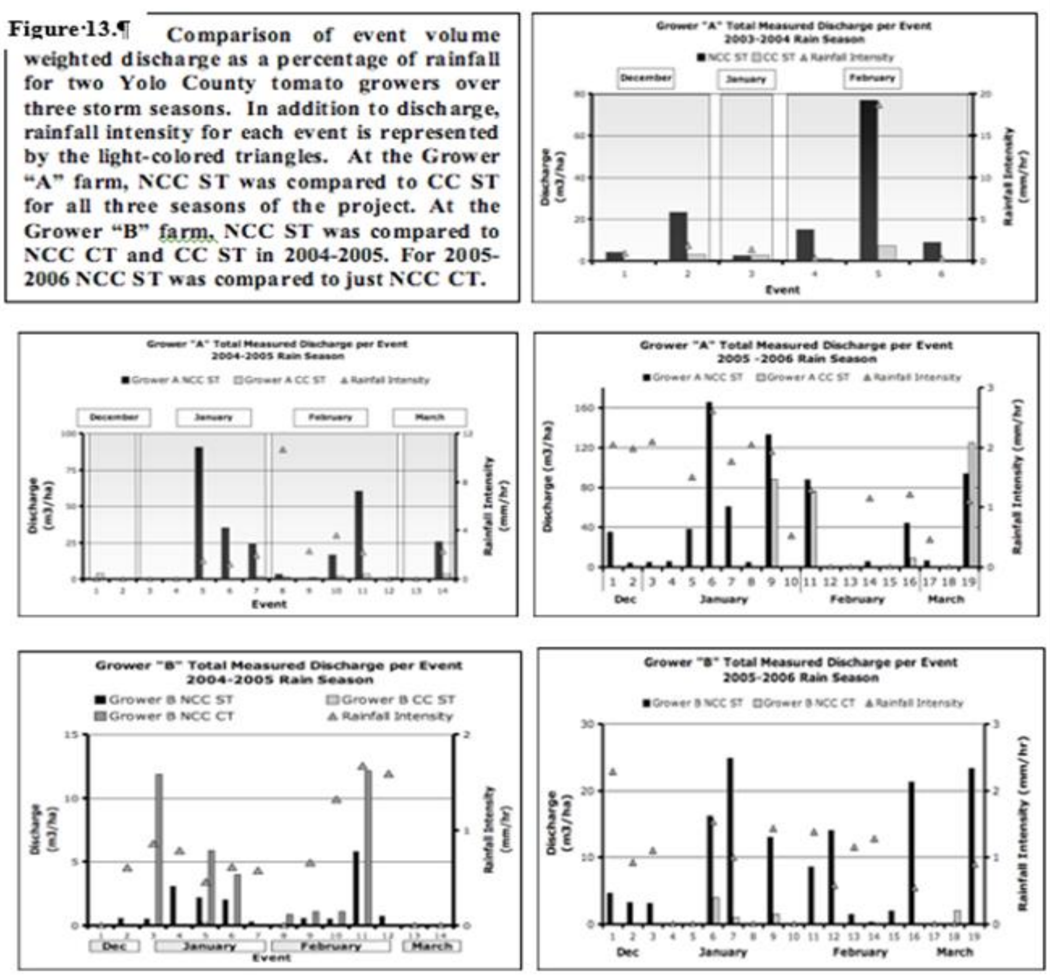
Grower CC system influence on discharge

Grower A's total discharge from the CC ST field was 90% lower than the NCC ST field while that of Grower B was just 2%. The reduction of cumulative discharge from the grower CC ST systems resulted in substantially lower loads of CAWQP (Table 6, Fig. 11).

Grower CT management influence on discharge

Table 6 demonstrates that CC treatments are substantially lower than NCC treatments when comparing discharge as a percentage of rainfall. Similar to the SAFS plots, CT management significantly influenced discharge depending on % residue cover. For example, total discharge (m^3 / ha) from Grower B's NCC CT field following corn in 2004-2005 was 40% greater than the NCC ST field (Table 6). This field met the definition of CT management based on the number of tractor passes (1) following planting. However, corn residue cover on this field was very near the 30% threshold (personal observation). Furthermore, this was the first and only consecutive year that this field was under CT management. Therefore, it would be expected that CT management may have minimal influence on discharge and could in fact increase discharge due to the sealing of soils as seen in the tomato CT management plots at the SAFS research facility. In the following year, the NCC CT discharge at Grower B's farm was 94% lower than the control. It is believed that this field followed the SAFS CT research plots because corn residue cover was greater than 30% (personal observation).

