27

Cover Crops: Progress and Outlook

Eileen J. Kladivko

Past Use and Understanding of Cover Crops

Cover crops are literally "crops that cover the soil" in agricultural fields during times of the year when the soil is typically fallow. The classic purposes of cover crops have been to protect the soil against water and wind erosion and to increase soil productivity by providing nitrogen (N) as green manures. Many ancient cultures, including those in China, the Middle East, and Rome, used cover crops as green manures to improve soil fertility (Lal 2015). American colonists and early settlers used cover crops to restore land that was "worn out" from continuous cropping. Thomas Jefferson planted "green dressings" as a normal part of his crop rotations, to ameliorate the soil, provide fertility for the succeeding cash crop, and not leave his fields fallow to grow weeds (Betts 1953). His farm book (Betts 1953) includes interesting correspondence with contemporaries, including George Washington, about new plants and how well they worked for different purposes—an 18th century example of farmers learning from other farmers to find cover crops that fit different niches!

Research during the early part of the 20th century included many topics familiar today. The motivation for much of the work was the reduction of fertility in agricultural lands and the recognition that there was little remaining virgin land to bring into crop production. Prior to the widespread availability of inorganic N fertilizers, green manures were a common method to fertilize the main crop. The microbiologist Selman Waksman, however, disagreed with the chemists of the time who suggested that N, phosphorus (P), potassium (K), and pH were the only aspects of importance for crop production, and he articulated many of the benefits of soil organic matter that went beyond

Eileen J. Kladivko is a professor in the Department of Agronomy at Purdue University, West Lafayette, Indiana.

fertility. He studied decomposition of green manures and elucidated many principles and concepts we know today about carbon (C):N ratios, the rapidity of decomposition, and the balance between mineralization and immobilization of N (Waksman 1929). Löhnis (1926) stated that N availability from green manures depended on quality and quantity of the green manure as well as the time of application and quality of the soil. He cautioned against incorporating N-rich green manures in fall if there was not going to be a crop planted until the following spring, as the N would be released and "washed away by a few heavy rains."

Pieters and McKee (1938) suggested that if legume green manures were turned under in the fall, then a cereal should be planted to capture the N released for later use. Their chapter in the *Yearbook of Agriculture* (1938) also provided many other recommendations for how to use cover and green manure crops as well as a listing of many of the common cover crops of the time. In this chapter and other writings (Pieters and McKee 1929), they discussed the importance of identifying the main purposes of the cover crop/green manure crop, for both selection of the appropriate species and its subsequent management for each region, soil type, and cash crop. It's interesting to note their comments on the lack of reliable seed supply, the need for practical economics analyses, and the need to consider green manures as an investment in the same way as lime or fertilizers.

Progress to Present: Key Milestones

During the 75 years in which the Soil and Water Conservation Society has been in existence, cover crops have waxed and waned in their importance in our agricultural systems (figure 1). The Dust Bowl galvanized attention on the state of US soils and our ability to sustain agricultural productivity over the long term. Soil conservation practices were researched and implemented to reduce erosion by water and wind. Hugh Hammond Bennett, in his text on soil conservation (1939), stated, "Soil completely covered with vegetation is in an ideal condition to absorb moisture and resist

Figure 1

Cereal rye cover crop in southeastern Indiana. Photo by Eileen Kladivko.

the inroads of erosion, provided the cover is continuous and the soil is well permeated with roots." Later he discussed seasonal cover crops as a way to keep the soil protected during times of the year when the regular crop is off the ground. In addition to erosion control, he identified cover crops as useful for "conserving those soluble plant nutrients subject to loss by leaching," and adding organic matter to the soil.

Cover crop use took a giant step backward during much of the 1960s and 1970s, as the "miracles of chemistry, genetics, and machinery" increased crop yields tremendously and masked the deterioration of the soil. Maintaining or building soil organic matter was not seen as important, because crop yields continued to increase with improved genetics and more fertilizer, and soil degradation and loss were overcome with tillage by larger, faster, and more powerful machinery. In addition, as farmers changed from small, mixed grain, forage, and livestock farms to larger, more specialized grain production farms, they no longer had a specific reason to grow forage crops or cover crops for livestock feed. Cover crops were not seen as necessary or important. Nitrogen fertilizer was inexpensive and readily available, so the use of cover crops as green manures was not needed. Erosion was still a problem, but the more powerful tillage machinery could till more acres, remove compaction, fill in rills and ephemeral gullies, and mix shallower topsoils with underlying soil to allow for continued high crop production. Much of the knowledge and experience of cover crops was likely lost during this "dark ages" of cover crops.

