Education for Farmers, by Farmers

FARMWALK2017

Cover Cropping for Soil Health

Lenwood Farms
Connell, WA

Monday, May 22, 2017

presented collaboratively by:

tilth
ALLIANCE

Food Systems
WASHINGTON STATE UNIVERSITY

CONTENTS...

Lenwood Farms is a 600 acre certified organic farm located in Connell, WA. This 2017 Farm Walk is focused on the cover cropping methods used to build soil health and address pest management strategies.

FARMWALK2017

Farmer, Brad Bailie, hosts this Farm Walk, taking us on a guided tour through areas of the farm where he has implemented innovative cover crop and beneficial habitat plantings. Information on the latest research in cover cropping will also be provided by Doug Collins, WSU Small Farms Extension Specialist, and Andy McGuire, Irrigated Cropping System Agronomist.

ABOUT LENWOOD FARMS...

Farmers Brad Bailie and Esther Daza-Bailie with their organically grown onions at Organicology Trade Show

Lenwood Farms' land has been in the family since the early 1900's. Great Grandma and Grandpa Meiser started farming on the land in 1915. The name Lenwood comes from the combination of the first and middle names of Brad Bailie's grandpa, Leonard Wood Bailie. In the mid 80's the land was enrolled in the Conservation Reserve Program (CRP). Then in the late 90's when the first CRP contracts began to expire, Brad and his dad, Roger, began converting the land to organic production. Until 2002, the land was leased out to another farmer who grew organic vegetables.

In 2003 Brad took back the family land and began growing organic vegetables and grains in partnership with his dad, Roger Bailie. Brad is the fifth generation farming the land. He and his wife Esther Daza are now 100% owners of Lenwood Farms, Inc.

Lenwood Farms has raised heirloom wheat, emmer, spelt, einkorn, black barley, onions, potatoes, spearmint, catnip, peas, sweet corn, beans, camelina, butternut squash, spinach and this year will be planting lima beans for the first time. Cover cropping plays a vital role in the rotation at Lenwood Farms. Brad strives to work in harmony with nature to produce high quality, nutritious crops. Two wells irrigate the 600 plus organic acres. There are several areas on the farm that are solely designated as habitat for beneficial insects and other wildlife.
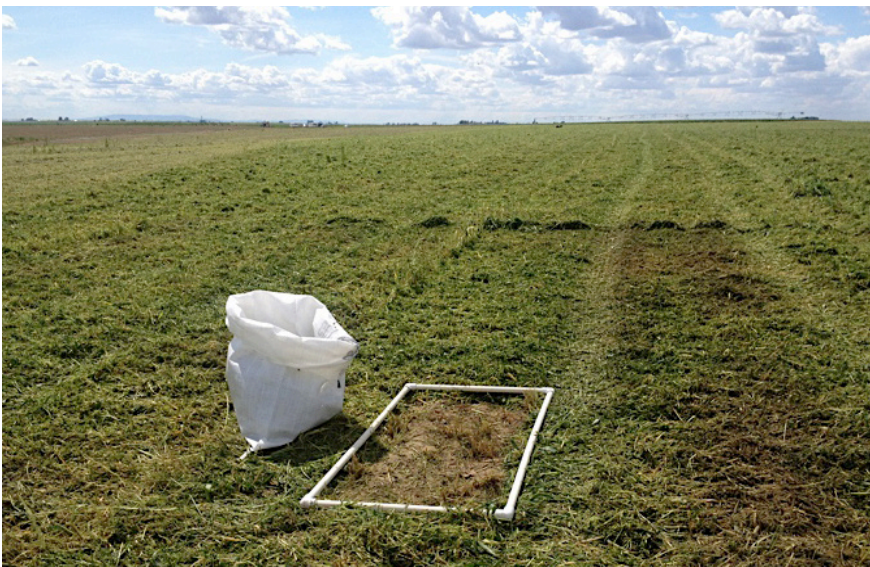
LENWOOD FARMS CONTINUED...

