A PACIFIC NORTHWEST EXTENSION PUBLICATION

Washington State University | Oregon State University | University of Idaho

BIOFUMIGANT COVER CROPPING IN POTATOES: DALE GIES

Farmer-to-Farmer Case Study Series: Increasing resilience among farmers in the Pacific Northwest

PNW PEER REVIEWED
PNW693

BIOFUMIGANT COVER CROPPING IN POTATOES: DALE GIES

By
Georgine Yorgey, Center for Sustaining Agriculture and Natural Resources, Washington State University. **Sylvia Kantor**, Center for Sustaining Agriculture and Natural Resources, Washington State University. **Chad Kruger**, Center for Sustaining Agriculture and Natural Resources, Washington State University. **Kathleen Painter**, Department of Agricultural Economics & Rural Sociology, University of Idaho. **Hilary Davis**, Department of Agricultural Economics and Rural Sociology, University of Idaho. **Leigh Bernacchi**, Department of Agricultural Economics and Rural Sociology, University of Idaho

Abstract

Dale Gies grows potatoes, wheat, and seed crops for vegetables and cover crops under irrigation near Moses Lake, Washington. In this publication, Gies discusses his experiences using a biofumigant cover crop to add organic matter and improve soil quality while successfully suppressing soilborne diseases and nematodes in potatoes.

This case study is part of the Farmer-to-Farmer Case Study project, which explores innovative approaches regional farmers are using that may increase their resilience in the face of a changing climate.

Information presented is based on growers' experiences and expertise and should not be considered as university recommendations. Mention of trade names or commercial products is solely for the purpose of providing specific information and does not imply recommendation or endorsement. Grower quotes have been edited slightly for clarity, without changing the meaning.

Readers interested in other case studies in this series can access them at on the REACCH website, as well as in the WSU Extension Learning Library.

Table of Contents

Biofumigant Cover Cropping in Potatoes: Dale Gies

Location: Moses Lake, WA

Average Annual Precipitation: 8 inches (irrigated cropping)

Cropping System: 2-year rotation of potatoes with winter or spring wheat, plus a biofumigant cover crop (mustard-arugula mix) in late summer after wheat harvest. Other crops grown on the farm include seed crops (mustard and arugula for cover crops, onion, carrot, and others) grown in rotation with wheat and vegetables.

Watch the companion video Mustard Cover Cropping in Potatoes, introducing Dale Gies and his cover cropping system.

Introduction

Dale Gies produces potatoes, wheat, and seed crops for vegetables and cover crops using irrigation from the Columbia Basin Project. He farms land his father started cultivating in 1952 just after the area was converted from native sagebrush. He hopes to one day pass the farm on to his two sons, who currently help in the operation.

With coarse sandy loam soils (Timmerman coarse sandy loam; NRCS 2013), low soil organic matter, and topsoil ranging from 12–36 inches in depth (averaging 18 inches), Gies does everything he can to prevent erosion and build soil quality. Using a reduced tillage system, he adds organic matter with a biofumigant mustard-arugula cover crop. This cover crop improves soil quality while successfully suppressing soilborne diseases and nematodes.

With this system, he has grown potatoes without chemical fumigation, despite his intensive two-year rotation. Conventional wisdom generally dictates a three-year or longer rotation for potatoes to produce a healthy crop, even with fumigation.

Gies also produces seed for vegetables and cover crops (Figure 1), and he consults with farmers around the world to help improve their disease suppression through rotations and biofumigant cover cropping.

Figure 1. Swathing mustard for cover crop seed production. Photo: Andy McGuire.

Innovating to Improve Soil Quality and Pest Suppression

From the beginning of his farming career in 1981, Gies has done things differently than other farmers in his area. He eliminated moldboard plowing, then standard practice in the Columbia Basin for all crops, and disked high-residue crops (generally wheat or corn) into the soil rather than removing them through burning or baling. After disking, he planted directly into the resulting stubble. Gies could see the benefits right away. “It eliminated the plow pan layer, the plants rooted better, the water infiltration was better—all the things we needed. Plus, it saved us a lot of labor and reduced wind erosion.”

But over time, despite these benefits, Gies noticed declining soil quality, especially on his potato acreage. Potatoes take a lot of nitrogen from the soil and require tillage both at planting and harvest. Although fumigants effectively controlled soilborne diseases and pests on his farm, Gies felt that his soil health suffered, noting that chemicals “are a little like chemotherapy in the soil in that they take out the good and the bad [microorganisms].”

Trying to rebuild his soil, Gies experimented with adding additional high-residue crops to his rotation. He tried a number of different possibilities, and ultimately chose mustard due to its desirable qualities. It can be planted late in the season, after a crop with a relatively early harvest, such as wheat. Some mustards are also frost tolerant, which means they can survive later into the fall and thus grow even more biomass to help build up the soil. Unlike wheat, mustard residue decomposes easily, reducing the possibility of problems when planting the following crop.

Biofumigant Properties

As he gained experience using green manure crops (tilled-in cover crops) to improve soil quality, Gies realized that “not all of them are good, as far as diseases and nematodes are concerned. Some of them were nematode hosts, and some of them elevated a number of different diseases.” Even among different mustard varieties, Gies noted variations in the impacts on nematodes and soilborne diseases.

These were surprising but important results for Gies, whose intensive cropping system has the potential for high levels of pest and disease pressure. (Conventional wisdom for potato production requires a minimum of a three-year rotation.) Gies particularly emphasizes the role of nematodes in his system. “A lot of growers don’t even know they have a nematode issue, but it’s eating their lunch.” (Nematodes of concern are described in more detail in the Role of Biofumigant Cover Crops in Managing Soilborne Pests in Potatoes sidebar.) Root knot nematodes (*Meloidogyne chitwoodi* and *M. hapla*) can lead to root lesions or blemishes that can cause processors to reject the crop. Getting an accurate understanding of nematode levels can be difficult due to high variation in samples within the same field.

