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Guidelines for Using Conservation Tillage Under Furrow Irrigation

Second Edition

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Extension

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Cover photos: Crop residue in growing corn. *Photos by Erik Wardle*

Technical editing, design, and layout by Lindsey Middleton

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Chopping residue. *Photo by Erik Wardle*

Introduction

This guidebook is intended to inform growers, representatives in agribusiness, government agency personnel, and others of the potential for using conservation tillage in furrow-irrigated conditions. While the guidebook is not exhaustive, it was designed to be of sufficient detail and scope to inform the reader of the various cropping and management possibilities for successfully using conservation tillage technology on furrow-irrigated cropland. Information from two Colorado State University experiments on conservation tillage is incorporated throughout the publication. One experiment was conducted at the Western Colorado Research Center (WCRC) at Fruita (Figure 1) and with cooperating growers on the Western Slope of Colorado. The other is ongoing at the Agricultural Research Development and Education Center (ARDEC) and with cooperating farmers along the northern Front Range of Colorado.

Tillage is defined as soil-stirring operations performed for the purpose of producing crops. Traditional practices on furrow-irrigated fields involve multiple energy-consuming tillage operations intended to loosen soil, bury residue, smooth and level soil surfaces, and create a suitable seedbed. However, these systems leave the soil surface uncovered and vulnerable to wind and water erosion during much of the year, when weather conditions are often most conducive to soil loss. Residue, often called "trash" by farmers, can cause furrow dams during irrigation, increasing advance times and limiting irrigation uniformity while increasing labor. Cool spring soil temperatures in undisturbed soil may limit early season plant growth and slow stand establishment. Disease and insect pest concerns in some crops have also limited widespread adoption. Recent developments in planting and tillage system technologies and new crop varieties offer more options for alleviating cool spring soil temperatures and successfully dealing with crop residue during planting and irrigation. These tillage systems, coupled with more accurate and economical Global Positioning Systems (GPS), are gaining widespread acceptance in Colorado and parts of the Western Great Plains and the Intermountain West.

The use of conventional or "clean" tillage often results in over-tilled soils, causing the loss of organic matter and the breakdown of soil structure. Clean tillage promotes soil erosion and nutrient loss, creates soil compaction, increases soil moisture loss, and increases labor and production costs.

The best tillage system is one that achieves profitable crop production along with environmental and social needs while incurring the least cost. Tillage need only promote good soil health and sustained crop production. No tillage operation can be justified by tradition or habit.

Conservation tillage is defined as any tillage and planting system in which either:

- at least 30% of the soil surface is covered by residue following planting, or
- at least 1,000 pounds of small grain residue is maintained per acre on the soil surface.

Farmers in many furrow-irrigated areas have been reluctant to adopt conservation tillage. This is a result of concerns associated with tilling, planting, irrigating, and harvesting in fields with surface crop residue. Conservation tillage practices are different than the conventional tillage methods farmers are accustomed to using on furrow-irrigated cropland. Furthermore, conservation tillage technologies developed for rain-fed or sprinkler-irrigated conditions are not generally directly applicable to furrow-irrigated conditions.

A major concern about conservation tillage under furrow irrigation is the uncertainty of being able to furrow-irrigate fields containing surface residue. Farmers may also be reluctant to make the encompassing changes, including the necessary financial and management investments, that are needed to adopt conservation tillage successfully on their furrow-irrigated croplands.

Conservation tillage is an umbrella term that includes tillage systems such as strip tillage, mulch tillage, no-till, zero tillage, minimum tillage, slot planting, till-plant, rotary till, ridge till, zone tillage, and others.

Figure 1. Pinto beans planted following corn at the Western Colorado Research Center at Fruita. *Photo by Calvin Pearson*

However, given that more farmers are incorporating conservation tillage on their sprinkler-irrigated land, they are also looking for options to utilize the same equipment on flood-irrigated farmland (Figure 2).

Growers must have sufficient justification to consider adopting conservation tillage technology. There are numerous reasons farmers may wish to adopt conservation tillage on furrow-irrigated cropland, including:

- Conservation tillage typically reduces production costs by eliminating several field operations, and it reduces soil erosion caused by wind and water, making crop production more sustainable.
- Conservation tillage can maintain yields by reducing the loss of fertile soils and nutrients.
- In certain environments, conservation tillage can improve yields by reducing erosion. Filling gullies and smoothing fields because of erosion can be expensive and detrimental to long-term field productivity. Unchecked erosion can reshape

Figure 2. Increased soil moisture storage in an early season corn stand often eliminates the need to irrigate a crop up. *Photo by Phil Westra*

Figure 3. Bailing off corn residue. *Photo by Erik Wardle*

fields as topsoil is moved to the bottom of the field, creating flat fields, or cause increased slopes at the bottom of the field when soil is moved off-site, making surface irrigation more difficult.

The reasons and motivations for adopting conservation tillage may differ among farmers and locations, but the net result is usually positive.

Managing Surface Crop Residue

How crop residues are managed affects the production of subsequent crops in terms of yields and the ease and ability to perform various field operations. When conducting field operations, farmers should perform each operation as precisely as possible. They must consider how a particular field operation influences subsequent operations. This is especially important when managing surface residue on furrow-irrigated land.

Several principles of managing surface crop residue have general application to most furrow-irrigated conditions. Crop rotation has numerous benefits and is one of the most effective tools for managing residue in conservation tillage systems. A system such as continuous grain corn production creates large amounts of residue each year, and while this can be effectively managed (as will be discussed below), it is not recommended. Rotating high residue crops with lower residue crops (i.e., dry beans, sugarbeets) can greatly simplify management. Small grains also work well in these systems. Crop residue should be spread and maintained as evenly as possible across the entire field, because other practices can be performed much more readily when surface crop residue is uniform. Uniform surface residue in fields is particularly important when planting and cultivating. Non-uniform surface residue will cause equipment to perform inconsistently and numerous adjustments may be required as conditions change across a field. Residue management begins at harvest, and using a combine with a chaff chopper and spreader to distribute residue will make subsequent operations easier.