The experience of working with a non-profit agricultural and community development organization in Guatemala changed Brad's life. Promoting sustainable and organic farming practices while volunteering influenced his decision to try organic farming back at home. One project he was passionate about, a farm tour, encouraged the sharing of information that helped indigenous Mayan families live healthier and more economically stable lives. On his own farm Brad has been offering tours designed to highlight some of the sustainable farming practices he is implementing.
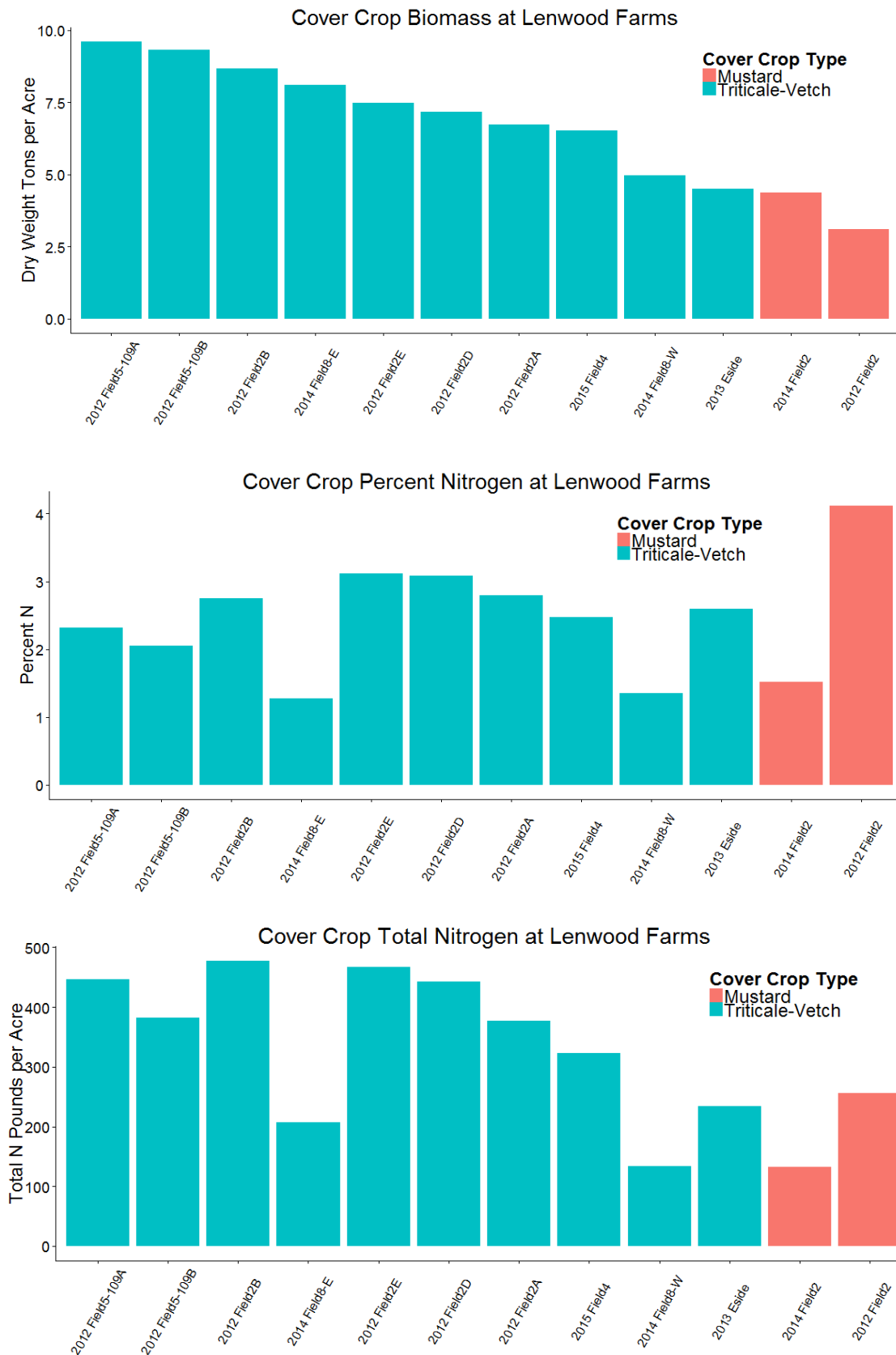