The Role of Biofumigant Cover Crops in Managing Soilborne Pests in Potatoes

With long season varieties and a warm growing season, potatoes experience significant pressure from soilborne pests and diseases in the inland Pacific Northwest. One major threat is potato early dying (also called *Verticillium* wilt). The disease can be caused by two soilborne fungal pathogens, *Verticillium dahliae* and *V. alboatrum*, either on their own or in combination with root lesion nematodes (*Pratylenchus penetrans*; Rowe and Powelson 2002). Nematodes of concern include the Columbia root knot nematode (*Meloidogyne chitwoodi*), stubby root nematodes (*Paratrichodorus* spp.; a vector for Tobacco rattle virus), and to a lesser extent, the Northern root knot nematode (*M. hapla*; McGuire 2012).

Mustard cover crops have shown potential for managing soilborne pests, including *V. dahliae* and parasitic nematodes (*M. chitwoodi* and *M. hapla*; McGuire 2012; see Matthiessen and Kirkegaard 2006 for a review of the use of *Brassica* for management of soilborne pests and diseases). The pest-suppressing properties of mustard are mainly due to compounds called glucosinolates, though other mechanisms such as development of suppressive soils and systemic plant responses are also likely important (McGuire 2012).

When glucosinolates are incorporated into the soil, they decay and release other chemicals that act as a soil fumigant and weed suppressant. High levels of glucosinolate breakdown are necessary for effective biofumigation and are favored by maximum cell disruption from vigorous physical incorporation, adequate soil moisture, and high soil temperature (Gimsing and Kirkegaard 2009). Soil type and pH are also important because soil type influences loss of active biofumigant compounds and low pH can lead to the generation of alternate breakdown products that may not have biofumigant properties.

Research has compared potato yields following a mustard cover crop with and without chemical fumigation (i.e., metam sodium) on the Gies farm and other farms in the inland Pacific Northwest (McGuire 2012). On the Gies farm, chemical fumigation did not benefit yield or tuber quality compared to no chemical fumigation despite the presence of damaging levels of *V. dahliae* (McGuire 2012). Gies had average yields of 32.5 tons per acre total, and 27.9 tons per acre for US No. 1 potatoes (>4 oz). Levels of parasitic nematodes generally decreased under the mustard cover crop rotation, and no buildup of *V. dahliae* was apparent.

Research results from other farms have been inconsistent. McGuire (2012) notes several possible reasons:

- Length of time using biofumigant cover cropping. The Gies trial had received three biofumigant cover crops over six years, whereas other trials only received one. Benefits may increase over time.
- Biofumigant cover crop management. Different approaches to managing the cover crop (e.g., nutrient management, timing of incorporation) may have impacted the quantity or quality of incorporated biomass.
- Site variability. Differences in pest levels, soil type, or other factors at each location may have been important.
- Potato management. Practices for managing potatoes were different at all locations.

Hoping to enhance his conventional fumigation program, Gies started to look for green manure types, varieties, and mixes with the best nematode- and disease-suppressing qualities. But as he tested green manures known to be highly effective with side-by-side sections that were fumigated with metam sodium (sodium N-methyldithiocarbamate) and non-fumigated, he was surprised to find no difference in potato yield or quality. Intrigued but not convinced, he collaborated with scientists at Washington State University (WSU) to carry out several years of replicated trials on his farm (Figure 2; McGuire 2003a).

After seeing the positive results of these trials, he decided to eliminate fumigation on his potato acreage. Gies laughs as he admits that his neighbors and others were skeptical. “Everybody was like, ‘He’s done.’ But some of my potato crops grown without fumigation were ten tons over the company’s average for that variety. So those were good spuds.”

Figure 2. Trials of biofumigant efficacy at the Gies farm. Photo: Andy McGuire.

Current Biofumigant Cover Cropping System

The biofumigant pest- and disease-suppressing properties of mustard and arugula are due in large part to compounds in mustard called glucosinolates, which break down in the soil to produce other chemicals that act as a soil fumigant and weed suppressant. (See The Role of Biofumigant Cover Crops in Managing Soilborne Pests in Potatoes sidebar.) Gies now uses a mustard-arugula mix to successfully grow potatoes in a two-year rotation. Potatoes are grown the first year. Winter or spring wheat, followed by the mustard-arugula mix, is grown in the second year. He has used that rotation on some of his fields since 1997.

After wheat harvest, Gies grows a cover crop mixture of ‘Caliente 199,’ a blend of Oriental (*Brassica juncea*) and white (*Sinapsis alba*) mustard licensed by the Italian Institute for Industrial Crops (ISCI) and an arugula (*Eruca sativa*) variety named ‘Nemat’. Arugula also contains glucosinolates, but it can act as a nematode trap crop by allowing some nematode species to infect the roots while limiting further development (Figure 3).

Planting

Gies plants his mustard-arugula cover crop around the 10th of August, after his wheat is harvested. In the late summer plantings that Gies uses, the ‘Caliente 199’ mustards tend to dominate the resulting plant population (Figure 4).

Figure 3. A stand of 'Nemat' arugula (*Eruca sativa*) in early June, 2004, with Gies' son Joe. Photo: Gies family

Figure 4. The cover crop mixture of 'Caliente 199' (*Brassica juncea* and *Sinapsis alba*) mustard and 'Nemat' arugula (*Eruca sativa*) in late October, 2007, with Gies' son Mike. Photo: Gies family.