Options for managing residue:

- **Rotating crops**
- **Spreading evenly**
- **Removal by bailing**
- **Moving residue to dry rows or pushing to the side**
- **Grazing**

There are two main approaches to handling the size of residue. Work done on the West Slope showed that crop residue should be maintained in pieces that are as large as practical. Large pieces of residue anchor to the soil more readily and are less subject to movement by wind and irrigation water than smaller pieces of residue. Disking and chopping residue into fine pieces may not always be desirable. The type of crop and the residue produced by various crops influences how well residue stays in place. For example, corn residue is less subject to movement by wind and irrigation water than wheat residue. Front Range cooperating farmers recommended sizing residue in order to facilitate moving it to a desirable location in the field. This can be done in a number of ways. Following high residue crops (like grain corn) chopping and baling a portion of stalks helps to size material and remove

Figure 4. Row cleaning. *Photos by Jordan Driscoll*

some of the residue from the system (Figure 3). Some growers perform a shallow disking operation when conditions are dry in order to slice residue without burying it. Once residue is sized, it can be moved into a non-irrigated row (in every other row irrigation) or pushed to the side of the beds with a ditcher, cultivator, or row cleaner (Figure 4). It is important to consider that residue removal will take nutrients out of the system that would be otherwise available for crop production. Loss of nutrients and soil carbon can have an impact on the long -term productivity of a field, requiring increased fertilizer costs; therefore, a mix of residue management options is recommended.

Seedbed Preparation

A suitable, uniform soil structure must exist across the entire field area to provide a favorable environment for seed germination and subsequent plant growth. While this may be achievable with conservation tillage practices, additional operations may be needed to create ideal conditions for plant growth and irrigation. Two important aspects should be considered during seedbed preparation when using conservation tillage under furrow irrigation: proper soil preparation and the consideration of water application when creating furrows.

The first aspect relates to the condition of the seedbed. The field surface must allow planting to be performed without difficulty. The seedbed must be sufficiently uniform so seeds are planted at a consistent depth across the field and placed into the soil to obtain good seed-to-soil contact. At ARDEC one of the largest impediments to the conservation tillage system was the difficulty in preparing a uniform seedbed. Planting on an eroded bed, into compacted soil, or on uneven surfaces created problems with seed placement. Poor emergence, erratic plant stands, vulnerability to lodging, and potential yield loss are often consequences of poor seed placement. Strip tillage allows for preparation of a suitable seedbed and minimizes problems associated with seed placement as mentioned above. Reducing compaction and ensuring a mellow but firm seedbed is one of the key advantages of strip tillage (Figure 5). The strip till operation can significantly flatten and reshape old beds, and some soil and residue move down into the furrow. Beds and furrows will usually need to be reformed prior to the first irrigation of the season.

The second aspect of proper seedbed preparation when using conservation tillage under furrow irrigation concerns water application. Furrow shape and size needed for irrigating under conservation tillage are often not the same as those used for conventional, clean-tillage. Furrows needed for conservation tillage are typically

Figure 5. Strip till operation - proper adjustments to the implement are critical; keep in mind this is seed bed preparation, not rough tillage operation. *Photo by Erik Wardle*

formed during seedbed preparation. Consideration should be given to furrow size and shape to ensure they will be adequate throughout the irrigation season.

Soil Fertility and Nutrient Management

Nutrient management in high residue, conservation tillage systems is not significantly different than management in other modern crop production systems, but some adjustment is required. Most of the Best Management Practices promoted in Colorado are applicable in all tillage systems and may be more important under conservation tillage. For example, routine soil sampling to determine residual soil fertility is a valuable tool for determining crop needs for supplemental nutrients. In conservation tillage, soil is no longer thoroughly mixed, and taking a representative soil sample requires accounting for variability from the banding location, irrigated vs. non-irrigated rows, and other factors. Split application of fertilizer (including starter at planting, deep placement, and side-dress nitrogen and phosphorus as needed) works well in these systems to produce a profitable crop and reduce potential environmental impacts. The strip till operation can also be used for deep placement of a portion of crop fertilizer needs (Figure 6). Proper fertilizer placement is critical, particularly with a lower quantity of mobile nutrients like phosphorus. Placing

Figure 6. Strip till unit set up for deep placement of liquid fertilizer. *Photo by Erik Wardle*

Figure 7. Planting corn through residue on the previous year's beds. *Photo by Erik Wardle*

nutrients where plant roots can reach them throughout the growing season can help reduce environmental losses and increase nutrient use efficiency.

When using conservation tillage, significant surface residue can lead to increased nitrogen immobilization. This is generally a short-term problem and can be readily managed by applying additional nitrogen fertilizer during the establishment phase of conservation tillage. Deeper placement of nitrogen is one approach that mitigates the need for increased fertilizer related to immobilization. In addition, higher residue environments will have cooler early season soil temperatures, which may exacerbate micronutrient deficiencies early in the growing season. The use of conservation tillage under furrow irrigation has prompted concerns that increased nitrogen leaching may occur. This concern arises out of the potential for reduced irrigation uniformity to increase deep percolation. Based on research results obtained at WCRC-Fruita from two separate experiments, increased nitrogen leaching is not a problem when using conservation tillage systems under furrow irrigation, particularly if growers use good irrigation water management practices.

An experiment was conducted during 1996 and 1997 at WCRC-Fruita with five nitrogen application rates from zero to 268 pounds of nitrogen per acre and three application timings. The three application timings were: 1) all nitrogen band applied at planting, 2) 1/3 of the nitrogen band applied at planting and the remaining 2/3 banded in wheat before the first node

Figure 8. Four-row strip tiller used at WCRC-Fruita. *Photo by Calvin Pearson*

Figure 9. No-till grain drill developed at the Western Colorado Research Center at Fruita. *Photo by Calvin Pearson*

and side-dressed in corn at the five- to seven-leaf stage, and 3) all nitrogen banded post-emergence in wheat before the first node and all side-dressed in corn at the five- to seven-leaf stage of development. All treatments were applied to both crops.

Results from this experiment indicated that nitrogen rate and timing applications could be quite flexible without adversely affecting corn yields or creating environmental problems related to nitrate leaching. Soil type is an important consideration for making nutrient management decisions related to crop production and reduced environmental impacts. Coarse textured sandy soils are more prone to leaching than finer textured clay soils, making management to prevent leaching relatively more important for fields with sandy textures.