Brad and Esther focus their work on developing the farm into a healthy and vibrant place to live and work. They hope to continue to experience economic and environmental sustainability. Both have a heart for helping others, enjoy working with and in other cultures and are open to the possibility of working abroad in agricultural and community development. When Brad and Esther are not working on the farm or at the local high school, respectively, they love to be in Esther's homeland, Colombia, visiting friends and family.

"I love having people visit my farm because I can learn so much from other peoples' perspective, knowledge and experience. These farm tours are a chance for me to have a lot of smart and talented people on my farm at one time so that we can all learn from one another. It provides an opportunity for people to connect and network with one another."

LENWOOD FARMS COVER CROP BIOMASS INFO

Section **2**

Related Publications &
Helpful Tools

WASHINGTON STATE UNIVERSITY EXTENSION

IMPROVING SOIL QUALITY ON IRRIGATED SOILS IN THE COLUMBIA BASIN

By
David Granatstein, Sustainable Agriculture Specialist, WSU Extension & CSANR, Wenatchee, WA. **Andrew McGuire**, Irrigated Cropping Systems Agronomist, WSU Extension & CSANR, Moses Lake, WA. **Mark Amara**, Moses Lake, WA

WSU PEER REVIEWED

FS252E

Improving Soil Quality on Irrigated Soils in the Columbia Basin

Soil Quality

Soil quality or health can be defined as the capacity of a specific kind of soil to function, within natural or managed ecosystem boundaries, to (1) sustain plant and animal productivity, (2) maintain or enhance water and air quality, and (3) support human health and habitation (Karlen et al. 1997). Soil quality encompasses the interrelated physical, chemical, and biological aspects of soil. For example, soil organisms decompose crop residues to release nutrients and drive the nitrogen cycle (mineralization, immobilization, denitrification). Soil fungi play a large role in formation of soil aggregates and structure, a physical property. Soil biota are in turn affected by soil pH (chemical property) where there is generally lower biological activity in more acidic soils, and waterlogging or compaction of soil (physical properties) often favor anaerobic organisms, some of which cause disease and others that cause nitrogen loss via gaseous forms (Granatstein 2003). Some soil properties, such as soil respiration, change quickly and are highly variable while others, like soil carbon, can take years or decades to change. Soil texture (sand, silt, clay) is generally considered fixed, but organic matter levels can ameliorate some of the negatives. For example, sandy soils have good aeration and drainage but relatively poor water-holding capacity and nutrient retention. Organic matter can increase the latter two. On the other end of the spectrum, clay soils have high water and nutrient retention but poor aeration and physical structure, and organic matter can address these limitations.

The soil properties are influenced by the natural environment (e.g., climate, geology, vegetation) as well as by human activity (e.g., erosion, fertilization, irrigation, plants). However, soil quality itself is not a soil property but rather a human judgment about how well a given soil can perform desired functions (Sojka and Upchurch 1999). Soil quality is important to growers since it plays a large role in crop production as well as on the environmental performance of a farm, affecting soil erosion, air and water quality, and greenhouse gas relations.

One factor in evaluating soil quality is your reference point. Often it has been the native soil in your location. So the prairie or grassland soils are a reasonable reference point for soil quality in a wheat field in Kansas or the Palouse. However, many soils had very different properties in their native ecosystems compared with their status when farmed, as is the case for the irrigated Columbia Basin. What should be the reference point for an irrigated potato field in Washington

State that was once shrub-steppe? Perhaps pasture becomes the most universal reference point for most temperate agricultural soils, as it exhibits many favorable soil properties for crop production. Or the direction of change in a soil can be used; with evaluation over years, you can determine whether the soil is being improved or degraded for the particular properties of interest. The reference point then becomes when you started evaluation.