Over time, Gies has refined his strategy for planting the cover crop mix. Originally, he disked the wheat straw residue prior to planting. However, he found that the decomposing wheat straw tied up the available nitrogen in the soil, slowing growth of the cover crop during the late summer. He also realized that weed control in the wheat stubble after harvest was important for getting a good stand of mustard and arugula.

Gies has experimented with various tillage operations prior to planting, including rollers, culti-packers, and harrows, but ultimately settled on a system that he feels gives him the best crop stands with the fewest weed issues (Figure 5). After wheat harvest, Gies plants the mustard-arugula mix into the dry standing wheat stubble with a pneumatic fertilizer spreader, using the boxes that normally hold micronutrients. After he plants and spreads starter fertilizer, he cuts the roots of any existing weeds using an undercutter at a depth of about 2–3 inches (Figure 6). The undercutter, which has overlapping V-shaped blades that run parallel to the soil surface, loosens the soil and helps place the seed in contact with the soil without much burial of the wheat stubble, boosting seedling emergence. An undercutter operation is also relatively fast, averaging 10 or more acres in an hour. Gies emphasizes that speed is important, "because every day we lose in August is like three in October at the end of the growing season."

Figure 5. The cover crop mix emerging through the wheat residue in the first week of September, 2002. Photo: Andy McGuire.

Figure 6. The undercutter Gies uses has 5.5-foot blades that are 5 feet apart. Gies operates the undercutter roughly 2–3 inches below the soil surface. Photo: Dale Gies.

Water and Nutrient Management

The cover crop is irrigated a few days after seeding, as soon as the undercut weeds die. Water and nutrient management are designed to keep the mustard and arugula growing vegetatively (without flowering) as long as possible (Figure 7). This is key to having sufficient levels of the active compounds in the biomass to suppress nematodes and other pests and diseases.

Figure 7. Gies irrigates the mustard-arugula cover crop and applies nutrients to ensure that he gets enough biomass to realize its pest-suppressing and soil-building benefits. Photo: Andy McGuire.

Gies aims to grow a minimum of 2.5 tons of dry matter per acre, and prefers 3–5 tons of dry matter per acre. Since the green cover crop is about 90% water, this translates to 30 to 50 tons wet biomass per acre in the field.

Gies irrigates to supply about 8–10 inches of water to the mustard and arugula cover crop over the course of the growing season. When some of the water needs are met by rainfall, he reduces his irrigation accordingly.

Gies applies 150 lb of ammonium sulfate (21-0-0-24) per acre, which translates into 31 lb of nitrogen (N) and 36 lb of sulfur to the cover crop at planting, with an additional 90–100 lb of nitrogen per acre applied using liquid urea ammonium nitrate (UAN, 32-0-0) in the irrigation water. “You have to be willing to put a little fertilizer on it up front that you’ll get back in the next year’s crop, because you won’t make biomass without nitrogen.” In Gies’ opinion, sulfur is important for building glucosinolates. He normally uses a nitrogen-to-sulfur ratio of five or six to one.

Applying nitrogen to his cover crop allows Gies to reduce nitrogen application on potatoes the following year. With a cover crop, he applies about 30% less nitrogen to the potatoes that follow the cover crop, averaging 230 to 250 lb N per acre, compared to about 350 lb N per acre without a cover crop. Exact amounts of nitrogen application for the potatoes are determined by weekly petiole tests. Overall nitrogen needs will be slightly higher over the entire rotation for a system with a cover crop than for a comparable potato-wheat rotation without cover cropping due to nitrogen application in the cover crop.

Initially, Gies was concerned that decomposing cover crop residue would release nitrogen over the late fall and winter and cause leaching problems as the nitrogen converted to its nitrate form. However, he has found that nitrogen doesn’t leach because the nitrogen remains in the organic form given the cool temperatures. “It hasn’t even converted to ammonium, let alone nitrate form, so it doesn’t move, which is good. We’re getting the nitrogen release from the wheat and mustard-arugula residues about mid-May to mid-June, which is the time we need to have the spuds close the rows in.”

Another advantage to Gies’ irrigation and nutrient management program is that it benefits his wheat residue management. Even with 3–4 tons of wheat straw per acre at harvest, he finds that by October, when the cover crop is tilled in, “the wheat residue is pretty well digested, which is favorable because too much residue can be an issue when planting spuds the following year.”

Pest Management in the Cover Crop

Gies finds that the mustard and arugula cover crop does not create any new concerns for management of weeds, insects, or diseases. With irrigation, the plants grow quickly enough to outcompete weeds. And even with occasional high humidity conditions from overhead irrigation, “the mustard and arugula seem to be nasty enough that most insects aren’t an issue.”

Incorporating the Cover Crop

The cover crop should be flail chopped and incorporated close to but before mustard full bloom (late October in Gies’ case) because glucosinolate levels in the mustard drop after full bloom. Incorporating just prior to full bloom also reduces the danger that the cover crop will set viable seed that could volunteer, causing weed problems elsewhere in the rotation. Gies incorporates his cover crop after he has finished with potato harvest, which helps ensure that he has the labor needed for incorporation. At this point, the mustard is typically close to full bloom.