Equipment

Specialized and specially-adjusted equipment is often necessary when using conservation tillage technology under furrow-irrigated conditions. Crops grown with furrow-

irrigation often have high yields, and with many crops, not all plant material is harvested or removed from the field; this leaves large amounts of crop residue in the field after harvest. It is important to remember crop residue management begins at the time of harvest, and ensuring residue is spread uniformly will make things easier during the next irrigation season.

The equipment must be capable of handling large quantities of surface residue when performing required operations. These operations include forming and shaping beds and furrows, planting, cultivating, ripping, chiseling, and applying fertilizers (Figures 7-8). Equipment developed and used in conventionally managed cropping systems may not be suitable for use in conservation tillage under furrow irrigation. For example, most commercial grain drills will not operate properly when used for conservation tillage under furrow irrigation. A grain drill that is suitable for furrow-irrigated conditions must have adjustable drive wheels to track irrigation furrows (Figure 9). Because furrow widths change depending on the crop and grower preferences, wheels must be movable to accommodate different distances between furrows. The grain drill must also have adjustable seed openers to allow proper seed row placement across the width of the bed. Grain drills for conservation tillage in furrow-irrigated conditions also must have multiple tool bars to stagger seed openers so residue will flow through the planter, or a drill must specifically accommodate high residue planting.

Planters that allow for individual adjustments to accommodate various row spacings, seed spacings, and individual seed opener planting depths are essential for conservation tillage under furrow irrigation. Modern row crop planters generally work well in conservation tillage on furrows without major adjustments. Front mounted row cleaners are usually needed to move residue off the seed bed.

Some growers have had success combining multiple operations into a single pass. For example, with adequate horsepower, it is possible to operate a strip till unit followed by shovels to rebuild beds along with a planter directly behind it. Multiple tool bars should also accommodate coulters for applying fertilizers or shovels for forming furrows.

Adjustments to the tractor and the down force springs of the planter are necessary to achieve proper seed placement.

Planting

Conservation tillage systems under furrow irrigation have aspects that differ from those encountered in clean-tillage conditions. Planters must be heavy enough so seed openers and planter units penetrate through residue and place the seed at the proper depth and in a uniform position along the length of the row. Setting the tractor three-point down draft force and adjusting the planter unit down force springs, if available, can help achieve proper seed placement. Surface residue must flow through the machine without catching, dragging, and accumulating, causing the planter to plug. Plugged planters create residue piles in the field that must be spread, which increases labor costs, can adversely affect plant stands, and causes difficulty performing other field practices such as irrigating. Proper seed placement on the bed is essential. Some growers plant directly through the previous year's row and have had good success. If following corn or another crop that leaves a significant stalk and root ball, removing these can cause some issues, both at planting and during irrigation. At ARDEC, seed was planted approximately three to four inches offset from the old crop row, leaving stalks and root balls mostly undisturbed (see back cover photo).

Experience has shown that planting in wet soils is more of a challenge than planting in dry soils. Wet conditions make it difficult for openers to penetrate through residue. Also, closing the seed row behind the planter unit to achieve good seed-to-soil contact is much more difficult in wet soils. This is less of a concern in strip tillage. These issues tend to present themselves early in the transition to reduced tillage and will be of less concern the more years a field has been in conservation tillage. In some cases, residue cover and soil conditions in fields under conservation tillage for a few years will allow field access and planting in wetter conditions than plowed ground.

Cultivation

Similar to planting, cultivating with large amounts of surface residue present creates challenges that differ from cultivating under clean-tillage conditions. Surface residue must flow through the cultivator freely, without catching, dragging, or creating clumps or piles. If the cultivator has row crop shields, they may need to be raised or removed to prevent these problems. Rolling cultivator tools are generally preferred, even when only moderate amounts of surface residue are present. Operators must be careful that residue and soil do not inadvertently cover or lodge plants. A timely cultivation can move residue around plants or in other areas to create a mulch layer that will provide weed control, retain soil moisture, and hold topsoil. During the last cultivation of the season, furrows and beds should be formed adequately to accommodate irrigation needs for the remainder of the growing season.

Weed, Insect, and Disease Management

Perennial weeds, such as field bindweed, may require special attention and management when using conservation tillage (Figure 10). With good management strategies, conservation tillage may be more effective in controlling some perennial weeds than has been the case with conventional tillage systems. This is particularly evident given the relatively recent availability of herbicide tolerance in several crops.

Methods of Weed Control

- Dense, vigorous stand
- Proper irrigation
- Adequate soil fertility
- Crop rotation
- Adapted varieties
- Good soil drainage
- Cultivation/tillage
- Residue management
- Planting time and methods
- Companion crops
- Weed-free seed
- Weed control before planting
- Mowing
- Burning/flaming
- Herbicides
- Biological (insects)
- Cover crops

In non-irrigated systems, shifts in weed species after changing tillage systems are common and should be expected under irrigated conditions as well. Desirable weed, insect, and disease management strategies will be similar to practices that are effective in controlling pests, no matter what tillage system is used. Clean-tillage systems depend heavily on mechanical means of weed control, but when using conservation tillage, other options must be considered. Some mechanical weed control occurs when forming beds or cultivating, but it is important to use an appropriate integrated pest management approach, including pesticides, conservation tillage, crop rotations, and genetically-engineered crop varieties. The increasing presence of herbicide resistant weeds may make weed control in all systems more challenging. A dynamic herbicide and weed management program that incorporates residual and contact products will be needed to keep these weeds under control.

Figure 10. Perennial weeds can be a challenge when converting to conservation tillage; however, after four years of conservation tillage and a sound weed management plan, the bindweed that was in this field is greatly reduced. *Photo by Erik Wardle*

Pest pressures change with increased crop residue. Diseases that overwinter in soil may require crop rotation or resistance to manage.

Disease and insect pressure may be more of a concern than weed management under conservation tillage. Significant surface residue and undisturbed soil can be excellent habitat for some pest populations. At ARDEC, Goss's wilt infestations have been seen in all tillage treatments, but higher prevalence has been found in the conservation tillage systems. Crop rotation can help with both insect and disease issues that may be exacerbated by conservation tillage. Field monitoring and regular crop scouting are essential to identify problems early so adequate time is available to select and schedule suitable responses.

