

# A decade of advances in cover crops

Jorge A. Delgado, Merlin A. Dillon, Richard T. Sparks, and Samuel Y.C. Essah



**Jorge A. Delgado** is a soil scientist at the Soil Plant Nutrient Research Unit, USDA Agricultural Research Service, Fort Collins, Colorado. **Merlin A. Dillon** is an extension agronomist and **Samuel Y.C. Essah** is a horticultural research scientist at the San Luis Valley Research Center, Colorado State University, Center, Colorado. **Richard T. Sparks** is an irrigation water management specialist for the USDA Natural Resources Conservation Service, Center, Colorado.

**C**over crops have been defined as crops grown to protect the soil from erosion losses and losses of nutrients via leaching and runoff (Reeves 1994). This definition was expanded in the *Encyclopedia of Soil Sciences* to those crops that are grown for improving soil, air, and water conservation and quality; nutrient scavenging, cycling and management; increasing populations of beneficial insects in integrated pest management; and/or for short-term (e.g., over-winter) animal-cropping grazing systems (Delgado et al. 2006). A detailed review on the use of winter cover crops for weed suppression and integrated pest management was presented by Dabney et al. (2001).

Several researchers have reported the benefits of cover crops to reduce sediment off-site transport (Frye et al. 1985; Mutchler and McDowell 1990; Holderbaum et al. 1990; Bilbro 1991; Langdale et al. 1991; Decker et al. 1994; Dabney 1998; Delgado et al. 1999). Additionally, several studies have reported the impacts of cover crops increasing nutrient use efficiencies (Lal et al. 1991; Lal 1997; Reicosky and Forcella

# Cover crops with limited irrigation can increase yields, crop quality, and nutrient and water use efficiencies while protecting the environment.

1998; Staver and Brinsfield 1998; Delgado 1998; Groffman et al. 1987; Meisinger et al. 1991; Shipley et al. 1992). Our multidisciplinary team studies found that cover crops can not only scavenge the residual soil nitrate-nitrogen ( $\text{NO}_3\text{-N}$ ) that was leached from the previous crop, they can also reduce the nitrate-nitrogen leaching of the following crop (Delgado 1998; Delgado et al. 2001a, 2001b). Additionally, new advances in modeling tools (Delgado et al. 1998) allow for the evaluation of cover crops as a potential vertical filter to mine nitrate-nitrogen from irrigated water (Delgado 1998; Delgado 2001; Delgado et al. 2001a). By including cover crops into the system, the amount of nitrate-nitrogen leaching was lower than the amount of  $\text{NO}_3\text{-N}$  that was being added to the system with irrigation water.

Our multidisciplinary team has been conducting limited irrigation studies with cover crops since 2003. Our new and recent advances with summer cover crops have shown that they can be grown with limited irrigation and still have large, significant impacts that are positive for the environment and cropping system sustainability while being economically viable.

This article focuses on advances in cover crops during the last decade that are being used by farmers in the San Luis Valley of Colorado and beyond.

## MULTIDISCIPLINARY TEAM APPROACH

Multidisciplinary team efforts can contribute to successful applied research advances that in turn lead to implementation of improved soil and water conservation practices. A good example of long-term research teamwork is the ongoing cooperation between the USDA Agricultural Research Service (ARS) Soil Plant Nutrient Research Unit, Colorado State University (CSU) San Luis Valley Research Center, USDA Natural Resources Conservation Service (NRCS) Alamosa Area Office, and commercial farm operations in the region. Since 1993, our team's efforts involved extensive communication, evaluation of cropping systems across the region, identification of research problems that need to be solved, and the development of applied research alternatives.

This multidisciplinary, multi-agency approach with farmers' cooperation is an example of team efforts that contribute to cutting edge applied research solutions for a given region. Not only do these multidisciplinary efforts contribute to resolve regional problems, they can also contribute to applied research that can be exported to other regions, states, or countries. An example of an impact from our team's cooperation is the isotopic  $^{15}\text{N}$  studies conducted for cover crops and potato rotations in the Pacific Northwest that were established using the same  $^{15}\text{N}$  experimental

design that was used to study  $^{15}\text{N}$  cycling from small grain cropping systems to potato systems in south-central Colorado (Delgado et al. 2004; Collins et al. 2007).