Figure 13. Comparison of event volume weighted discharge as a percentage of rainfall for two Yolo County tomato growers over three storm seasons. In addition to discharge, rainfall intensity for each event is represented by the light-colored triangles. At the Grower "A" farm, NCC ST was compared to CC ST for all three seasons of the project. At the Grower "B" farm, NCC ST was compared to NCC CT and CC ST in 2004-2005. For 2005-2006 NCC ST was compared to just NCC CT.



Grower Storm Season Concentration

Table 6. Grower field seasonal average discharge as a percentage of rainfall comparison of various cover management strategies over several storm seasons.

Grower	Management System	Total Winter Discharge (m^3/ha) as a Percentage of Rainfall (m^3/ha)		
		2003-2004 (a)	2004-2005 (b)	2005-2006 (c)
		--- % ---		
A	Conventional ST (NCC)	**8.2**	**12.0**	**16.3**
	Cover Cropped ST (CC)	**0.9**	**0.9**	**7.0**
	Conventional CT (NCC)	**X** (d)	**X**	**X**
B	Conventional ST (NCC)	**X**	**0.96**	**3.81**
	Cover Cropped ST (CC)	**X**	**0.02**	**X**
	Conventional CT (NCC)	**X**	**2.13**	**0.24**

Grower "A"

Volume-weighted average concentration comparisons of CAWQP show mixed results. TSS concentrations are significantly reduced in the CT and CC treatments compared to NCC treatment. However, NO_3-N and DOC concentrations are significantly higher in the CC treatment compared to the NCC treatment. There was no significant difference in concentrations of PO_4-P and NH_4-N between NCC and CC. The CT treatment produced the highest concentrations of NO_3-N. However, there were statistically significant lower concentrations of PO_4-P than the NCC treatment. This may be related to the lower concentrations of sediment leaving the CT field. It is important to recognize that volume-weighted seasonal average concentrations of phosphate, DOP, NO_3-N, NH_4-N, DON, and DOC were all below 5 mg/L. This is well within drinking water quality standards for the city of Davis (Table 7).

Grower "B"

Volume-weighted average concentrations were fairly consistent for all CAWQP comparisons. Concentrations of phosphate, NO_3-N, NH_4-N, and DOC were all highest in the CC ST treatment. TSS concentrations were highest in the NCC ST discharge for both years and lowest in the CC ST treatment in 2004-2005

Table 7. Volume weighted average concentration sampled from 3 consecutive storm seasons. Grower "A" is a tomato farmer in Yolo County, California. The 2004-2005 fields were the exact same as those used in 2003-2004. However, for the 2005-2006 season, the fields themselves were the same, but the management practices were switched. Therefore, the NCC ST field from 2003-2005 became the CC ST field and the 2003-2005 CC ST field became the NCC ST field for 2005-2006.

Grower	Year	Management System	Tillage	TSS mg/L	Phosphate mg/L	DOP mg/L	NO3-N mg/L	NH4-N mg/L	DON mg/L	DOC mg/L
A	2003 - 2004	Conventional (NCC)	ST	2471 (±6.37)	0.04 (±0.03)	0.31* (±0.10)	0.40 (±0.13)	0.06 (±0.05)	1.74 (±0.13)	2.88 (±0.16)
		Cover Cropped (CC)	ST	874* (±3.86)	0.04* (±0.03)	0.03* (±0.02)	0.39* (±0.08)	0.08* (±0.03)	0.77* (±0.09)	2.87* (±0.12)
A	2004 - 2005	Conventional (NCC)	ST	1728* (±3.99)	0.09 (±0.03)	. .	3.80* (±0.23)	0.10* (±0.06)	. .	3.91* (±0.20)
		Cover Cropped (CC)	ST	447* (±1.73)	0.12* (±0.02)	. .	2.30* (±0.46)	0.08* (±0.03)	. .	4.86* (±0.15)
A	2005 - 2006	Conventional (NCC)	ST	1417* (±2.01)	0.10* (±0.01)	0.07* (±0.01)	4.43* (±0.15)	0.37* (±0.05)	2.27* (±0.12)	4.58* (±0.09)
		Cover Cropped (CC)	ST	197 (±3.47)	0.36 (±0.04)	0.23 (±0.05)	1.81 (±0.20)	0.20 (±0.10)	1.24* (±0.17)	8.05 (±0.36)