Irrigation

Conservation tillage can affect numerous aspects of furrow irrigation (Figure 11). Water infiltration rates were 24% higher in 1991 and 50% higher in 1992 at WCRC-Fruita with conservation tillage than with conventional management. Research in other parts of the U.S. has also shown that infiltration rates are higher with conservation tillage than with clean tillage under furrow irrigation.

Irrigation water advance times may be longer with conservation tillage than with conventional tillage (Figure 12). Advance time is the time is takes irrigation water to move down the furrow. Residue dams and mellow soil can slow the advance of water down the field and affect irrigation uniformity from furrow to furrow. At WCRC-Fruita, irrigation water advance times were 37% longer in 1991 and 25% longer in 1992 with conservation than with conventional tillage. However, this is not always the case, and depending on soil type, surface compaction, and other factors, advance times may be faster than with clean tillage. At ARDEC in 2012, irrigation advance times in both conservation tillage treatments were significantly shorter than the time required in the plowed ground during the first irrigation of the year. This was due in part to the severely dry spring and the moisture that was lost during tillage operations. The conservation tillage plots were not powder dry and were firm, and early season irrigations were more effective. Extremely long advance times in the fully tilled ground had a number of negative impacts, including pumping costs, leaching of water and nutrients at the top of the field, and a poorly irrigated crop at the bottom end of the field. These impacts were avoided using conservation tillage systems.

Soil water content is often higher, especially at planting, when conservation tillage is used compared to clean tillage. Soil water content averaged 17% higher for corn, 17% higher for soybean, and 27% higher for dry bean with conservation than with clean tillage at WCRC-Fruita. Higher infiltration rates and higher soil water content in conservation tillage may allow for irrigating less often than with clean tillage. Irrigating less often and more efficiently using conservation tillage can save water and the labor needed to irrigate crops. Early season soil moisture content at ARDEC was significantly different between tillage treatments in each cropping year. At

planting, in the top six inches of soil, the conservation tillage plots had 0.75-1" more water. This increased surface moisture allowed the seed to germinate and begin root development prior to an irrigation. In three of the four study years, this early development allowed the crop to tap deeper soil moisture and grow without irrigation until cultivation in the strip-till treatment. Not having to irrigate means not turning a well on early or being able to use available water on a higher priority field.

Furrow stream size, the growing crop, field slope, soil type, residue quantity and type, field length, soil roughness, and soil compaction affect furrow irrigation. Attempting to achieve uniform infiltration along the length of the furrow in a field, while minimizing the amount of runoff, necessitates managing as many of these factors as much as possible. For example, when irrigating in furrows containing large amounts of residue, a grower may need to increase the furrow stream size to compensate for the effects caused by the residue. Care must be taken not to increase stream size too much, as excess flow may erode beds, cause increased damming, and offset sediment reduction benefits. Furrows may need to be larger than normal. Furrows may also need to be smoother with fewer soil clods and more compacted to lower furrow roughness to maintain advance times at an acceptable rate.

Growers need to actively manage the amount of residue in the furrow. When too much residue is in the furrow,

Figure 11. Conservation tillage contributes to increased infiltration and soil water content during irrigation. *Photo by Erik Wardle*

Irrigation adjustments with conservation tillage include:

- ***Altered irrigation flow rate***
- ***Larger furrows***
- ***Potential for irrigating less often due to increased soil moisture***

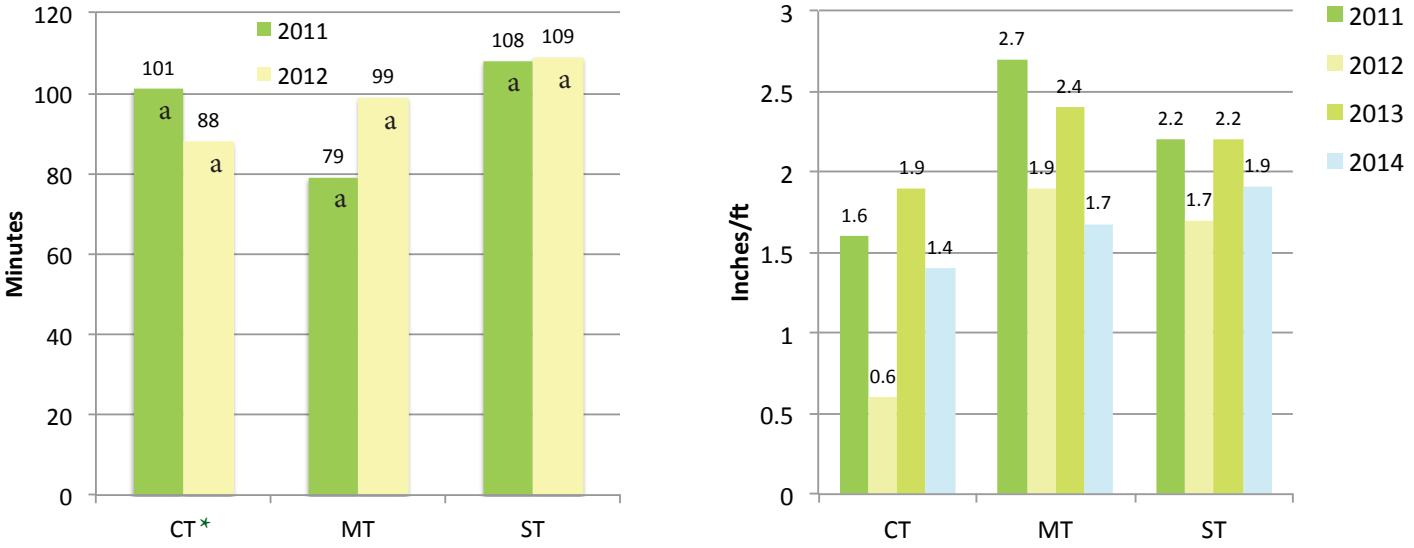

Figure 12. Left: Irrigation advance times in minutes for 2011 and 2012 shown as an average of all irrigations; Right: Soil moisture at planting zero to six inches. *(CT - conventional till, MT - minimum till, ST - strip till; lowercase letters indicate statistical differences)*

*** Does not include first irrigation of the year for 2012**

some of it may need to be moved to alternate rows or between rows using cultivator tools or row cleaners where it won't interfere with irrigations or growing plants. With corn residue, a practical management technique is to move residue to alternate furrows during seedbed preparation or just prior to planting. Moving residue too early can leave it vulnerable to being moved by wind back into the parts of the field where it will cause problems for planting and irrigating. The irrigation after planting can be done in these alternate furrows that have lower amounts of residue. Once crop plants are big enough, residue in other furrows can be mulched around the plants, and all furrows can be irrigated for the remainder of the growing season.