The establishment of these applied research studies for the San Luis Valley also contributed to the development of new concepts and tools that are being applied across other regions in the state and at the national level. Some examples are (1) the new Nitrogen Losses Environmental Analysis Package (NLEAP) model with three-layer capabilities (Delgado et al. 1998), (2) new NLEAP with Geographical Information System (NLEAP-GIS) capabilities (Delgado and Bausch 2005), (3) assessment of delta nitrogen losses at a field level (Delgado et al. 2007b), (4) ongoing NRCS efforts to develop a new Nitrogen Trading Tool (NTT) (Delgado et al. 2007b; Gross et al. 2007), (5) a new nitrogen index (Delgado et al. 2006), (6) precision conservation (Berry et al. 2003, 2005), (7) limited irrigation studies (Delgado et al. 2007a), (7) international cooperation with the Swiss National Science Foundation, Zurich, Switzerland, and the transfer of new conservation technologies to the National Institute of Forestry, Agricultural and Animal Research, Mexico, and (8) cover crops for economical sustainability (Delgado et al. 1999).

## RESEARCH AND IMPLEMENTATION ON COMMERCIAL FARM FIELDS

Dabney et al. (2001) reported that there have been a large number of studies across the United States showing the benefits of cover crops. However, besides the well-known benefits of cover crops, these systems are still not as widely used as possible. Our multidisciplinary team has been conducting studies in the south-central Colorado region since the early 1990s (Delgado et al. 1998, 1999; Delgado 1998). Initially, these cover crop studies conducted from 1993 to 1999 focused on the use of winter cover crops to develop practices to reduce wind erosion and protect water quality. Cover crops are currently

### Figure 1

Agricultural Research Service soil scientist Jorge A. Delgado (left) and farmer Keith Holland talking about the stage of growth and biomass production of sorghum-sudan aboveground biomass produced with limited irrigation in a potato-summer cover crop rotation system under commercial field operations.



Note: Photo by Joseph Willson, USDA Agricultural Research Service.

being used in the region by farmers.

The San Luis Valley, with over 2,000 center-pivot irrigated fields, is one of the leading fresh-market potato (*Solanum tuberosum* L.) producing areas in the United States and produces about 90% of Colorado's fresh market. Since the dominant soils across the region are sandy soils with low soil organic matter content and high in pH levels, crops that are susceptible to micronutrients can show deficiencies of iron, zinc, and other nutrients. These coarse textured soils are also susceptible to nitrate-nitrogen leaching, especially for irrigated crops with shallow root systems (Eddy-Miller 1993; Delgado 1998, 2001). Additionally, wind erosion has been identified as an event that can affect the off-site transport of nitrogen, recalcitrant organic matter, and soil particles, especially during the spring when winds are stronger and fields are left with low levels of crop residue after a potato or vegetable harvest (Pannell et al. 1973; Delgado 1999; Al-Sheik et al. 2005).

This semi-arid western United States region has limited water resources. The

San Luis Valley of south central Colorado has been affected by droughts during the last decade. Concerns exist that these extended drought periods have reduced the recharge rates of underground water resources for this region of Colorado, and there have been recommendations to cut back on the amount of irrigated acreage. Limited irrigation concepts, such as those applied in other regions (Hu et al. 2005), can be an alternative to developing sustainable cropping systems. Our multidisciplinary group has been working with farmers to develop viable applied research alternatives that can be used by farmers to reduce wind erosion, reduce off-site transport of nutrients and soil particles, reduce leaching, increase nutrient and water use efficiencies, and maximize yield production while protecting the environment (see figure 1).