Table 8. Volume weighted average concentration sampled from 2 consecutive storm seasons. Grower "B" is a tomato farmer in Yolo County, California. The 2004-2005 fields included three treatments. A fallow, standard tillage system (NCC ST), a cover cropped, standard tillage system (CC ST), and a conservation tillage (NCC CT). Conservation tillage is defined as a practice that leaves at least 30% residue cover or reduces tractor passes by at least 40% or conventional practices. The NCC ST field was the same for 2004-2005 and 2005-2006 but the NCC CT fields were different in the two years of trials.

Grower	Year	Management System	Tillage	TSS mg/L	Phosphate mg/L	DOP mg/L	NO3-N mg/L	NH4-N mg/L	DON mg/L	DOC mg/L
B	2004- 2005	Conventional (NCC)	ST	2543 (±3.66)	0.39 (±0.04)	. .	0.33* (±0.03)	0.04* (±0.02)	. .	3.47 (±0.08)
		Cover Cropped (CC)	ST	249 (±1.68)	0.78 (±0.09)	. .	3.45 (±0.25)	0.35 (±0.11)	. .	7.36 (±0.30)
		Conventional (NCC)	CT	1863* (±4.59)	0.18* (±0.03)	. .	2.12* (±0.21)	0.03* (±0.02)	. .	4.19* (±0.23)
B	2005- 2006	Conventional (NCC)	ST	3546 (±2.88)	0.45* (±0.03)	0.23* (±0.04)	1.48* (±0.09)	0.02 (±0.01)	1.21* (±0.09)	2.29 (±0.08)
		Conventional (NCC)	CT	1982 (±8.52)	0.24 (±0.04)	0.15 (±0.07)	0.95 (±0.22)	0.04 (±0.03)	0.37 (±0.06)	3.20 (±0.25)

(Table 8). Like concentrations from Grower A's farm, volume-weighted seasonal average concentrations of phosphate, NO_3-N, NH_4-N, and DOC were all below 10 mg/L and well within drinking water quality

standards for the city of Davis.

Missing DOP values from both Grower A and Grower B fields are due to the same challenges faced in collecting DOP values for the SAFS plots (see above). However, missing DON values were a result of holding times being exceeded before the samples could be processed (*Standard Methods*, 4500-N C.). In addition to encountering our first successful year of data collection from the SAFS facility, it was also the first year we included Grower B in our study. Our team was simply overwhelmed with samples and needed time to acquire and train additional staff members to assist in processing these samples. By 2005-2006, we were prepared and all CAWQP were successfully analyzed, despite the addition of a third grower to the project and twice as many rain events to collect from.

Grower Storm Season Load

Grower CC influence on Load

A formal analysis has not been performed on grower field load of CAWQP as of this date. However, it is in the works and will be available soon. What can be said for now is that, as mentioned above, the reduction of cumulative discharge from the CC fields compared to the NCC fields produced substantially lower loads of CAWQP from the CC treatment. This was true in all cases regardless of year or farmer except for the 2005-2006 Grower A trials (Figure 11 and Table 9).

Grower CT influence on Load

Table 9. Grower A volume-weighted seasonal average load for all three storm seasons where data was collected. The fields were exactly the same in 2003-2004 and 2004-2005. In 2005-2006, the treatments switched fields so that, although the same two fields were still being compared, the treatments flip-flopped. For example, the 2003-2005 NCC ST treatment became the CC ST treatment.