As no-till planting and other conservation tillage systems evolved from experimental to practical through the 1970s and 1980s, cover crops were seen as an addition to no-till to improve fertility, to enhance weed control, to increase surface cover, and to ameliorate compaction. In South America, cover crops were often considered as a natural complement to no-till. In the United States, studies on using legume cover crops for N production for no-till corn were implemented. Conferences and special publications documented the knowledge and research needs for better integration of legumes into these systems (Power 1987).

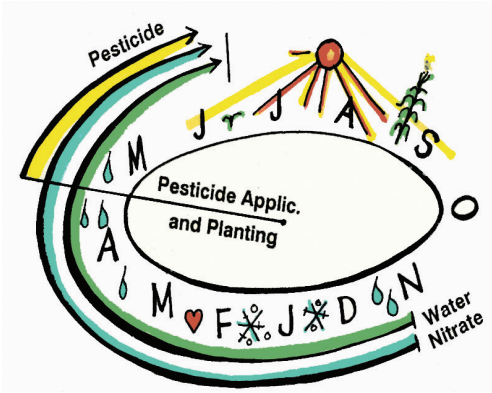
Work on cover crops started increasing significantly in the 1990s and has really exploded over the past decade or so. Topics being studied have expanded much beyond the earlier interests in erosion and green manuring. Key drivers for both researchers and farmers have been the concerns about water quality and soil health, but many other topics have also become of interest.

Water Quality. Concerns about water quality, both locally and in places like the Gulf of Mexico and the Chesapeake Bay, drove interest in the potential role of cover crops in reducing nitrate leaching and in controlling erosion

and loss of sediment-bound phosphorus in surface runoff. Many researchers have documented reductions in nitrate loads from agricultural fields by growing cover crops during the fallow periods of grain crop rotations (Kaspar et al. 2012; Kladivko et al. 2014), and cover crops are now part of the nutrient loss reduction strategies of many states (figure 2). Phosphorus losses with sediment are generally reduced by cover crops due to their reduction of erosion, but effects on soluble phosphorus are less clear (Blanco-Canqui 2018).

Figure 2

Cycle of the year illustrating times of corn growth (or other summer annual crop), fallow periods, and times with drainage and nitrate leaching. Cover crops can help fill the fallow periods in fall and possibly spring. Illustration by Lou Jones.



Soil Health. Interest in soil health among farmers and researchers has skyrocketed in the past decade, in part due to a strong educational effort by the US Department of Agriculture's Natural Resources Conservation Service. The basic rationale behind the use of cover crops to improve soil health is to have a living, growing plant for more months of the year than our typical annual cropping systems do, thus shortening fallow periods (figure 3). This concept applies whether the purpose is soil erosion and nitrate leaching management, as articulated by Bennett (1939), or whether the goals are broader and include feeding soil organisms, building soil organic matter, improving soil

Figure 3

Corn silage field with and without cereal rye cover crop in Iowa. Photo by Tom Kaspar.

physical properties, and improving overall productivity (Kaspar and Singer 2011; Fisher 2020).

Nutrient Cycling. Nutrient cycling is one aspect of the larger soil health umbrella affected by cover crops. Studies include both the use of legumes to produce N and the use of nonlegumes to scavenge and recycle N. Many questions are being asked, including the amount of N produced or scavenged and the timing and amount of N released, for both shoots and roots for different cover crops, soil types, and locations. Some recent work discusses managing the tradeoffs between N supply and N retention when growing cover crop mixtures (White et al. 2017), as an example of the complex interactions occurring.