Since the early 1990s, our team has been trying to develop viable and sustainable systems. We have been conducting applied research to evaluate the potential problems due to losses of nutrients via leaching of nitrate-nitrogen. Wind erosion due to

unprotected soil surfaces contributes to the loss of soil quality, reduction in soil organic matter, and losses of nutrients and important fine particles that are essential for maintaining soil fertility in sandy soil systems. The problem of maximizing the use of water resources was also studied by the team. A key applied research alternative studied was the use of crop rotations as viable tools to develop sustainable systems. The use of cover crops has been studied since the early 1990s (Delgado et al. 1999; Delgado 1998).

Our applied research studies have shown that cover crops can reduce soil erosion, increase nitrogen to the following crop, increase the cycling of macro- and micronutrients to the potatoes, increase nutrient and water use efficiencies, scavenge nitrate that has been already leached from previous shallower crops, and mine nitrate-nitrogen from underground water since the deeper rooted systems simulate vertical filter strips that recover nitrates.

### WINTER COVER CROPS AND THEIR CONSERVATION IMPACTS

Winter wheat and winter rye cover crops are being used in this region in a rotation after potato, lettuce, or other vegetable harvests. They are excellent crops to grow after a short summer vegetable, such as lettuce, which is harvested by August (see figure 2). There are a large number of degree days after the harvest of lettuce or spinach, which allows for a significant growth period of winter cover crops before winter kill. This fast growth allows for a rapid recovery of soil nitrate-nitrogen from the soil profile; keeps the soil cover, which minimizes the erosion; and can serve as a source of grazing during the winter for animals.

Winter cover crops scavenge an average of 100 to 178 lb of N per acre and up to 300 lb of N per acre when they are grown in vegetable potato systems with high residual soil nitrate-nitrogen. Early planted cover crops planted after spinach and lettuce can scavenge from 100 to 200 lb of

**Figure 2**

Richard T. Sparks, NRCS irrigation water management specialist (left), and Jorge A. Delgado, Agricultural Research Service soil scientist, evaluating a winter cover crop field.



Notes: Winter cover crops can be planted after the harvesting of potato. Photo by Stephen Ausmus, USDA Agricultural Research Service.

**Figure 3**

Inspecting incorporation of aboveground biomass cover crop residue under commercial field operations.



Note: Photo by Juan Herrera, formerly at the USDA Agricultural Research Service, now at the Swiss Federal Institute of Technology.

$\text{NO}_3\text{-N}$  per acre and up to 300 lb of  $\text{NO}_3\text{-N}$  per acre. The winter cover crop reduced the nitrate-nitrogen available in the soil profile to leach by up to 184 lb of  $\text{NO}_3\text{-N}$  per acre. Since nitrate-nitrogen is a high mobile element that is susceptible to be transported below the root zone to underground water resources, by scavenging these large quantities of nitrate-nitrogen, these cover crops contribute to protecting water quality. Additionally, these early planted winter cover crops can return a large amount of biomass that is beneficial for these soils that are mainly sandy coarse soils with low soil organic matter. The amount of dry biomass returned to the surface can average 3.4 dry weights per acre for the early planted winter cover crop.

The winter cover crops can be planted after the harvesting of potato in late August, early September, and October. Although these later planted winter cover crops recover smaller quantities of available soil nitrate-nitrogen and have nitrogen uptake ranges from 15 to 70 lb of N per acre, they are still significant and contribute to reducing nitrate-nitrogen leaching and off-site transport due to wind erosion.

We conducted sequential analyses of cropping systems and found that by using deeper rooted crops, such as winter cover crops, the deep rooted systems scavenge nitrate-nitrogen that was already leached from the previous shallow lettuce crop, and by reducing and cleaning the soil profile from nitrate-nitrogen that is available to leach, the losses of nitrate-nitrogen from the next year with the potato crops were also lower (Delgado 1998, 2001). Additionally, as these cover crops are irrigated with underground water that has high nitrate-nitrogen water content, the cover crops with deep rooted systems act as a reclamation crop that mines nitrate-nitrogen from underground water (Delgado 1998, 2001; Delgado et al. 2001a, 2001b). Deeper rooted systems, such as malting barley, winter wheat, and winter rye reduces the net nitrate-nitrogen leaching losses, mining, and recovering

nitrate-nitrogen from underground water resources.