How the bottom of the furrow is managed is important in controlling irrigation water infiltration. Residue in the furrow can increase soil wetting in a lateral direction. Therefore, to achieve acceptable advance times under conservation tillage conditions, it may be necessary to have a slightly larger furrow with a smooth, compact, clod-free bottom. Under conservation tillage, infiltration increases, and if increases in infiltration are partitioned toward lateral water movement and less toward vertical movement, the leaching potential may be reduced. When furrow roughness is too excessive under clean-tillage systems, infiltration will to be too high and advance time too slow. A common farmer practice to avoid this situation is to drive furrows to reduce furrow roughness or run roller packers. Reducing furrow roughness under clean-tillage systems smoothes the furrow by increasing soil compaction and eliminating or reducing soil clods. This approach is equally effective in conservation tillage systems. Increasing the furrow stream size too much may create an erosive energy that causes the water to transport residue. Residue moving with the irrigation water may result in "furrow damming."

Maintaining residue size as large as practical and using an appropriate

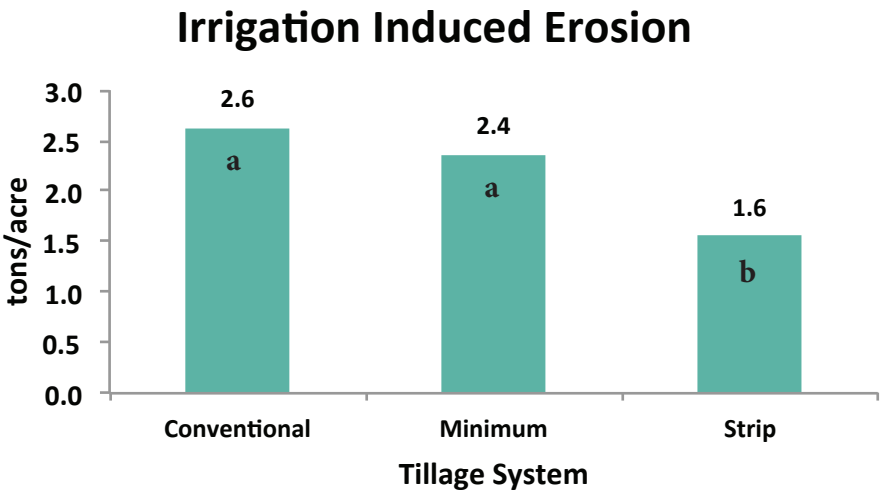

Figure 13. Average annual sediment loss measured at ARDEC for the three tillage systems, determined by multiplying sediment concentration in runoff samples by runoff amounts (*numerical labels indicate statistical differences)*

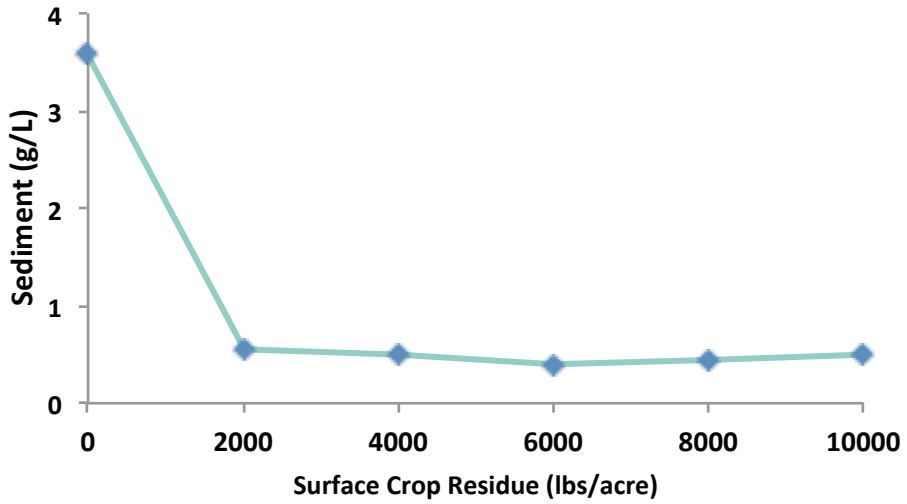

Figure 14. The effect of surface crop residue on the amount of sediment in irrigation water

stream size will reduce the likelihood of residue movement. To furrow irrigate successfully under conservation tillage conditions, farmers must learn to balance infiltration and advance time, taking into account the added effects created by surface residue.

Maintaining crop residue on or near the soil surface using conservation tillage technology reduces furrow erosion during irrigating. In addition, most farmers and industry experts agree that keeping residue on or near the surface makes it much easier to manage than residue that is buried. Deep disking or other operations that bury or incorporate crop residue and mix it with soil can make it difficult to move and manage. Supplemental tillage operations that can be kept only an inch or two deep will allow for more options for residue management. Furrow width was found to be 8% wider under clean tillage in the first irrigation and 24% wider under clean tillage compared to furrows under conservation tillage in the western Colorado experiment. Soil is more protected from the erosive energy of irrigation water when surface residue is present. Thus, furrows are less subjected to the effects of erosion and movement of soil when conservation tillage is used compared to the wider furrows that occur under clean-tillage cropping systems.

Water Quality

Sediment from irrigation water runoff can contribute to water quality

degradation by transporting nutrients (nitrogen and phosphorus), adsorbed pesticides, and potentially selenium to surface water bodies. As such, the Colorado Phosphorus Index Risk Assessment lists residue and tillage management as a Best Management Practice appropriate to decrease the relative potential for off-site P movement for sites with high P runoff potential (Sharkoff et al., 2012). An excessive amount of nutrients in surface water can cause excessive algae blooms which reduce sunlight penetration and available oxygen, resulting in fish kills. Additionally, irrigation induced erosion results in valuable topsoil losses from fields and slowly changes the desired slope of graded fields. Conservation tillage is one tool to help alleviate sediment and nutrient losses from surface irrigated fields (Figures 13-14).