After flail chopping, Gies immediately incorporates the biomass with an offset disk that has a roller packer or culti-packer pulled behind to seal the soil. If needed, they sometimes make a second pass with a tandem disk. This method is designed to maximize the disease- and pest-suppressing impacts. “If you’re going to make biofumigation work rather than just having a green manure, you’ve got to have a good flail chopper to macerate the biomass. And you’ve got to work the biomass into the soil immediately or you’ll lose your volatile compounds to the atmosphere instead of sealing them in the soil, where they are going to have a lot better suppression activity than they will out in the neighbor’s backyard.” Watch the video clip “Flail Chopping and Incorporating Mustard Cover Crop” to see the flail chopping and incorporation of mustard-arugula cover crop on Gies' farm. Wheat stubble, a longer lasting residue than the mustard and arugula, will also be worked into the ground at this point.

Adequate soil water after cover crop incorporation activates the biofumigation chemistry and helps seal active compounds in the soil. Gies aims for soil water content to be about 80% of field capacity, either by timing incorporation just prior to a forecast rain or by irrigating.

Learning and Collaborating

Gies is naturally curious. He reads research studies to understand the latest developments in diversified vegetable production, has established relationships with researchers around the world, and experiments with side-by-side trials on his own farm.

Gies has collaborated with researchers at WSU and all over the world to improve his system. He has worked with researchers from the Italian Research Institute for Industrial Crops, which has extensively studied biofumigant crops and has developed several mustard varieties specifically for biomass production and glucosinolate content (e.g., Lazzeri et al. 2008).

Gies' collaborations with regional scientists at WSU, OSU, and USDA-ARS have included comparisons of the impact of fumigation and biofumigant cover cropping as well as mustard variety tests (Figure 8). Research trials on his farm have tested how pest-suppressing benefits of mustard cover crops are impacted by planting date, amount of biomass, soil pH, methods and timing of incorporation, soil water content, and other factors (McGuire 2001; McGuire 2002; McGuire 2003b; McGuire 2003c; Collins et al. 2006).

Figure 8. Mustard variety trials on the Gies farm. Photo: Andy McGuire.

Though some of this information is now a decade or more old, Gies still finds it helpful. (See the Resources on Mustard Cover Cropping in Irrigated Systems and Use of Biofumigant Cover Crops in the Irrigated West sidebars.) As he says, "I always looked at it as a cooperative effort that WSU and I became involved with the research institute in Italy that developed the varieties that are currently being used on our farm and around the world."

Among Gies' recent collaborations are two projects that examine the impacts of his farming practices on climate change. First, Gies collaborated on an Italian study that

Resources on Mustard Cover Cropping in Irrigated Systems

Varieties of mustard commonly grown in the irrigated Pacific Northwest include:

- 'Caliente' – a blend of Oriental (*Brassica juncea*) and white mustard (*Sinapsis alba*) licensed by the Italian Institute for Industrial Crops (ISCI)
- Pacific Gold (*juncea*) – a variety from the University of Idaho (UI) breeding program
- Ida Gold (*alba*) – also from UI
- Martigena (*alba*), to a smaller extent (McGuire, 2012)

Mustard variety trials results from the University of Idaho Brassica Breeding and Research website can help producers select appropriate varieties.

The Mustard Green Manures website at WSU's Center for Sustaining Agriculture and Natural Resources includes cultural and agronomic information and on-farm research results.

Four Extension publications may also be of interest:

- Mustard Green Manures, WSU Extension Publication FS219E
- Using Green Manures in Potato Cropping Systems , WSU Extension Publication FS218E
- Controlling Early Season Wind Erosion in Columbia Basin Potato Fields (discusses the benefits and limitations of cover crops for control of wind erosion), WSU Extension Publication FS025E
- Estimating Plant-Available Nitrogen Release from Cover Crops, OSU Extension Publication PNW636

Use of Biofumigant Cover Crops in the Irrigated West

Seed sales data suggest an increase in the use of mustard cover crops in the Columbia Basin in Washington and Oregon over the last 15 years, from approximately 1,800 acres in 1999 to roughly 30,000 acres in 2012 (McGuire 2014). Most mustard cover crops are used prior to planting potatoes, though some precede onions and green peas (McGuire 2012). Meanwhile, seeds sales data indicated that farmers in Idaho, California, and Arizona were using the practice on an additional 29,500 acres (McGuire 2012).

A 2010 survey of potato growers in Washington State indicated that soil-building benefits were more important than pest control in farmers' decisions to try biofumigant cover crops. Better soil tilth, increased soil organic matter, reduced wind erosion, and improved water infiltration were the top-rated benefits (McGuire 2012).

compared the climate impacts of his biofumigant cover cropping system to those of a more traditional system reliant on chemical fumigants and without a cover crop (Lazzeri et al. 2010). (See the Climate Benefits of the Biofumigant Approach in Gies' Wheat-Potato Rotation sidebar.) Second, he is collaborating with scientists from the Regional Approaches to Climate Change for Pacific Northwest Agriculture (REACCH) project who are directly measuring greenhouse gas balances in one of his fields. (See the Measurements of the Greenhouse Gas Balances of a Field on the Gies Farm sidebar.)

Climate Benefits of the Biofumigant Approach in Gies' Wheat-Potato Rotation

Though Gies grows mustard-arugula cover crops primarily for their biofumigant and soil-building properties, his system also tends to be more climate friendly than the conventional system it replaces (Lazzeri et al. 2010).

Life cycle analyses (LCAs) can be used to compare the impacts of different management systems. In this case, Lazzeri and colleagues used an LCA to track the impacts of cover cropping on multiple greenhouse gases which are responsible for human-caused climate change. The LCA compared Gies' biofumigant potato-wheat rotation to a potato-wheat rotation that used chemical fumigation and no cover crops. The authors accounted for emissions associated with irrigation (for pumping), diesel use, as well as fertilizer and chemical production and use in both systems. To account for the differential impacts of various greenhouse gases, all impacts were expressed in terms of carbon dioxide equivalent emissions (CO_2e). Results indicated that the mustard cover crop approach generated 700 kg of CO_2e per hectare (625 lb CO_2e per acre) less than the conventional approach.