Evaluations of soil quality rely on choosing a set of indicator properties that can be quantitatively measured and related to a baseline or reference point for comparison. Indicators should reflect a problem to be solved or a desired state to be achieved. For example, if poor water infiltration is a problem, then indicators related to this property such as infiltration rate should be used to monitor whether management changes have the desired effect. Various studies have sought to find an ideal suite of soil measurements for evaluating soil quality (Hefner et al. 2009; Moebius-Clune et al. 2016). Of these, one of the better developed and practical is the Cornell Soil Health Assessment which measures 10 properties, normalizes them, rates them according to specific criteria, and then calculates an overall soil health rating. However, this assessment was developed for soils in the northeastern US, which differ greatly from western US soils in organic matter levels (higher) and chemical properties (more highly weathered, in general). Therefore, this test can be useful in comparing different management but may not reflect optimal conditions for western US soils. Often the crop itself can be used as an indicator of soil quality change, as it integrates the effects of the different soil properties. Improved crop performance is an outcome desired by growers and one they can usually measure quantitatively.

Soils and Columbia Basin Agriculture

Irrigated growers in the Columbia Basin of Washington State have expressed increased interest in improving soil quality and in learning about the benefits versus the costs of implementing soil improvement practices. In addition, producers have been under increasing public scrutiny concerning efforts to maintain and improve soil resources, especially for off-farm impacts such as wind erosion and water quality. A 2012 survey of attendees at the WSU Building Soils for Better Crops Workshop in Moses Lake, Washington, showed that 73% had increased their use of soil improvement practices in the last five years, with "improved soil tilth" as the most recognized benefit (Granatstein and McGuire 2012).

The soils in the western US are much different than those in the eastern part of the country, where the concept of soil quality was developed (Doran and Parkin 1994). In the Columbia Basin, the arid climate and sandy textures have produced soils naturally low in organic matter. If these soils were found in the central Corn Belt, their organic matter levels would be considered inadequate for proper function (Loveland and Webb 2003). Yet with irrigation, agricultural inputs, and management, they can be highly productive. Nevertheless, farmers do have challenges with these soils.

Columbia Basin soils are susceptible to wind erosion, especially during the spring and fall when bare soils often coincide with high wind events (Figure 1). Water erosion caused by irrigating soils that have low infiltration rates (the result of intensive tillage and associated loss of soil aggregates) can also be a problem. Related problems of soil crusting, poor drainage, and ponding can cause reductions in crop growth and yield. Soils often have low buffering capacity and can experience an undesirable pH decline due to continued use of acid-forming nitrogen fertilizers (Bouman et al. 1995).

While the low level of organic matter in soils causes some problems, it also allows for improvement. Since the 1950s, when irrigation and higher yielding crops were introduced to the Columbia Basin, organic matter has generally increased over the native levels of less than 1% (Cochran et al. 2006). This is in stark contrast to the Midwest where farmers struggle to maintain high organic matter levels formed under tallgrass prairie.
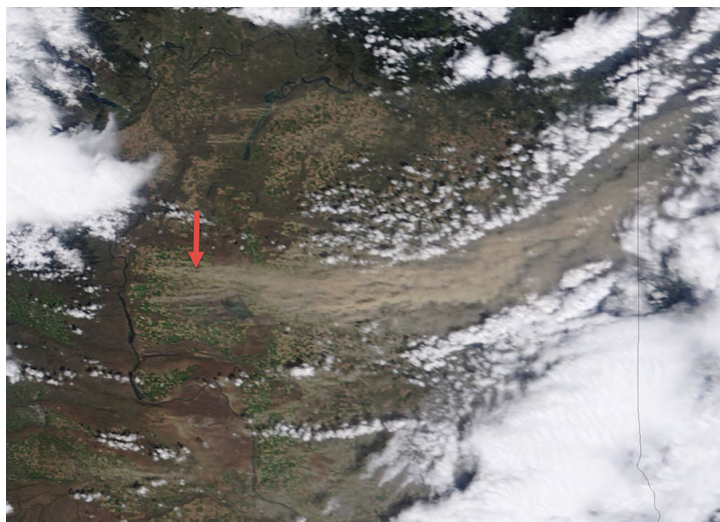

Figure 1. NASA satellite photo of a May 3, 2010, dust storm in the Columbia Basin of Washington. Arrow shows origin of dust plume.