Sediment loss is greatest in bare, smooth (no clods) soil compared to soils containing even small amounts of surface residue. The amount of residue required to reduce sediment loss can vary based on a number of factors, but large quantities are not necessarily required. At WCRC-Fruita, using a furrow residue simulator, increasing surface residue beyond 3,570 lbs/acre for a loam and 1,800 lbs/acre for a sandy soil did not further reduce sediment loss. Farmers who learn to manage even small quantities of surface residue could reduce soil erosion on furrow-irrigated cropland (Figures 15-16). In the ARDEC demonstration, residue up to 7900 lbs/acre after planting was managed to allow for successful irrigations and a 40% reduction in sediment loss.

Surface soil texture has a significant effect on sediment losses that can be expected when using conservation tillage under furrow irrigation. Research findings in Colorado indicate that surface residue in furrow-irrigated, field conditions is more responsive to management in finer textured soils such as loams and clays than in coarse textured soils such as sandy loams.

Nutrient losses in irrigation runoff can be reduced by conservation tillage, but fertilizer placement and timing is

Figure 15. Sediment-free irrigation water runoff at the end of the furrow and into a tail ditch when conservation tillage was used in pinto bean production. *Photo by Calvin Pearson*

Figure 16. Irrigation water runoff containing sediment at the end of the furrow when conventional tillage was used in pinto bean production. *Photo by Calvin Pearson*

critical in these systems. For example, concentrations in total phosphorus decreased in the ARDEC demonstration project, but soluble phosphorus did not decrease (Figure 17). Total nitrogen was not affected, but soluble nitrogen, nitrate, increased in the minimum tillage treatment. This was because the fertilizer was placed at a shallower depth in the harder soil furrow and was more available to being solubilized by irrigation water. Thus placement is critical in conservation tillage systems. Banding fertilizer in the dry furrow or near the top of the irrigation bed is one solution to reduce these losses. Additionally, over time, phosphorus levels in conservation tillage fields can become stratified if P is surface applied since P is not mobile in soil (Figure 17). Higher P levels at the soil surface have resulted in increased P loses in some studies in non-irrigated environments. Injection of P as a band below the soil surface can mitigate these affects and can also lower the P rate required for profitable crop yields.

Harvesting

Reduced tillage systems require careful and deliberate residue management beginning at harvest. Growers should consciously consider how equipment and equipment attachments affect crop residue. Stripper headers, straw spreaders, straw choppers, and chaff spreaders are a few devices, along with their sizes, configurations, number, and adjustments that can have considerable impact on crop residue condition and distribution in the field. Evenly distributed and sized residue is easier to manage than piles, wind rows, or clumps. Avoid stopping in the middle of fields to prevent residue piles.

Growers should consider how the type of equipment used, associated attachments, and the operation and performance of equipment can affect future field operations and situations. Proper management should be used to obtain a uniform distribution of surface crop residue across the field.

Growers should also consider how wheel traffic from grain trucks, carts, and tractors affects residue and soil conditions and how subsequent field operations may be affected by wheel traffic that occurs during harvesting. Field traffic especially across beds should be minimized as much as possible.

Post-Harvest Field Management

Once harvest is completed, growers may be inclined to discontinue field work until next spring; however, the manner in which fields are managed following harvest should be thoughtfully considered during and after harvest. For example, once corn grain has been harvested, growers should decide if they should flail the residue or leave it standing through the winter. At WCRC-Fruita, we have found that more residue is retained in the field when flailing is performed than when corn stalks are left standing during the winter. When corn stalks are left standing during the winter, the wind removes leaves and other lighter

Managing Crop Residue in Irrigation Furrows

Water flows down a furrow at a rate (Q), causing infiltration (i), advance time (t), and wetted perimeter (p).

The wetted perimeter is the distance across the furrow where water contacts the soil (from arrow to arrow).

Adding residue in the furrow slows water flow (Q), increases infiltration (i), decreases advance time (t), and increases wetted perimeter (p).

A larger furrow allows for an increased wetted perimeter.

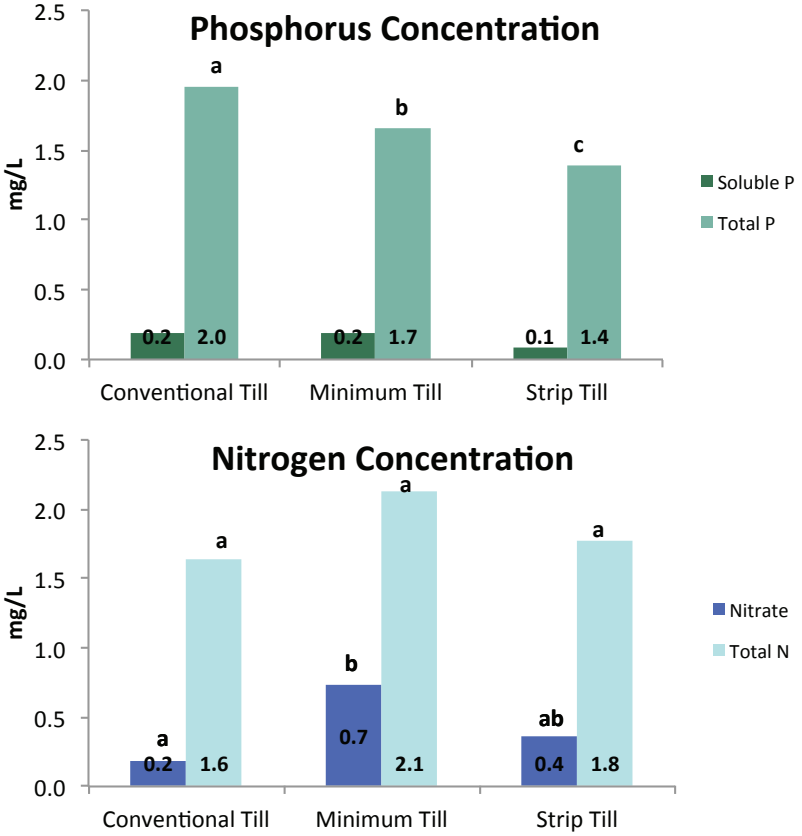

Figure 17. Average concentration of nutrients in irrigation runoff water as affected by tillage treatment *(lowercase letters indicate statistical differences)*

material and transports them out of the field, relative to flailing the corn stalks. It is important to not chop stalks too low to the ground. Leaving four to six inches of stalk standing will help hold residue, capture winter snow, and reduce wind erosion potential. Taller stalks will tend to capture and hold more snow than shorter stalks, so soil moisture benefits should be weighed against practical management needs.