Agricultural (and forestry) systems can also draw carbon dioxide out of the atmosphere and store carbon in the soil. When organic matter levels increase, additional carbon is sequestered. Soil organic matter content in Gies' soil was around 0.6% when he implemented the biofumigant approach in 1997; by 2010 it had increased to 1.2%, a significantly higher level than other soils in the area. The amount of new carbon sequestered would decrease over time, as soils will not continue to add carbon indefinitely. However, in the initial thirteen years, the biofumigant approach (including both soil carbon and the other greenhouse gas impacts discussed above) saved over 3,900 kg CO_2e per hectare (3,500 lb CO_2e per acre) annually compared to the approach that did not use a cover crop.

Measurements of the Greenhouse Gas Balances of a Field on the Gies Farm

Sarah Waldo, Jinshu Chi, Patrick O'Keeffe, Shelley Pressley, and Brian Lamb, Laboratory for Atmospheric Research, Washington State University

Agricultural activities impact climate change by taking up, and emitting, carbon dioxide, nitrous oxide, and methane: three greenhouse gases that contribute to warming. In croplands, agricultural soils can be a large source of nitrous oxide; however, soils can also store carbon in organic matter. By installing instrumented flux towers (Figure 9) at five different sites across the inland Pacific Northwest (including dryland sites and an irrigated site at the Gies farm), scientists are hoping to shed light on three major questions:

- What management practices impact the greenhouse gas balance of an agricultural field?
- Are agricultural soils in this region a sink for carbon dioxide?
- How much nitrous oxide is emitted by soils in this region?

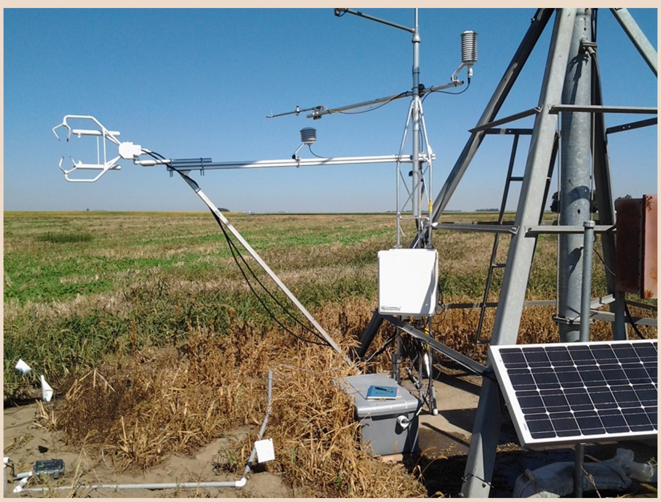

Figure 9. The flux tower attached to the irrigation pivot at the Gies farm. Photo: Patrick O'Keeffe.

The flux towers take direct, continuous measurements of the exchange of carbon dioxide and water between the surface and the atmosphere. The method, called eddy covariance, works by comparing the amount of carbon dioxide or water in updrafts and downdrafts of winds. A video about eddy covariance flux towers gives more detail (Kantor 2013).

The data collected by the flux towers are used to calculate the overall uptake or release of carbon and the overall evapotranspiration every half hour. Information over longer time periods—a growing season or multiple years—can be used to determine the carbon budget for the field or the water use efficiency for different crops. The project is part of the Regional Approaches to Climate Change in Pacific Northwest Agriculture project.

Though the study is still ongoing, Gies expects that it will not lead to insights that have direct management implications. However, in addition to contributing to scientific knowledge, he hopes that his participation will benefit the farming industry as a whole. "I collaborate on these kinds of projects to show that farmers aren't just here raping and pillaging the earth, to show that we *do* care and there are some things we can do to help solve some of the issues."

Beyond his research collaborations, Gies is continuing to experiment on his own to find additional crops (including both cash and cover crops) that could add organic matter and diversity on his farm. In looking for a new crop, he weighs four main factors. First, he wants a crop that produces enough residue to contribute to organic matter, but not so much that planting the next crop is difficult. Second, he avoids crops that will "volunteer" in ways that cause weed problems later in the rotation. Third, he looks at the impacts the crop might have on pest issues in other parts of the rotation. Fourth, he evaluates whether there is a market for the seed, or whether it will be grown solely as a cover crop.

With these criteria in mind, Gies is currently investigating the prospect of double cropping millet after mustard grown for seed. Millet generates a medium level of residue that is generally easy to handle and work in. It is unlikely to create weed issues, appears not to be a host for nematodes, and could be marketed.

Benefits

Gies summarizes the benefits of his system in this way: "We're able to produce good potato yields, good quality, and improve the soil while we're doing it." He has found that with biofumigant cover cropping, his potatoes have higher specific gravity, a benefit for which he can receive an incentive payment from processors (Figure 10). Meanwhile, his soils have better cation exchange capacity, more stable aggregates, and soil erosion is reduced. In addition, over the first 13 years of biofumigant cover cropping, organic matter doubled from

0.6% to around 1.2% in the soil on his farm. Gies feels that the incorporated cover crop—not just standing stubble—seems to be key for preventing wind-blown soil erosion in his soils. “We’ve seen fields with a lot of corn stalks in them, but the soil is blowing away around them. So it has to be kind of processed into organic matter and carbon.”

Figure 10. Gies shows the high quality of his potatoes. Photo: Andy McGuire.