Grower	Year	Management System	Tillage	TSS kg/ha	Phosphate g/ha	DOP g/ha	NO3-N g/ha	NH4-N g/ha	DON g/ha	DOC g/ha
A	2003 - 2004	Conventional (NCC)	ST	84 (±2.02)	0.82 (±0.18)	7.75* (±0.51)	4.11 (±0.36)	0.70 (±0.13)	47.66 (±1.38)	61.88 (±1.41)
		Cover Cropped (CC)	ST	2* (±0.22)	0.09* (±0.04)	0.12* (±0.06)	0.69* (±0.12)	0.25* (±0.08)	2.40* (±0.26)	8.08* (±0.44)
A	2004 - 2005	Conventional (NCC)	ST	45* (±0.59)	3.42 (±0.26)	. .	85.13* (±1.01)	5.57* (±0.48)	. .	110* (±1.46)
		Cover Cropped (CC)	ST	1* (±0.11)	0.30* (±0.06)	. .	23.44* (±0.84)	0.19* (±0.06)	. .	11.48* (±0.33)
A	2005 - 2006	Conventional (NCC)	ST	83* (±0.73)	5.26* (±0.16)	3.31* (±0.14)	143* (±1.05)	16.75* (±0.35)	46.98* (±0.44)	184* (±0.98)
		Cover Cropped (CC)	ST	16 (±1.07)	27.46 (±1.06)	18.49 (±0.90)	148 (±2.90)	17.81 (±1.23)	98.41* (±2.41)	654 (±5.84)

For our grower field trials we relied on Grower B to provide us with a field under CT management as one was not available to us at Grower A's farm. In 2004-2005 where corn residue was near the 30% threshold, CT management produced higher loads of sediment, NO_3-N, and DOC compared to the NCC ST treatment. However, despite the higher discharge volume, lower loads of PO_4-P and NH_4-N were measured in the CT

field compared to both the NCC ST and CC ST treatments. This could be related to the lower concentrations of these compounds. Further analysis is necessary.

In 2005-2006, where corn residue was substantially greater than 30%, CT was more effective at minimizing load of CAWQP when compared to ST management. Although a formal statistical analysis has yet to be initiated, it is expected to reveal CT management as significantly reducing all CAWQP load when compared to the NCC ST treatment (Table 10)

It is important to point out that grower winter season cumulative load was very low for all of the CAWQP, regardless of year, grower, or treatment. For example, the largest seasonal volume-weighted average load of TSS was from the 2003-2004 Grower A NCC ST treatment and measured less than 90 kg/ha (0.04 tonnes/acre). This is a great deal less than the 13,450 kg/ha (6 tonnes/acre) seen in the Midwest (K-State Research Extension, 2005).

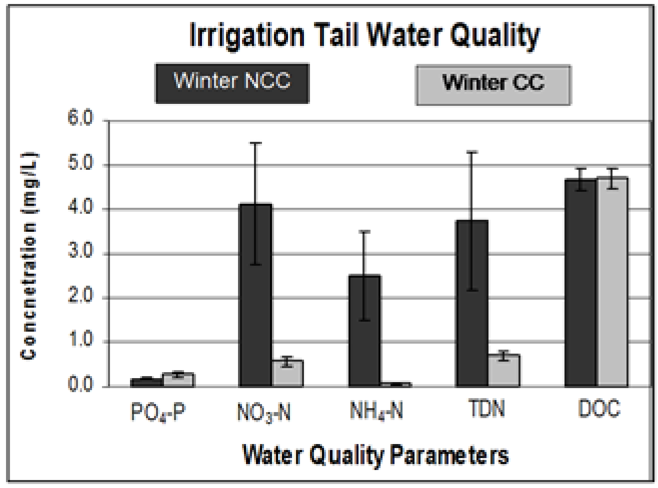


Figure 12. Comparison between average concentrations of constituents that affect water quality parameters from irrigation tail water discharge leaving a winter non-cover cropped field (fallow, bare) and winter cover cropped field. Error bars are ± standard error of mean.

Grower Tail water Analysis

While cover crops may increase rainfall infiltration in the winter, their increased evaporative demand late winter and early spring has been shown to deplete soil moisture from deeper layers of the soil as they mature, limiting soil water availability for the ensuing crop. In addition, enhanced infiltration from cover cropping during the winter months may extend into the growing season. Thus, it is expected that more surface water deliveries may be required in order to meet the water needs of summer crops. These questions are being examined by our project by collecting irrigation discharge data in the summer months.

In the summer of 2004, data-loggers were placed at the discharge point for the NCC ST and CC ST treatments on Grower A's farm. These fields were both under processing tomato at the time. In addition to measuring discharge volumes,

Table 10. Grower B seasonal volume-weighted average load for two storm seasons. Three treatments were compared in 2004-2005, NCC ST, CC ST, and NCC CT. The NCC CT treatment had ~ 30% corn residue left on the soil surface during the storm season. In 2005-2006 only two treatments were compared. The NCC ST treatment was from the same field as in 2004-2005. However the NCC CT treatment was in a different field and had substantially greater than 30% corn residue remaining on the soil surface during the storm season.