Soil compaction likely reduces yields more than growers realize in all types of cropping systems. Concerns have been expressed about soil compaction problems developing when conservation tillage is used in furrow-irrigated conditions. Based on field research conducted in western Colorado, soil compaction was similar between conservation and conventional tillage in the three crops that were studied over a two-year period, except for soybean in one year where soil compaction was 23% higher with conservation tillage than with conventional tillage. This situation represents one in six cases that soil compaction was affected by tillage and occurred after only three years of conservation tillage. This finding indicates that soil compaction under conservation tillage systems is a potential problem and should be monitored similar to recommendations currently made for other tillage systems. At ARDEC, strip tillage has worked well to alleviate soil compaction, especially in the crop row. Harvesting silage under wet soil conditions in 2013 caused significant compaction from equipment and required deep ripping all tire tracks in the field (Figure 18). While compaction can be a concern, growers should keep in mind that options, such as deep ripping, are available as needed to reduce the impact on crop productivity.

Crop Rotations

A number of crop rotations are possible when conservation tillage is used under furrow irrigation (Figure 19). Some crops and some crop rotations are more conducive than others for using conservation tillage on furrow-irrigated land. A few crop rotation possibilities are presented in this publication.

Winter wheat and winter barley have been successfully grown under furrow irrigation using conservation tillage following dry beans. Growers should be mindful of using herbicides in dry bean that may carry over and cause damage in small grains. Dry bean residue should be spread as uniformly as possible across the field during harvest.

Corn harvested for silage followed by winter wheat can be accomplished using conservation tillage with furrow irrigation. Having a planter that is capable of planting or that can be adjusted to plant in uneven conditions is important. Following planting, furrows may need to be reshaped. Corn for silage or corn for grain following alfalfa is a common crop rotation that

Managing soil compaction is critical in all tillage systems.

growers have accomplished successfully. Alfalfa stands can be killed using appropriate herbicides, often Roundup for non-Roundup Ready™ alfalfa, in the fall or spring. Grain yields of corn grown with conservation tillage following alfalfa have been comparable to yields grown using clean tillage.

Fewer field operations are needed when using conservation tillage. This allows more time for farmers to be growing crops in the field instead of spending time doing field operations. Double-cropping is the production of two crops in one growing season. With conservation tillage technology, it may be possible to develop double-cropping systems in furrow-irrigated areas, where it has not been possible under conventional tillage systems.

Limitations for Using Conservation Tillage with Furrow-Irrigation

Developing conservation technology for various crops grown under furrow irrigation and in different crop rotations requires considerable field research and experience to identify the specific practices that perform well in a particular cropping system. In some cropping systems, it may be difficult to maintain conservation tillage over the long term, but in other situations, it is possible to use conservation continuously or at least for several years. For example, re-leveling fields periodically that have been under conservation tillage for a period of time may be necessary to maintain uniform furrow-irrigated conditions. Land leveling is difficult when large quantities of surface crop residue are present. Additionally, crop species, crop rotations, and cropping practices vary considerably across the various furrow-irrigated regions of the U.S. Regional nuances must be considered when developing and using conservation technology.

Figure 18. Silage harvest in conservation tillage. *Photo by Troy Bauder*

Some crops in the rotation may require different row spacings. Changing row spacings from year to year may be impractical and thus limit the use of conservation tillage. Considerable soil disturbance occurs during harvest of various crops such as potatoes, sugarbeets, onions, and dry beans. These and similar crops complicate the use of conservation tillage and may not allow continuous use of conservation tillage.

Growing no-till winter wheat following grain corn presents challenges when large amounts of surface residue are present. Large amounts of surface corn residue can cause difficulty for wheat seedlings to emerge and can cause non-uniform plant stands. Also, at planting if the soil is too wet the slot made by the seed opener may not seal properly, leaving the seed without adequate seed-to-soil contact. Planting wheat when the soil and residue are dry usually results in the best outcome.

Planting pinto beans following winter barley as a double-crop using conservation tillage at WCRC-Fruita was not successful. The problem encountered was caused by increased soil moisture. Because of the barley stubble, soil moisture increased and promoted development of root rot diseases in pinto bean, causing reduced bean yields. Furthermore, during pinto bean

Figure 19. Winter wheat grown following silage corn at Fruita, Colorado. *Photo by Calvin Pearson*

harvest, barley roots held onto clods that were similar in size to bean seed. Large quantities of these small clods were harvested along with the pinto beans. Double-cropping pinto beans after winter barley using conservation tillage is not recommended.

Fields that are difficult to irrigate under clean-tillage conditions (long runs, flat fields, very sandy or gravelly soils) will likely be more challenging with residue. Growers must be aware that problems can occur when using conservation tillage under furrow irrigation, and they must seek to develop ways to avoid or overcome them. Growers should keep in mind that it is always better to start on a few acres and learn how to make conservation tillage work on their farm before scaling up to more acres.

Economics

The economics of conservation tillage systems have been studied extensively in other parts of the country. The financial benefits of reduced fuel use, fewer hours on tractors and equipment, and less labor cause many growers to consider switching to a conservation tillage system. Of course, these reduced costs will not result in grower profits without maintaining comparable yields and quality. In furrow-irrigated systems, additional considerations include irrigation uniformity and getting water through the field without spending too much time in the field with a shovel. Poor irrigation and increased labor costs if forced to walk the field can offset some of the financial benefits of conservation tillage. One of the goals of the experiment at ARDEC was to keep a detailed farm budget and compare how conservation tillage and conventional tillage behaved after three years of continuous corn production. Data collected included fuel use, labor requirements, other input costs, crop yields, irrigation advance times, labor requirements, and other relevant information. Economic analysis after three years showed that conservation tillage can have economic benefits for growers by reducing input costs, which helps maintain profitable yields and allows growers to benefit from soil moisture savings. The strip till system had a nearly $70 higher net return per acre than conventionally tilled ground. These results are similar to the previous work done at WCRC-Fruita.