Cover cropping has also improved water infiltration rates and water-holding capacity, which together have increased Gies’ water use efficiency. Measurements showed that water infiltration rates in fields with wheat followed by the mustard-arugula cover crop and rotated with potatoes were generally higher than those on an adjacent field in a similar crop rotation without the biofumigant cover crop (McGuire 2003a). (An overview of this study is provided in the Infiltration Rates in Rotations with and without a Biofumigant Mustard Cover Crop sidebar.)

Meanwhile, separate measurements carried out in collaboration with the Ground Water Management Area have indicated that the top foot of his soils holds almost one-third more water than the same foot of soil in a conventional system with no cover crop (Ground Water Management Area, unpublished data). “The average water-holding capacity for this sandy loam soil is about 2 inches per foot if it is in decent condition, less if the soil has poor structure. The samples showed water-holding capacity in our soil was about 2.3 inches per foot, and the poor tilth soil across the ditch was about 1.8 inches per foot.” As Gies points out, this increase of roughly 30% has important management implications. “That’s like gaining a day in terms of water. I can add more water, can water less frequently, [and] the root system is deeper. If the water goes off or the power goes out, I have a bigger cushion for surviving without serious crop damage. And it’s absolutely critical in disease management.”

In addition to the impacts on soil quality, Gies finds that the biofumigant cover crop provides both short-term and long-term benefits to his disease management. In the short term, when the cover crop is worked into the soil in October, the cover crop helps manage soilborne pests. This effect has been consistent over time, and Gies has not seen any issues with resistance.

Over the long term, Gies feels that the mustard-arugula cover crops have a positive impact on populations of nematode-trapping fungi and other nematode predators, and the enhanced carbon levels benefit aerobic bacteria and fungi. As Gies says, “There is a lot more life below the soil surface than there is above it. And scientists haven’t even identified all the things that are in there. But we do know that if you feed it, it kind of takes care of itself.”

Gies relies on both these disease-management benefits to maintain high quality crops in his intensive two-year rotation. This, in turn, allows him to grow his target acreage of potatoes without having to rent additional ground, keeping their operation compact and benefitting his bottom line. His current operation includes just over 200 acres in a two-year potato rotation, plus about 500 acres of vegetable seed, wheat, and other crops.

Finally, Gies describes a deep satisfaction from being able to manage his land in a sustainable way.

“You know, we don’t really own the ground. We just get to use it during our lifetime. Other people need to survive off of this. And so if we destroy it because it’s an easier way to make a living, that doesn’t sit well. It doesn’t sit well with most farmers. You know, we enjoy our toil under the sun, and hopefully we can pass on the idea to our kids and our neighbors and their kids that there are ways to do this that are compatible with good soil stewardship and that aren’t contrary to making a decent profit. The challenge is in finding that balance” (Figure 11).

Challenges

Gies acknowledges that there are significant challenges to growing biofumigant cover crops successfully. Cover crops take water, time, and labor to grow (though they may provide some savings of water, time, and labor elsewhere in the system). In particular, Gies notes that reliable irrigation water in the late summer and fall is a key factor that allows him to quickly and reliably grow a cover crop.

Gies has also noted some special considerations for growing a biofumigant cover crop. “People look at this as a cover crop. If it comes up and covers the ground, mission accomplished. For

Infiltration Rates in Rotations with and without a Biofumigant Mustard Cover Crop

Georgine Yorgey, Center for Sustaining Agriculture and Natural Resources, Washington State University; and Andy McGuire, Grant and Adams County Extension, Washington State University

Irrigation water runoff is a frequent problem for Columbia Basin potato farmers because center-pivot irrigation systems often operate above the infiltration capacity of soils (McGuire 2003a). This leads to non-uniform water and chemical distribution and can increase disease potential in wetter areas. Infiltration rates were compared between two adjacent fields: one on the Gies farm that was in a wheat-mustard cover crop-potato rotation, and another on a neighboring farm that was in a rotation of crops commonly grown in the area (wheat, sugar beets, and other crops), without cover crops. McGuire (2003a) describes sampling, analysis, and results in more detail.

Infiltration rates in the field with mustard cover cropping exceeded those in the other field in all but two of the comparisons (Table 1). The field with the cover crop had more water-stable aggregates than the other field, which likely contributed to improved infiltration rates. Because the two fields had different rotations, the effects cannot be directly attributed to mustard cover cropping. However, the cover crop increased soil organic matter inputs, which are well-known to improve aggregate stability.

Table 1. Average infiltration rates after consecutive one-inch applications of ponded water.

	Average Infiltration Rates (inch/min)[a]		
Point in Rotation[b]	1st inch	2nd inch	3rd inch[c]
September 3, 1999	N	2 to 4	1.2 to 2.3
After wheat harvest (MGM[d])	1.39[e]	0.48	
After wheat harvest	0.13	0.18	
November 2, 2000			
After potato harvest (MGM)	0.20	0.19	0.16
After sugar beet harvest	0.39	0.05	
March 7, 2001			
Potatoes/winter (MGM)	0.57	0.10	
Sugar beets/winter	0.06	0.05	
March 5, 2002			
Potatoes/winter (MGM)	0.14	0.09	0.08
Fallow/winter	0.10	0.05	

[a]Mean separation, within date and inch applied, by PLSD at 0.01 level.
[b]Before sampling, the fields had no tillage operations after harvest of the crops in the first two comparisons, and no spring tillage operations in the latter two comparisons.
[c]Third inch not measured on the first and third dates due to time constraints, and on the other dates because measurements for the second inch were halted at 20 minutes for all replications in that field.
[d]Rotation with mustard green manures (MGM).
[e]Values in shaded pairs (MGM rotation compared to conventional rotation for the same inch of water) are significantly different at $P = 0.05$.