Grower	Year	Management System	Tillage	TSS kg/ha	Phosphate g/ha	DOP g/ha	NO3-N g/ha	NH4-N g/ha	DON g/ha	DOC g/ha
B	2004-2005	Conventional (NCC)	ST	4 (±0.24)	0.68 (±0.09)	. .	0.53* (±0.07)	0.11* (±0.05)	. .	5.86 (±0.26)
		Cover Cropped (CC)	ST	0.03 (±0.03)	0.04 (±0.03)	. .	0.07 (±0.03)	0.01 (±0.02)	. .	0.26 (±0.08)
		Conventional (NCC)	CT	12* (±0.52)	0.76* (±0.11)	. .	6.08* (±0.28)	0.12* (±0.05)	. .	14.77* (±0.48)
B	2005-2006	Conventional (NCC)	ST	31 (±0.40)	4.16* (±0.16)	2.33* (±0.11)	19.27* (±0.45)	0.27 (±0.05)	10.59* (±0.23)	27.99 (±0.47)
		Conventional (NCC)	CT	4 (±0.41)	0.53 (±0.16)	0.29 (±0.10)	1.85 (±0.30)	0.08 (±0.06)	0.8 (±0.18)	7.62 (±0.65)

over 600 samples were taken back to the lab for CAWQP concentration analysis. Figure 12 is shown as an example of results that were obtained from these measurements. However, keep in mind that a formal statistical analysis has yet to be performed on all tail water data for all three seasons this data was collected.

In the summer of 2005 data-loggers were again placed at the discharge point of two fields on Grower A's farm. For this season the CC ST treatment was once again under processing tomatoes. However the previous winter's NCC ST treatment was under sunflower. To accommodate, we moved data collection for a winter NCC ST treatment to a different field on Grower A's farm in order to compare to the winter CC ST treatment. A few other changes occurred during this summer as well.

For example, we added data collection from Grower B's farm and placed data-loggers on winter NCC ST and winter CC ST treatments. In addition we placed data-loggers at the irrigation inputs after noting this was missing from the summer 2004 data collecting effort. We will be able to use the input information to determine concentration baselines as well as be able to determine if winter cover cropping may require additional water in the summer compared to winter fallow treatments. Over 800 water samples were collected in the summer of 2005. As mentioned before, this data is available, but has yet to be formally analyzed statistically.

The summer of 2006 was similar to data collection in the summer of 2005. Both Grower A and Grower B were used and data-loggers were put and both the input and output of irrigation water.

Conclusions

The net effect of increased water use vs. increased infiltration depends on several factors, such as cover crop dry matter production rate, degree of soil residue cover and soil slope, soil infiltration rate, and rainfall intensity. Statistical analysis of our data suggests significant enhanced infiltration of rainwater during the winter months due to the winter cover cropping (see above). Interestingly, for the summer months, approximately 50 percent of the irrigation water applications to the winter fallow (bare) field were not discharged and are assumed to have infiltrated. Surprisingly, during the same period, only 19 percent of surface water deliveries discharged from the winter cover cropped field. Research in the San Joaquin Valley has suggested the opposite, that cover crop evapotranspiration may negatively affect water balance. Perhaps cover crop root channels were developed during the winter, or changes to it and to other soil physical characteristics as a result of cover crop residues enhanced infiltration deeper into the soil. Enhanced biotic activity, ranging from earthworms and microbial turnover, may increase aggregate stability and soil structure to promote infiltration in cover cropped fields. Our results suggest that cover cropped fields may offset evapotranspiration through increased winter infiltration or by infiltrating water past the rooting zone in this part of California. The decreased infiltration in the CC field compared to the NCC field during irrigation implies declining water use efficiency if established irrigation schedules are used in fields managed for winter runoff with winter cover crops. More research is needed to determine whether irrigation schedules or frequency of water application can be reduced to increase water use efficiency in cover cropped fields. Our major finding are:

1. On fields prone to winter runoff cover crops significantly reduced runoff. Cover crops had little affect on fields with a tendency to produce low runoff.
2. The effect conservation tillage was not uniform and produced mixed results. The reason for mixed results is that conservation tillage was broadly defined being implemented either as leaving 30% or greater residue cover on the soil surface or a 40% reduction in tillage passes. Therefore, conservation tillage either increased or decreased winter runoff with no clear trend attributed to soil type.
3. The quality of water in runoff was generally within EPA drinking water guidelines for both winter and summer runoff except total suspended solids. Generally, less than 1% of applied fertilizers were found as inorganic or organic constituents in runoff annually.
4. Conservation tillage had comparable yields to conventional tillage using the same fertilization practices within the same farming system (i.e., conventional, organic). The main exception was for organic management where we found conservation tillage to be incompatible with manure amendments that are required to be soil incorporated to provide nitrogen to crops.
5. Conventionally managed systems generally had higher yields of corn compared to low-input or organic management. Tomatoes yields were similar among all systems regardless of source of fertilizer nitrogen, tillage or cover crop management

Farming practices that preserve or enhance soil cover entering the rainy season appear to be effective at reducing cumulative runoff and, hence, CAWQP loads. In general, research plots and grower fields demonstrate challenges to agricultural runoff monitoring. Adherence to strict CT practices can immediately reduce fuel costs, but the potential benefits to water quality may take years to realize0 if the % of residue cover is near or below 30%. In the short term, growers may have other water conservation options, including reconfiguring fields to reduce runoff velocity and thus erosion. Our research has shown that that CC and CT can behave differently in California compared to other areas. On a farm scale, CC significantly reduces winter runoff but also may affect subsoil water recharge and soil moisture content at the time of planting. The potential for winter CC to alter the water budget of subsequent crops under furrow irrigation systems poses important questions, considering future water supply concerns. Additional research is needed to develop conceptual models that correlate water inputs and load reductions with alternative agricultural management practices in California. Such information would be beneficial to water quality stakeholders hoping to address future quality and supply issues.

In conclusion, there is no universal prescription to reduce winter runoff except for the use of cover cropping on fields prone to winter runoff. We therefore recommend that a system of classification that scores fields based on runoff vulnerability be implemented to target fields prone to winter runoff. However, timing is a serious issue where planting cover crops before fall rains is generally a constraint facing farmers. In addition, farmers who cover crop may experience significant delays in spring field entry due to managing the cover crop putting them at a competitive disadvantage compared to growers who do not cover crop.

Presentations

A. Ristow, W. R. Horwath, W. W. Wallender, B. Sivakumar, S. Prentice, and M. Arnold. February 02, 2005 (Poster Presentation). Tillage and Cropping System effects on runoff and water quality from irrigated Agriculture : California Plant and Soil Conference, Modesto CA. (60 participants)

A. Ristow, S. Prentice, W. Horwath, W. Wallender, M. Arnold. June 16, 2005. Seasonal Effects of residue management on surface water quality from irrigated agriculture. Conservation Tillage Annual Conference, Five Points, CA (100 in attendance)

A. Ristow, S. Prentice, Z. Kabir, M. Arnold, S. Ma., W. Wallender and W. Horwath. June 25th, 2005. Water Conservation in Cover-Based Cropping Systems. Sustainable Agriculture Farming Systems Project, Davis, CA (200 in attendance).

A. Ristow, S. Prentice, Z. Kabir, M. Arnold, S. Ma., W. Wallender and W. Horwath. October 26, 2005. Improving Agricultural Runoff Management for Irrigated Lands in California, Water Quality Stakeholder's Meeting, UC Davis (25 participants)

A. Ristow, S. Prentice, W. Wallender, Z. Kabir and W.R. Horwath, November 8-9, 2005, Water conservation on cover crop based cropping systems. California. Soil Science Society of America. Salt Lake City, Utah. (200 in attendance)

A. Ristow, S. Prentice, Z. Kabir, W. Wallender, W. Horwath. November 15, 2005. Improving Agricultural Runoff Management for Irrigated Lands in California, SAFS Annual Pow Wow, UC Davis, (25 participants)

C. M. Kallenbach, W. R. Horwath, Z. Kabir, D. Rolston and J. Mitchell. November 7-8, 2005. Conservation tillage, subsurface drip irrigation and cover cropping to reduce green house gas emission and sequester carbon. Soil Science Society of America. Salt Lake City, Utah. (150 in attendance)

J. P. Mitchell, February 2, 2005. Recent advances in tillage management in the Central Valley. Invited presentation 5th Soil Health Symposium. Southern Low Desert Resource Conservation and Development Office. Coachella, CA. (60 participants).