The study conducted at WCRC-Fruita in the early 1990s compared conservation with conventional tillage in a cropping system of corn, soybean, winter barley, and dry beans under furrow irrigation. Direct costs

Costs and Returns of Tillage - 3 Year Average
(2011, 2012, and 2013)

	Conventional Tillage	Strip Tillage	Minimum Tillage
	3 Yr Avg	3 Yr Avg	3 Yr Avg
Gross Revenues	$/Acre	$/Acre	$/Acre
Returns per Acre	$1,253.19	$1,241.48	$1,064.61
Variable Cost	*Conv*	*Strip*	*Min*
Seed	$110.00	$110.00	$110.00
Fertilizer	$123.54	$123.54	$123.54
Herbicides	$36.33	$36.33	$36.33
Insecticides	$9.11	$9.11	$9.11
Crop Insurance	$27.67	$27.67	$27.67
Irrigation Energy and Labor*	$75.00	$75.00	$75.00
Machinery Operating	$48.00	$21.60	$18.72
Fuel	$54.23	$30.26	$25.59
Machinery Repair	$7.00	$3.45	$2.96
Machinery Labor	$9.00	$4.44	$3.81
Farm Overhead	$25.00	$25.00	$25.00
Property Taxes	$23.67	$23.67	$23.67
Interest (6 months at 8%)	$43.88	$39.21	$38.51
Total Variable Cost	$592.43	$529.27	$519.92
Fixed Costs			
Machinery Ownership	$48.00	$21.60	$18.72
Total Fixed Cost	$48.00	$21.60	$18.72
Total Cost	$640.43	$550.87	$538.64
Return to Land and Management	**$612.76**	**$690.61**	**$525.97**

* Estimated from CSU Extension Agriculture & Business Management Crop Enterprise Budgets, http://www.coopext.colostate.edu/ABM/cropbudgets.htm

averaged 4% higher under conventional tillage than conservation tillage for corn, soybean, and winter barley. Property and equipment costs under conventional tillage averaged nearly 50% higher than for conservation tillage. Net return was slightly higher (2%) for conventional than for conservation tillage when the four crops were considered together in the cropping system. The data from this study showed similar profitability for conservation and conventional tillage when all four crops in this cropping system were considered together. Growers have found that using conservation tillage on their farms provides them with an additional $25 to $50 per acre of income.

Production costs and profitability are highly dependent on individual grower circumstances. By refining production practices based on grower experience and the latest research, net returns using conservation tillage are likely to increase. Reducing input costs by reducing the number of field operations needed to produce a crop while maintaining crop yields will promote increased net grower returns.

The Benefits of Using Conservation Tillage on Furrow-Irrigated Cropland are:

- Reduces runoff and evaporation and increases soil moisture
- Reduces on and off-site soil erosion
- Increases soil organic matter
- Provides shelter and habitat for wildlife
- Traps snow during winter months
- Conserves fuel and labor by reducing the number of field operations
- Saves time due to fewer field operations
- Protects water quality by reducing surface water pollutants that may bind to soil particles, become suspended, and subsequently carried off the field in tailwater
- May improve grower ability to assess perennial weed problems and identify effective control methods
- Improves public relations with the urban community by using environmentally sound cropping methods

Figure 20. Seedlings emerging from corn residue in a no-till field. *Photo by Erik Wardle*

Making Conservation Tillage Work

Research and experience have shown that conservation tillage can be used successfully in most cropping systems. In many situations, surface crop residue on furrow-irrigated cropland can be managed without adversely affecting yields. Furthermore, large amounts of surface crop residue can be managed effectively under furrow irrigation without causing problems when irrigating, cultivating, or performing other field operations. Specialized and specially-adjusted field equipment and appropriate management practices are necessary for managing surface crop residue. Producing crops using conservation tillage requires growers to be patient and creative in order to be successful at growing and managing crops under these conditions. Profitable and sustainable yields can be achieve using conservation tillage, and significant savings on fuel, labor and input costs make this an attractive opportunity for growers. The environmental and water quality benefits provide additional value and incentives to growers. Research projects conducted on both sides of the Continental Divide in Colorado show compelling evidence that conservation tillage can work under furrow-irrigated systems. As additional research results are produced and growers obtain experience with conservation tillage under furrow irrigation, more extensive use of this technology is likely to occur. Conservation tillage under furrow irrigation may not work in every situation, but where it does, it makes good agronomic, environmental, and economic sense.

Conservation tillage opens additional possibilities, such as the use of living mulch cropping systems.

Conservation Tillage – Technology That Works

Conservation Tillage Tips

- There is no "one size fits all" system
- Start Small – test new equipment and practices on limited acreage to ensure they will work before starting on the rest of the farm
- Residue Management
  - Size it – flail chopping, straight disk (vertical tillage equipment)
  - Move it – row cleaners
  - Mix it – row cleaners, ditcher
  - Rotate crops – rotate high residue crops with low residue options
- Strip Till
  - Offset strip till operation works well – leave the root ball in the ground
  - Take time to get the strip till operation right – stay straight! A crooked strip till operation will lead to challenges at planting and cultivation and cause irrigation difficulties
- Fertility
  - Deep injection with the strip till unit followed by starter and a side-dress application works well
  - Broadcast applications are not recommended due to lack of incorporation
  - More nitrogen may be needed when initiating conservation tillage due to nitrogen tie-up caused by the residue
- Weed Management
  - May have earlier weed pressure and management requirements
  - Volunteer corn can be a challenge in continuous corn when using Roundup Ready™/LibertyLink varieties
  - Targeted integrated pest management can help control difficult perennial weeds
- Irrigation
  - Flow rates must be closely monitored and adjusted for conditions – very high flow rates cause increased residue damming, blown out furrows, and other issues
  - May need to level field before beginning system
  - Be ready to irrigate up (if needed) – having beds and furrows early in the season (before the crop is up) can reduce issues related to bedding up with small plants in the field

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