The incorporation of these small grain systems with potato rotations and the incorporation of crop residues also contribute to the sequestration of carbon and nitrogen in the particulate organic matter of these irrigated sandy soils (Al-Sheikh et al. 2005; see figure 3). Studies conducted across the region have found that cover crops can contribute to maintaining high levels of soil organic matter levels, reducing losses of fine particles, and maintaining the nutrient levels for soils that are susceptible to wind erosion and particulate organic carbon (Al-Sheikh et al. 2005). These deeper rooted systems have the potential to contribute to precision conservation (Berry et al. 2005) and can be used to scavenge higher amounts of nitrogen from the areas of the field with higher residual soil nitrate-nitrogen (Delgado 1998, 2001; Delgado et al. 2001a).

#### Figure 4

Samuel Y.C. Essah, Colorado State University horticultural research scientist, Jorge Delgado, Agricultural Research Service soil scientist, and Merlin A. Dillon, Colorado State University extension agronomist, inspect cover crops grown under commercial farm operations.



Notes: From 2001 to 2006, the team studied green manure cover crops—canola, sorghum-sudan, sorghum-sudan hay, and white mustard—on aboveground biomass production and cover crop effects on nutrient cycling. Photo by Juan Herrera, formerly at the USDA Agricultural Research Service, now at the Swiss Federal Institute of Technology.

#### SUMMER COVER CROPS AND THEIR CONSERVATION IMPACTS

The average cover crop dry matter production with limited irrigation for the summer cover crops studied was 3,000, 4,300, 4,500, and 6,261 lb per acre for sorghum-sudan, mustard, radish, and canola, respectively (Delgado et al. 2007a; see figure 4). The sorghum-sudan extracted twice the amount of copper and manganese than radish, canola, or mustard. Additionally, the sorghum-sudan zinc content was higher than that of the mustard and canola. These data suggest that sorghum-sudan has a higher potential to cycle these micronutrients into a potato crop.

Our four-year summer cover crop studies suggest that increasing the cycling of macro- and micronutrient content in the aboveground biomass of the sorghum-sudan is also cycling these nutrients to the potato rotation (see figure 5). We defined the micronutrient cycling use efficiency as the following:

## Figure 5

Nitrogen cycling studies to assess the effect of aboveground biomass using the Delgado et al. (2004) method to assess nitrogen cycling from cover crops to potato systems.



**Notes:** Note the large aboveground summer crop biomass produced with limited irrigation (seven inches) and the potential to cycle nutrients into potato systems under commercial operations. These crops are being grown and incorporated for environmental protection and to grow a higher yield and better tuber quality crop. Photo by Jorge A. Delgado, USDA Agricultural Research Service.

micronutrient cycling use efficiency = (micronutrient content of potato in potato plots following sorghum-sudan cover crop – micronutrient content of potato in tuber plots following fallow plots) / aboveground biomass micronutrient content) × 100.

We defined the macronutrient cycling use efficiency in a similar way. We measured the macro- and micronutrient cycling from the aboveground biomass to the cover crops and to the tubers. We calculated that the copper, manganese,

and zinc use efficiencies of the sorghum-sudan aboveground cover crop were 4%, 19%, and 4%, respectively (Delgado et al. 2007a). The potassium, calcium, and magnesium sorghum-sudan cover crop nutrient use efficiencies were 3%, 22%, and 40%, respectively (Delgado et al. 2007a). Preliminary results suggest that the correlation of yield and nutrient levels indicate that the response can be directly correlated to nutrient cycling.

The total marketable tuber yield, which was increased by 12% to 30% when potatoes followed a sorghum-sudan green manure instead of wet fallow plots. For the potatoes following sorghum-sudan, there was a superior tuber quality, with 40% higher production for tubers greater than 8 ounces. These preliminary results show that there is the potential to generate additional income (\$60.00 to \$400.00 per acre), enough to offset the cost and management of the cover crop. We conducted an analysis of delta nitrogen losses with these rotations, and we found a potential for large reductions in nitrogen losses when using a summer cover crop rotation with a potato rotation (Delgado et al. 2007a; see figure 6).