Factors Affecting Soil Management

Soil management is complicated by the diversity of crops grown in the region. Some crops, such as potatoes and onions, require intensive tillage for planting and harvest and, along with other vegetable crops, leave low amounts of crop residue after harvest. Tillage is reduced in perennial forage crops, such as alfalfa and timothy, but crop residue additions to the soil are low as they are nearly all harvested for hay. Their root contributions are important but their root biomass is lower than that of many native perennial grasses (Kramer and Weaver 1936). To maintain soils, low residue crops should be rotated with high residue crops, like wheat and corn, but the latter are often less profitable. Adding perennial crops, which reduce tillage frequency, also helps. Furthermore, much of the land is farmed under short-term leases, which lessens the motivation to pursue the long-term benefits of soil improvement.

Although the region's farmers are applying soil improvement practices the costs and benefits of these practices have not been evaluated. Potential benefits of improved soils include reduced erosion, improved nutrient cycling and soil tilth, reduced pressure from soilborne diseases, and improved water-holding capacity and infiltration, all of which combine to maintain or even improve crop yields. In order to further justify the investment in soil improvement practices and encourage more farmers to implement them, a 2015 WSU study assessed the impacts of soil improvement practices in the Columbia Basin by conducting a suite of soil quality tests on soils from adjacent fields with and without soil improvement practices. Interviews with growers about the costs of the practices and the benefits they perceive or measure were also conducted (see the companion publication TB41E An Evaluation of Soil Improvement Practices Being Used on Irrigated Soils in the Columbia Basin).

Soil Improvement Practices

Soil improvement in the Columbia Basin can be divided into three broad categories, each of which contains specific practices. These are covered below.

Organic Soil Amendments

Various materials from plants or animals may be used as organic soil amendments (Magdoff and van Es 2010). Generally, wastes from either food processing (cull vegetables or mint slugs), livestock production (manure), or human waste (biosolids) can be applied raw or composted (Figure 2).

Figure 2. Precision application of organic amendments is a commercially available option offered by several companies in the Columbia Basin.

Figure 3. Mustard no-tilled into wheat stubble, an example of a fall green manure crop in the Columbia Basin.

Composts are processed products managed to meet pathogen reduction standards, are more uniform and decomposed, and should contain few to no viable weed seeds. Composts help to improve soil tilth and provide a slow-release source of nutrients. They can originate from any of the above-mentioned organically derived materials. Manures are a mixture of bedding and raw fecal material which contains organic matter and nutrients. They may contain raw and aged materials, foodborne pathogens, and weed seeds, usually have a relatively high nutrient content, and can help improve soil tilth. These materials are imported to fields either from other parts of the farm or from off the farm, and they are applied in higher quantities than fertilizers due to their bulky nature and lower nutrient concentration. Thus, they typically involve high transport and handling costs and are usually more expensive than field-grown plant material (cover crops, crop residues). However, these amendments also import nutrients into the system and may replace other purchased fertilizer, which mustard green manures (non-legume) and high residue farming do not do. Organic amendments should be carefully selected to avoid unwanted contaminants (e.g., herbicide residues, plastics, heavy metals) and weed seeds.

Cover Crops and Green Manures

Cover crops are not normally harvested; they are either killed or allowed to winterkill, remaining on the soil surface for soil protection while their root systems contribute directly to soil improvement. Green manures (Figure 3) are cover crops that are grown specifically to be incorporated into the soil with tillage (Clark 2008).