Figure 11. Gies farms with a view to passing on the farm to his sons and their children. Pictured here are his son Mike and his grandson Owen. Photo: Brittany Gies.

biofumigant cover crops, you have to focus on the last part where it's a crop." Biomass needs to be sufficient, and the cover crop needs to be macerated well and worked in promptly. If soil pH is too low (below about 5.5 in Gies' experience), it can also interfere with biofumigation.

Managing Risk

Gies' intensified cropping rotation and his reliance on a mustard-arugula cover crop for disease suppression may seem risky. However, he feels that, overall, it reduces risk. "Our system is versatile and keeps the soil in good shape, so that we can adapt to other crops, and not start out with a big load of nematode and disease issues from day one." This allows Gies to respond more easily to economic signals, giving him added flexibility.

Within his system, Gies feels that two complementary strategies are necessary for reducing risk. The first is that he takes the biofumigant cover crop very seriously, and considers it a key part of his cropping rotation. The second is that he has used cover cropping consistently over time. This has built up soil quality and created a buffer for years when his mustard cover crop stand is not as good as he would like it to be.

As Gies points out, fumigation is not risk free, either.

> "Growing mustard green manures is not as easy as fumigating, but we also know that guys who fumigate think that's going to work, and we see plenty of evidence that it's not. I even know some of the people in the chemical business who will tell you that fumigation is not always effective all season long anymore. That's a risk because you could go into the season thinking you're golden, and then in August when the heat hits, all of a sudden your potatoes start to yellow up and sections of the field die and by the middle of September the weeds are coming through. It's a different risk I guess, and it's one everybody, I think, should evaluate in their own situation."

Gies feels that knowing his ground intimately also helps reduce risk. "We feel pretty comfortable because we know this ground, we know the disease pressure, we know how this variety of potato responds, and we have a pretty good idea of how to grow a consistent cover crop and work it in." And he adds, "A lot of potato growers rent different ground they really don't know. What is the *Verticillium* pressure [for instance]? They get a kind of a glimpse of the nematode levels in the sampling, but they don't even guarantee that's accurate; and if you don't find any, it doesn't mean they're not there—it just wasn't in your sample. So you know, there's risk there too."

Looking Forward

Gies values the ability to continually learn and adapt. "At this temporary point in time, we may have a successful system, but, you know, things can change: the climate, the markets, regulation, and so on. As I tell my sons, if you know everything I know, you're good for about five years." Gies feels that ongoing experimentation is essential to staying ahead of ongoing changes in equipment, farming techniques, competition, and other areas.

Gies has observed distinct differences in the climate within his lifetime, and he expects continuing changes in the future. Though he doesn't know whether the future will follow the changes he has seen so far, he says, "I've been told that when we look at the total heat units in a 12-month period, it hasn't changed that much over my lifetime. It's just that it has shifted. The springs and early summers are cooler, and the falls and winters are warmer. In the spring it's particularly extreme and you don't know what's coming and how to react, especially for water management, but even for planting dates."

However, he thinks that his resilient system will help him continue to thrive, whatever climate changes the future may bring. For example, he has adapted to cooler springs by changing the type of wheat he grows. "The potatoes don't seem to mind cool springs, but we would like to harvest the wheat earlier than we have been. We've actually been producing some dark northern spring wheat that we are planting in the fall. Theoretically, it will yield better, but it will harvest earlier, which will help us get our mustard in." And he is better able to survive hot spells in the summer because increases in his organic matter have led to increased water-holding capacity.

On the topic of sustainability, Gies also notes that his current practices are aligned with ongoing regulatory and market pressures to develop more sustainable systems. (See the

Adapting Biofumigant Cover Cropping in Other Locations

Through his mustard-arugula cover crop seed business, Gies has had the opportunity to work with growers throughout the world, including in Maine, Tasmania, New Zealand, Finland, and other parts of Europe. He has learned that the use of biofumigant cover crops needs to be adapted in each location to fit within existing crop rotations. For example, in Maine, because the growing season is so short, they have found better results if they substitute mustard growing full season for wheat, rather than growing both in the same year. Though the mustard does not generate profits, improved potato yields the following year more than make up for the loss of the wheat, which has relatively low yields because of the short growing season.

Gies has also learned that biofumigant cover cropping can be particularly helpful where existing tools for managing pests and disease are limited. “For organic farmers or places that don’t have the option to use [chemical] fumigants, either the infrastructure or the registered chemicals to use, it’s amazing what you can do with this.” Gies also finds that organic growers like the fact that cover crops cycle nitrogen at the end of the season, making it available to their vegetable crop the following year. “They’ll put chicken manure on ahead of the [biofumigant] green manure crop which they like because it’s a lot safer than putting it directly on the onions or carrots or whatever they are coming in behind it with.”

Advice for Others

Gies was asked what advice he would give to other growers who are interested in adopting cover cropping.

Crop rotation is first and foremost. “You need a crop rotation that works economically and keeps disease pressures manageable.”

Correctly identify your soil quality, disease, and pest issues. “Your strategy for dealing with root lesion might be different than root knot or stubby root or spiral or potato cyst or sugar beet cyst [nematode]. Crops that work well to reduce populations of sugar beet cyst nematode, like [oilseed] radish and white mustard, aren’t necessarily going to work on root knot or root lesion or stubby root. So you have to know the issue.” Figuring out the specific issue can come from a combination of symptom diagnosis, plant tissue or soil testing, and experience.

Start small, testing new practices on your own farm before you implement them on a large scale. “If you want to know how well a specific cover crop will work in your particular rotation, with your soil pH and soil type and pest pressure, evaluate it on your own farm, because you can’t afford to take a hit in today’s economy.”