## Figure 6

Incorporating the summer cover crops.



**Notes:** Potato tubers will be planted, and they will be monitored under commercial farming operations. Note the difference in crop residue between the fallow (no cover crop grown) and the summer cover crop sorghum-sudan in front. The brassica cover crop is located in the back. Photo by Daniel Manter, USDA Agricultural Research Service.

### LIMITED IRRIGATION COVER CROPS

Since the early 2000s, we began studies to look for alternative summer crops that could be grown with limited irrigation (see figure 7). These recent summer cover crop studies under commercial farm fields have shown that potato tuber yields can be increased if a summer sorghum-sudan crop is grown with limited irrigation, harvested for hay, or an aboveground sorghum-sudan incorporated crop is grown before the potato crop; the yields increased by 12% to 30% when compared to a wet fallow system. These limited irrigation sorghum-sudan crops not only increased the yield, but there was also higher potato tuber quality—40% of the tubers weighed more than 8 ounces. The area in summer cover crops has been increasing significantly during the last two years and is

**Figure 7**

Irrigated potatoes (left) and recently planted summer cover crop with limited irrigation (right).



**Note:** Photo by Juan Herrera, formerly at the USDA Agricultural Research Service, now at the Swiss Federal Institute of Technology.

**Figure 8**

The tuber production yield and quality for the potato following sorghum-sudan plots were significantly higher (tubers on the right side) than the production following a wet fallow plot (tubers on the left side).



**Note:** Photo by Jorge A. Delgado, USDA Agricultural Research Service.

currently about 6,000 acres (10% of the potato area).

Potato crops can use 18 to 20 inches of irrigation water. One alternative that would minimize the use of irrigation water across a region is to use a summer cover crop with limited irrigation water of 6 to 7 inches. The amount of water used would still be lower than the average amount of irrigation water needed by alfalfa (26 to 28 inches), small grains such as barley (15 to 17 inches), or winter wheat (17 to 19 inches). A low input cover crop will reduce the need for pumped water by greater than 50%, protect water quality with a lower chemical and fertilizer dependence, and will not require any fertilizers to be used that would reduce nitrate-nitrogen leaching. Not only will

the summer crops reduce nitrate-nitrogen leaching, but they will significantly reduce the leaching from the following potato growing systems and even scavenge nitrate-nitrogen from background irrigated water. Farmers can use the summer cover crops for hay or can incorporate it to the soil. We found that sorghum-sudan hay treatments also increased tuber quality and tuber production above the fallow systems (see figure 8). A summer cover crop (hay) can reduce water use and be a viable alternative in the region with large, positive environmental impacts. Cover crops reduced soil profile nitrate and water content, minimizing the net nitrate leaching under vegetables and potato crops, even mining nitrates from underground water.

## SUMMARY AND CONCLUSIONS

In summary, our multidisciplinary, multi-agency cooperation team has been developing sustainable cropping systems that reduce the environmental impacts, conserve soil and water quality, and even improve soil and water quality that will increase and maintain yields and crop quality. The erosion and losses of soil particles are being decreased across the region with these practices. The leaching of nutrients to the underground water is being reduced and the sequestration of carbon and nitrogen is being increased with these new practices.

The area under summer crops is being expanded, and farmers are currently harvesting the products of this applied

research. This joint ARS, CSU, NRCS, and farmer cooperation has contributed to expanding the use of cover crops across the San Luis Valley region to maintain and increase yields while protecting the environment. Communication and team efforts are essential for developing sustainable and viable vegetable and potato cropping systems. By bringing farmers to the conservation efforts, the applied research efforts are already being disseminated from the start. The impacts of these joint cooperation efforts are also being applied in other regions and countries with projects that invite postdoctoral and visiting scientists to participate.

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