Both green manure and cover crops can provide multiple benefits including increasing soil organic matter; improving soil structure; providing wind and water erosion control, nitrogen fixation (legumes) and nutrient recycling, weed

control, and suppression of soilborne diseases and nematodes; and enhancing soil microbial activity. While growing, both can provide nectar to pollinators and habitat for wildlife.

High residue Farming

High residue farming refers to cropping systems in which the volume of soil that is tilled is reduced in order to maintain residue cover of the soil (McGuire 2014). No-till (direct seeding), strip till, vertical tillage, and zone tillage are all considered variations of high residue farming (Figure 4). Farmers adopting one of these methods benefit through reduced equipment use, operating time, and fuel, increased water conservation, less incidence of wind erosion, and improved soil tilth. For more information on high residue farming under irrigation see the Other Resources section below.

Figure 4. Dry edible beans direct-seeded into an alfalfa stand near George, WA.

Measurements of Soil Quality

The following soil properties can all be measured quantitatively and are directly relevant to the soil quality issues in the Columbia Basin. Most tests are available from a commercial laboratory. Standard chemical soil analyses include key soil quality tests such as pH or salinity that should also be considered.

Soil Organic Matter

Soil organic matter is the driver of soil quality in most soils. This is especially true for the low organic matter soils of the arid West. It is a source of carbon for soil biology, it can hold several times its weight in water, and it adds to the nutrient retention ability of soil by increasing cation and/or anion exchange capacity. Soil organic matter acts like a sponge, holding water and nutrients and making them available to the crops over time. Increases in soil organic matter help reduce plant stress during dry periods. Soil organic matter supplies much of the food for the soil biota, which in turn help create soil aggregates through the "glues" they exude and the action of fungal hyphae. More stable aggregates on the soil surface reduce the risk of wind erosion, which can damage young seedlings and cause off-site problems from blowing dust. Better surface aggregation can help maintain water infiltration and avoid surface sealing, which helps with irrigation efficiency and reducing water runoff. Loss of soil aggregation and structure can lead to poor soil aeration, which favors certain fungal diseases in the soil. Soil organic matter influences all these functions and more. Increased activity by the soil biota also helps cycle nutrients which can provide them to crops as well as prevent their loss. Taking repeated soil organic matter tests over time is a good way to monitor long-term soil improvement, but tests should be done at the same location in a field, at the same time of year, at the same depth of soil, in a similar place in the management cycle (e.g., rotation, manure application), and with the same laboratory method to allow for meaningful comparison over time.

Soil Respiration

Most living organisms in the soil respire (breath), giving off carbon dioxide. So soil respiration is a measure of the level of biological activity in the soil at the time of the test. It can increase with warming temperatures, soil wetting, and the application of organic materials (food for microbes) but also with tillage, which, with an influx of oxygen, stimulates an increased breakdown of existing organic matter. Interpretation of soil respiration, therefore, must take into account recent management. This measurement can be highly variable within a day and during a growing season, making interpretation more difficult. The test does not provide information about what organisms are most abundant or what functions they are providing. It does indicate whether different practices (e.g., one strip with a green manure and another without), all other factors being equal (same soil, same history, same crop, etc.), have a stimulating effect on the soil biota.

Available Water Capacity

Available water capacity reflects a soil's ability to store water for use by plants. It is considered to be the water held between field capacity (about 30 cbars of tension) and the permanent wilting point (about 150 cbars of tension). It is affected by texture (lower for sands, higher for silty soils) and organic matter, which acts as a sponge in the soil. It is important for irrigated agriculture because, given a certain weather pattern, it dictates the interval between irrigations. Increasing the available water capacity means you can go longer between irrigations, or that your crops may be less stressed during a very hot period. This property can be measured at any time.