J. P. Mitchell, February 2, 2005. Toward improving soil quality in the Central Valley. Invited presentation. 5th Soil Health Symposium. Southern Low Desert Resource Conservation and Development Office. Coachella, CA. (60 participants).

J. P. Mitchell, February 17, 2005. Conservation tillage. Invited presentation to California State University, Fresno Plant Science 253 class. (12 participants).

J. P. Mitchell, April 27, 2005. Conservation tillage research and extension education in California 2001 – 2005. University of California, Davis, Department of Plant Sciences Spring Seminar Series (60 participants).

J. P. Mitchell, May 12, 2005. Managing emissions and storage of greenhouse gases in soils. Invited presentation for "Climate change: Challenges and Solutions for California's Agricultural Landscape." Sponsored by the John Muir Center and the Kearney Foundation for Soil Science. University of California, Davis (100 participants).

J. P. Mitchell, J. Six, L. E. Jackson, September 8, 2005. Potential for a management issues of carbon sequestration in California agricultural soils. A grower workshop "Soil Carbon Sequestration in California Agriculture: Technical issues, economics and policy applications, UC West Side Research and Extension Center, Five Points, CA. (100 in attendance).

J. P. Mitchell September 29, 2005. Conservation tillage in the Palo Verde Valley. A grower workshop "CT-Conference": Palo Verde Valley, CA (60 in attendance).

J. P. Mitchell, W. R. Horwath, A. Shrestha, E. M. Miyao, R. Fry, R. Roy and Z. Kabir , November 7, 2005. Surface residues in conservation tillage systems in California. Soil Science Society of America. Salt Lake City, Utah. (60 in attendance)

J. P. Mitchell, A. Shrestha, R. Hutmacher, J. Beyer R. Roy and R. Fry. November 7, 2005. Conservation tillage in California: Contributions of the conservation tillage workshop. Soil Science Society of America. Salt Lake City, Utah. (65 in attendance)

W. R. Horwath, January 18, 2005. The Role of Soil Organic Matter and Its impact on Crop Production. Organic Vegetable Production Short Course, UC Cooperative Extension Monterey County, CA (75 in attendance).

W. R. Horwath, February 2, 2005. The Role of Soil Organic Matter and Management of Soil Quality. California Plant and Soil Conference, Modesto CA. (60 participants)

W. R. Horwarth, C. Kallenbach, Z. Kabir, June 23, 2005. Water management and conservation in cover-based cropping and drip irrigation systems.

Sustainable Farming Systems Field Day, Russell Ranch, UC Davis. (80 participants).

W. R. Horwath, S. Kaffka and D. Bryant, June 23, 2005. Carbon sequestration in no- tillage, cover crop, corn, wheat and tomato cropping systems. Sustainable Farming Systems Field Day, Russell Ranch, UC Davis. (80 participants).

W. R. Horwath November 30, 2005. Effects of conservation tillage on nutrient losses to runoff in alternative and conventional farming systems. 13th Annual Fertilizer Research and Education Program Conference, California Department of Food and Agriculture, Salinas, CA (55 participants)

Z. Kabir, T. A. Doane, K. M. Reed and W. R. Horwath. November 7-8, 2005. Soil nitrogen in different farming systems in relation to corn plant nitrogen and yield. Soil Science Society of America. Salt Lake City, Utah. (140 in attendance)

Z. Kabir and W. R. Horwath, December 01, 2005. Results from the SAFS project on water quality. 2005 Vegetable Crops Continuing Conference, UC Davis (55 in attendance)

A. Ristow, S. Prentice, Z. Kabir, M. Arnold, S. Ma., W. Wallender and W. Horwath. June 25th, 2006. Water Conservation in Cover-Based Cropping Systems. Sustainable Agriculture Farming Systems Project, Davis, CA (200 in attendance).

A. Ristow, S. Prentice, W. Wallender, Z. Kabir, W. Horwath. October 24, 2006. Improved Agriculture Management Practices for Soil and Water. 4th Biennial CALFED Science Conference. Sacramento, California. (200 in attendance).