Crop Yield. Cover crop effects on cash crop yield is of major interest to farmers as well as researchers. Because cover crops improve soil health, cover crops might be expected to have uniformly positive yield effects. Unfortunately, yield effects vary with the type of cover crop and cash crop, and the specific management practices used in the study. A meta-analysis by Marcillo and Miguez (2017) showed a neutral to positive yield response of corn to cover crops, with more positive responses occurring with legume cover crops, as expected due to N contributions from the legume. Soybeans have in general shown more positive yield responses to cover crops than has corn, although yield response is also sometimes neutral. Although yield improvements are usually a goal, the bottom line profitability may still be improved even when yields are not, due to a variety of other factors (Myers et al. 2019). Even so, understanding why cover crops have not consistently improved crop yields over the long term will allow us to reach the full potential of cover crops.

Water Conservation. Cover crops protect the soil surface and often lead to increased infiltration and less evaporation, thus conserving water for use later in the growing season. The effectiveness of cover crops in improving crop water supply depends very much on the management of the cover crop system, and whether water supply is a primary purpose of the manager or not (Ogilvie et al. 2019).

Climate Resiliency, Greenhouse Gas Emissions, and Carbon Sequestration. Improving resilience to climate stresses has become of great interest over the past decade, along with contributing to mitigation of climate change by sequestering carbon and reducing greenhouse gas emissions. Recent meta-analyses have reviewed the literature about cover crops for both mitigation and adaptation (Kaye and Quemada 2017). Overall the authors noted very few tradeoffs between the adaptation and mitigation purposes for cover crops, suggesting that researching and promoting cover crops for ecosystem services related to climate resiliency would be synergistic with services related to

mitigation. Increased climate resiliency may arise from cover crop impacts on water infiltration and retention, erosion control, nutrient cycling, and overall soil health.

Grazing and Forage. One of the places where cover crops may provide economic benefit over the short term is when they can be grazed by livestock or cut for forage (Myers et al. 2019). Farmers have implemented numerous variations on the theme, including single species covers or simple or complex mixtures of covers. They gain the forage value of the cover along with soil health improvements from the cover crop roots and the shoot growth remaining after grazing/cutting, along with manure from the grazing animals.

Pest Control (Weeds, Insects, and Natural Predators). Cover crops may have effects on weeds, insects, natural predators, and diseases. Work is being conducted on the balance between pests and beneficials, for example, and management strategies to increase populations of natural predators. Similarly, research on the impact of cover crops on soil fungi and bacteria in terms of diversity and presence of both beneficial and pathogenic species is ongoing. The ability of cover crops to suppress weeds is also highly dependent on the specific cover crops and management practices used, including planting and termination dates of the covers, seeding rates, tillage system, and other weed management practices used (Osipitan et al. 2019). The challenge of herbicide-resistant weeds in some locations has provided extra motivation for research on cover crop alternatives for control of these weeds.

Economics. As mentioned earlier, the economics of integrating cover crops into a cropping system is of paramount importance to farmers. Although the many benefits to soil health and water quality are well known, they often don't provide an immediate economic benefit to the farmer in terms of yield increase or input cost decrease. Myers et al. (2019) provided an assessment that includes some less obvious ways that cover crops can pay over the shorter term, before yield increases are evident. Some of the potentially short-term benefits have already been discussed (grazing, herbicide resistant weeds, soil moisture management), but others include ameliorating soil compaction, speeding up the transition to no-till, and sequestering manure nutrients. The report also reminds readers to consider cover crops as an investment, akin to some other actions like lime addition or new machinery purchases, that may not pay off in the first year.

Tools Developed to Facilitate Progress. Modern no-till planters and drills have been crucial to the adoption of cover crops as well as for no-till cash cropping itself. Being able to no-till the cover crop in fall into the cash crop residues saves time, allowing farmers to seed covers immediately after harvest without waiting to do fall tillage. Likewise, terminating the cover crop in

spring and no-till planting the cash crop into the cover crop, without needing multiple tillage passes to incorporate the cover crop, saves time and increases options for the farmers. In fields that are not in a no-till system, the ability of cover crop seeding implements to establish a stand quickly in the fall are still key. Other innovations for seeding cover crops, like high-clearance seeders, aerial seeders, interseeders, and planters that work well for "planting green" (planting cash crop into still living cover crops), are increasing the options for getting covers established. Improved herbicide technology and development of roller-crimpers have allowed for termination of cover crops without the necessity of tillage, for those covers that are winter-hardy.