Be realistic about water and cover cropping in a rainfed production system. “Is your gain from the cover crop going to offset that loss of moisture [from growing the cover crop]? I’m a little skeptical about cover cropping without irrigation and I’ve played around with this in a lot of places. You know, there’s no substitute for water.”

Adapting Biofumigant Cover Cropping in Other Locations sidebar.) “Worldwide, the controls that we had for nematodes are disappearing and the nematode pressure is increasing.” Consumer-driven pressures can be as disruptive as new regulations to growing practices. “You know when McDonald’s says they want potato growers to cut their pesticide use in their French fries in half, they just as well could have said we want you to cut your fumigant use in half because you could cut everything else out—every insecticide, fungicide, herbicide—and you still wouldn’t get to half. I see that coming, not only here but elsewhere around the world. I guess for us, you know, we’re pretty minimal fumigant users.”

He also sees that regulation to reduce global climate change impacts from agriculture, if that were to happen, has the potential to reward farmers who use beneficial practices such as growing cover crops. “At some point there may be an opportunity for growers to offset the cost of growing a green manure crop by the amount of carbon they can pull out of the air. And we need carbon in the soil, so it could fit. But there are a lot of politics.”

Acknowledgements

We extend our sincere gratitude to Dale Gies for generously sharing his time and expertise with us to prepare this case study. We are also grateful to Andy McGuire for providing photos, answering questions that came up during the writing and review process, and for providing helpful comments on an early draft of the case study.

This material is based upon work that is supported by the National Institute of Food and Agriculture, U.S. Department of Agriculture, under award number 2011-68002-30191, the Regional Approaches to Climate Change for Pacific Northwest Agriculture (REACCH-PNA) project, and by the Laird Norton Family Foundation.

References

Collins, H.P., A. Alva, R.A. Boydston, R.L. Cochran, P.B. Hamm, A. McGuire, and E. Riga. 2006. Soil Microbial, Fungal, and Nematode Response to Soil Fumigation and Cover Crops Under Potato Production. *Biology and Fertility of Soils* 42: 247–257.

Gimsing, A.L., and J.A. Kirkegaard. 2009. Glucosinolates and Biofumigation: Fate of Glucosinolates and Their Hydrolysis Products in Soil. *Phytochemistry Reviews* (8): 299–310.

Lazzeri, L., O. Leoni, and L. D'Avino. 2008. Biorefinery: Brassicaceae Plants as More Than Biofumigants. Third International Biofumigation Symposium CSIRO Plant Industry. Canberra ACT Australia, 21–25 July.

Lazzeri, L., L. D'Avino, and D. Gies. 2010. Additional Benefits of the Efficacy in Containing Soilborne Pest and Pathogens with Biofumigant Plants and Materials. In A. Gamliel, J. Coosemans A. Vanachter, and J. Katan, eds. Proceedings of the 7th International Symposium on Chemical and Non-Chemical Soil and Substrate Disinfestation: Leuven, Belgium, September 13–18, 2009.

Matthiessen, J.N., and J.A. Kirkegaard. 2006. Biofumigation and Enhanced Biodegradation: Opportunity and Challenge in Soilborne Pest and Disease Management. *Critical Reviews in Plant Science* (25): 235–265.

McGuire, A. 2001. Mustard Green Manures: On-Farm Research Results, 1999–2001. County Extension Publication.

McGuire, A. 2002. Recommendations for Growing Mustard Green Manures. *Potato Progress* 2(7). Washington State Potato Commission.

McGuire, A. 2003a. Mustard Green Manures Replace Fumigant and Improve Infiltration in Potato Cropping System. *Crop Management* 2(1).

McGuire, A. 2003b. Green Manuring with Mustard: Improving an Old Technology. *Agrichemical and Environmental News* 206(June): 13.

McGuire, A. 2003c. Planting Dates for Mustard Green Manures. *Potato Progress* 3(11). Washington State Potato Commission.

McGuire, A. 2012. Mustard Green Manure Use in Eastern Washington State. In Sustainable Potato Production: Global Case Studies by Z. He, R. Larkin, and W. Honeycutt, eds. Springer Publishing Co., New York, NY.

McGuire, A. 2014. Mustard Types, Seed Sources, and Acreage Estimates. Washington State University Center for Sustaining Agriculture and Natural Resources.

NRCS (Natural Resources Conservation Service). 2013. Web Soil Survey. Natural Resources Conservation Service, United Stated Department of Agriculture.

Rowe, R.C., and M.L. Powelson. 2002. Potato Early Dying: Management Challenges in a Changing Production Environment. *Plant Disease* 86(11): 1184–1193.

Order Information:

Washington State University Extension
http://pubs.wsu.edu
Fax 509-335-3006
Toll-free phone 800-723-1763
ext.pubs@wsu.edu

Oregon State University Extension Service
http://extension.oregonstate.edu/catalog
Fax 541-737-0817
Toll-free phone 800-561-6719
puborders@oregonstate.edu

University of Idaho Extension
http://www.cals.uidaho.edu/edComm/catalog
Fax 208-885-4648
Phone 208-885-7982
calspubs@uidaho.edu

Pacific Northwest Extension publications are produced cooperatively by the three Pacific Northwest land-grant universities: Washington State University, Oregon State University, and the University of Idaho. Similar crops, climate, and topography create a natural geographic unit that crosses state lines. Since 1949, the PNW program has published more than 650 titles, preventing duplication of effort, broadening the availability of faculty specialists, and substantially reducing costs for the participating states. Published June 2017.