K. M. Reed, W. R. Horwath, Z. Kabir J. P. Mitchell, S. R. Kaffka, G. Miyao and K. Brittan. August 7-9, 2006. Long-term assessment of nitrogen use and loss in irrigated organic, low-input and conventional cropping systems. International Conference on the Future of Agriculture: Science, Stewardship and Sustainability. Sacramento, CA (100 participants)

C. M. Kallenbach, W. R. Horwath, Z. Kabir and J. P. Mitchell. August 7-9, 2006. Use of Subsurface drip irrigation, conservation tillage and cover cropping to reduce greenhouse gas emissions in California Agriculture. International Conference on the Future of Agriculture: Science, Stewardship and Sustainability. Sacramento, CA (100 participants)

A. Ristow, S. E. Prentice, W. W. Wallender, Z. Kabir and W. R. Horwath. August 7-9, 2006. Using conservation tillage and cover crops to reduce runoff in irrigated California corps. International Conference on the Future of

Agriculture: Science, Stewardship and Sustainability. Sacramento, CA (100 participants)

J. P. Mitchell. August 7-9, 2006. Conservation tillage practices in California. International Conference on the Future of Agriculture: Science, Stewardship and Sustainability. Sacramento, CA (100 participants)

L. E. Jackson, H. Minoshima, S. Sanchez-Moreno, T. R. Cavagnaro and H. Ferris. August 7-9, 2006. Conservation tillage practices in California. International Conference on the Future of Agriculture: Science, Stewardship and Sustainability. Sacramento, CA (100 participants)

A. Shrestha, K. Hembree, T. Lanini, J. Mitchell, R. Vargas and S. Wright August 7-9, 2006. Conservation tillage practices in California. International Conference on the Future of Agriculture: Science, Stewardship and Sustainability. Sacramento, CA (100 participants)

W. Horwath. October 25, 2006. Impact of Conservation Tillage and Cover Crops on Agricultural Runoff Water Quantity and Quality. 4th Biennial CALFED Science Conference 2006. Sacramento, CA (75 in attendance).

W. R. Horwath November 2, 2006. Managing Soil Ecosystems. Sustainable Ag Expo, Monterey County Fairgrounds, Monterey, California. (65 participants)

Z. Kabir, C. Kallenbach, W. R. Horwath J. Mitchell and D. Rolston. November 13-15, 2006. Subsurface Drip Irrigation, Strip Tillage and Cover Crops in Mitigating Greenhouse Gas Emissions. Soil Science Society of America. Indianapolis, Indiana. (200 in attendance).

Z. Kabir, A. Ristow and W. Horwath. November 14, 2006 Agricultural Management Practices on Sediment and Nutrient Losses to Runoff. Soil Science Society of America. Indianapolis, Indiana (100 in attendance).

W.R. Horwath, November 29, 2006, Nitrogen Mineralization,14thAnnual Fertilizer Research and Education Program Conference (CDFA), Monterey, CA. (70 participants)

<u>Publications</u>

S. Prentice, A. Ristow, W. Horwath, “With loss of ag wavier looming, SAFS researchers shed light on runoff dilemmas,” *Sustainable Agriculture Farming Systems Project*, 5:1, Fall, 2004. Available online at http://safs.ucdavis.edu

W. Horwath, A. Ristow, and Z. Kabir, “Are alternative agricultural management practices right for water runoff?” *Sustainable Agriculture Farming Systems Project*, 5:3, Spring/Summer, 2005. Available online at http://safs.ucdavis.edu

A. Ristow, S. Prentice, and W. Horwath, “Sustainable ag research highlights differences among water conservation management practices” *Sustainable Agriculture Farming Systems Project*, 6:1, Fall, 2005. Available online at http://safs.ucdavis.edu

L. Halprin, G. Miyao, A. Ristow, "Growers review winter cover crops, conservation tillage" *Sustainable Agriculture Farming Systems Project*, 6:3, Summer & Fall, 2006. Available online at http://safs.ucdavis.edu

T. Lanini, G. Miyao, K. Brittan and Z. Kabir, "Weed Control in Conservation tillage systems. Available online at http://safs.ucdavis.edu

JP Mitchell, DS Munk, B. Prys, KK Klonsky, JF Wroble and RL. De Moura. 2006. Conservation tillage production systems compared in San Joaquin Valley cotton. California Agriculture Vol. 60 (3) 140-145. Available online: http://CaliforniaAgriculture.ucop.edu

JJ Veenstra, WR Horwath, JJ Mitchell and DS Munk 2006. Conservation Tillage and cover cropping influence soil properties in San Joaquin Valley cotton-tomato crop. California Agriculture Vol. 60 (3) 146-153. Available online: http://CaliforniaAgriculture.ucop.edu