Progress to Present: Lessons Learned

Research and farmer experience over the past 75 years have provided many advances in knowledge and practice along with some lessons learned. First, there is a learning curve for farmers, researchers, crop advisors, and others as they start to integrate cover crops into their farming operation or their research studies. Management practices must be tailored to the site, cropping system, machinery, logistics, and available time and labor. Additionally, the intended purpose of the cover crop is important. Management practices and timing that might be best for one cover crop purpose may cause problems or failure for another purpose. For example, growing large amounts of a grass cover crop may be best for N scavenging and weed suppression, but can cause cash crop yield declines due to N immobilization. Conversely, if a cover crop is planted too late or does not overwinter and there is very little growth, then it is unlikely to provide any benefits regardless of the purpose. Not only does the cover crop management need to be tailored to the purpose, but the overall cropping system management will likely need to be modified to integrate cover crops successfully. There are numerous examples of farmers or researchers saying that a new practice "doesn't work," when in fact the management was inappropriate for the site and the desired purpose. Some of this learning must occur through trial and error as the practice is adapted to the cropping system, machinery, and logistics of a particular operation. Some of the learning, however, should occur by reading previous work and talking with farmers and others with experience. Thus, today there are many efforts to facilitate learning of farmers, advisors, and researchers in field days, workshops, and outreach materials of many types.

Plans for the Future

A recurring theme is that both the selection and the management of a cover crop depends on the specific purpose for the cover crop and on the specific

soil, climate, and cropping system. Thus, future research should include studies of basic principles related to cover crop suitability for different purposes, and locally based studies to evaluate cover crop effectiveness in specific soils, climates, and cropping management systems. Delgado and Gantzer (2015) expressed this idea as the 4Rs for cover crops: choosing the *right* cover crop, seeding and terminating it at the *right* time, and using the *right* management practices at the *right* location.

Future research should continue to build on the knowledge gained over the past 100+ years, related to cover crop effects on crop yields, economics, water quality, soil health, water conservation, pest management, grazing, and resiliency to climate stresses. In particular, more attention is needed on (1) site specific selection and management for specific purposes; (2) multifunctional cover crop systems to meet several purposes in an optimized way, including the use of multispecies mixes; (3) cover crop breeding and selection for different purposes and environments; (4) how long it takes for measurable benefits to occur and ways to speed up this process; (5) practical economics at the farm scale for better accounting of cover crop benefits; and (6) improved technologies for cover crop seeding and termination, especially given a changing and variable climate.

An important goal for policymakers would be to remove various disincentives and barriers that hinder cover crop adoption and innovation by farmers. This includes integrating cover crops into regular farm policy, programs, and crop insurance. It may also include new types of incentives that reward farmers for using cover crops for the many ecosystem services they provide.

New opportunities for agribusiness have been opened by the increased interest in cover crops. Advice and service can include helping customers evaluate their desired goals for cover crops, developing site-specific recommendations for their fields, and offering seeding and termination services. As labor and cover crop expertise are often limited on many farms, co-ops and other agricultural infrastructure have an opportunity to provide timely service to increase cover crop adoption.

Cover crops have many benefits and offer new opportunities to improve crop production, the environment, and the agricultural economy. There is momentum surrounding cover crops, and the time is ripe to integrate cover crops more fully into our modern agricultural systems to reap their full potential!

Resources to Learn More

- Clark, A. 2007. Managing Cover Crops Profitably, 3rd ed. College Park, MD: Sustainable Agriculture Research and Education.
- Midwest Cover Crops Council (MCCC). http://mccc.msu.edu
- Northeast Cover Crops Council (NECCC). http://northeastcovercrops.com/
- Southern Cover Crops Council (SCCC). https://southerncovercrops.org/
- Sustainable Agriculture Research and Education (SARE). https://www.sare.org/
- USDA Natural Resources Conservation Service (NRCS), Soil Health. https://www.nrcs.usda.gov/wps/portal/nrcs/main/soils/health/
- Western Cover Crops Council (WCCC). https://westerncovercrops.org/

References

Bennett, H.H. 1939. Soil Conservation. New York: McGraw Hill.

Betts, E.M. 1953. Thomas Jefferson's Farm Book. With commentary and relevant extracts from other writings. Charlottesville: American Philosophical Society and University Press of Virginia.

Blanco-Canqui, H. 2018. Cover crops and water quality. Agronomy Journal 110:1633-1647.

Delgado, J.A., and C.J. Gantzer. 2015. The 4Rs for cover crops and other advances in cover crop management for environmental quality. Journal of Soil and Water Conservation 70(6):142A-145A. https://doi.org/10.2489/jswc.70.6.142A.

Fisher, B. 2020. Building resilient cropping systems with soil health management. *In* Soil and Water Conservation: A Celebration of 75 Years, eds. J.A. Delgado, G.F. Sassenrath, and C.J. Gantzer. Ankeny, IA: Soil and Water Conservation Society.

Kaspar, T.C., D.B. Jaynes, T.B. Parkin, T.B. Moorman, and J.W. Singer. 2012. Effectiveness of oat and rye cover crops in reducing nitrate losses in tile drainage water. Agricultural Water Management 110:25-33.

Kaspar, T.C., and J.W. Singer. 2011. The use of cover crops to manage soil. *In* Soil Management: Building a Stable Base for Agriculture, eds. J.L. Hatfield and T.J. Sauer. Madison, WI: American Society of Agronomy and Soil Science Society of America.

Kaye, J.P., and M. Quemada. 2017. Using cover crops to mitigate and adapt to climate change. A review. Agronomy for Sustainable Development 37:4, doi: 10.1007/s13593-016-0410-x.

Kladivko, E.J., T.C. Kaspar, D.B. Jaynes, R.W. Malone, J. Singer, X.K. Morin, and T. Searchinger. 2014. Cover crops in the upper midwestern United States: Potential adoption and reduction of nitrate leaching in the Mississippi River Basin. Journal of Soil and Water Conservation 69(4):279-291. https://doi.org/10.2489/jswc.69.4.279.

Lal, R. 2015. Soil carbon sequestration and aggregation by cover cropping. Journal of Soil and Water Conservation 70(6):329-339. https://doi.org/10.2489/jswc.70.6.329.

Löhnis, F. 1926. Nitrogen availability of green manures. Soil Science 22:253-290.

Marcillo, G.S., and F.E. Miguez. 2017. Corn yield response to winter cover crops: An updated meta-analysis. Journal of Soil and Water Conservation 72(3):226-239. https://doi.org/10.2489/jswc.72.3.226.

Myers, R., A. Weber, and S. Tellatin. 2019. Cover crop economics: Opportunities to improve your bottom line in row crops. Sustainable Agriculture Research and Education Technical Bulletin. https://www.sare.org/resources/cover-crop-economics/.

Ogilvie, C.M., W. Deen, and R.C. Martin. 2019. Service crop management to maximize crop water supply and improved agroecosystem resilience: A review. Journal of Soil and Water Conservation 74(4):389-404. https://doi.org/10.2489/jswc.74.4.389.

Osipitan, O.A., J. A. Dille, Y. Assefa, E. Radicetti, A. Ayeni, and S.Z. Knezevic. 2019. Impact of cover crop management on level of weed suppression: A meta-analysis. Crop Science 59:833-842.

Pieters, A.J., and R. McKee. 1929. Green manuring and its application to agricultural practices. Agronomy Journal 21:985-993.

Pieters, A.J., and R. McKee. 1938. The use of cover and green-manure crops. *In* Soils and Men. USDA Yearbook of Agriculture. Washington, DC: US Government Printing Office.

Power, J.F., ed. 1987. The Role of Legumes in Conservation Tillage Systems. Ankeny, IA: Soil Conservation Society of America.

Waksman, S.A. 1929. Chemical and microbiological principles underlying the decomposition of green manures in the soil. Journal of the American Society of Agronomy 21:1-18.

White, C.M., S.T. DuPont, M. Hautau, D. Hartman, D.M. Finney, B. Bradley, J.C. LaChance, and J.P. Kaye. 2017. Managing the trade off between nitrogen supply and retention with cover crop mixtures. Agriculture, Ecosystems and Environment 237:121-133.