Water Infiltration

Water cannot be stored if it runs off before entering a soil. Therefore, a high water infiltration rate is important for efficient irrigation, especially in the outside spans of center pivot sprinkler irrigation systems where applications rates are high. Although freshly tilled soils may have a higher infiltration rate initially, the rate often decreases after the first irrigation. This is caused by a breakdown of aggregates at the soil surface leading to a sealing layer of fine soil particles. When soil organic matter is added through soil improvement practices, the formation of water-stable aggregates can increase, which then helps resist degradation and maintain high infiltration rates. Crop residues on the soil surface also serve to protect the soil from water droplet impact, which can also maintain higher infiltration rates. Water infiltration is generally measured in the field in undisturbed (not recently tilled) locations using various devices, such as the simple single-ring infiltrometer. Multiple measurements should be made in a field since there is large spatial variation for this property.

Bulk Density

Bulk density is a measure of how much of the soil material, the sand, silt, clay and organic matter, is packed into a certain volume. In general, lower bulk density is better, as that means there are more empty spaces for air and water movement. Bulk density can affect water infiltration and also root growth. In untilled soils, bulk density can be misleading as the effects of higher bulk density can be offset by semi-permanent pores from earthworms and old root channels that are not found in tilled soils. Special soil sampling probes are used to collect an undisturbed core of soil of known volume that is then dried and weighed.

Soil Conditioning Index

The USDA Natural Resources Conservation Service (NRCS) developed a tool called the Soil Conditioning Index in the 1960s to assess what we now call soil quality. The Index uses three components: organic matter returned to the soil and removed, effects of tillage and field operations, and predicted soil erosion. It is currently part of the RUSLE2 model that NRCS uses with growers for conservation planning. The model generates three values, one for each component, and sums them for an overall soil condition rating. The components are weighted, with organic matter at 40%, field operations at 40%, and soil erosion at 20%. Scores can be negative (indicating a decline in soil condition), zero (maintaining soil condition), or positive (improving soil condition). By seeing the component scores, you can identify where a major problem may be and focus on management changes that will most readily influence that component. Growers can access this index through their local NRCS office.

Cornell Soil Health Test

Researchers at Cornell University responded to growing interest among growers for a more quantitative approach to monitoring soil quality. They evaluated many different laboratory tests that were generally used in research settings to determine which would produce meaningful values for physical, chemical, and biological properties of soils that are affected by management, and that also could be done in a commercial lab at a cost a grower could afford. This resulted in the current packages of 10–12 different tests they will conduct. As stated earlier, data are normalized and scored based on northeastern US soils, but this can be a useful test for side-by-side comparisons here in Washington. Oregon State University now offers a soil health package based on the Cornell program.

Potential for Improving Soils in the Columbia Basin

Soils in the Columbia Basin are highly productive for agriculture but can have problems related to their physical properties (e.g., poor water infiltration on loamy soils, wind erosion) that can be influenced by different soil improvement practices. The low native levels of soil organic matter can also be increased through management, even in systems that have regular soil tillage. Various tests are available to help growers monitor changes in their soil quality over time. A 2015 study of soils in the Columbia Basin found that several key soil properties were improved with the use of organic amendments, green manures, or high residue farming, and the potential benefits to the grower equaled or exceeded the costs of the soil improvement practices (McGuire et al. 2017).

Other Resources

Economics of Improving Soils

Ransom, M., R. Holcomb, and L. Hedrick. 2014. Why Grow a Crop You Don't Sell? USDA-NRCS Conservation Webinar.

Soil Quality Testing

Cornell Soil Health Assessment.

Oregon State University Soil Health Test.

Soil Conditioning Index.

Organic Soil Amendments

WSU Compost and Nutrient Management website.

WSU Manure as a Resource website.

Sullivan, D., C. Cogger, and A. Bary. 2015. Fertilizing with Biosolids. Pacific Northwest Extension Publication PNW508. Oregon State University.

Green Manures

Mustard Cover Cropping in Potatoes. REACCH Case Studies, Dale Gies System profile.

McGuire, A. 2016. Mustard Green Manures. Washington State University Extension Publication FS219E.

McGuire, A. 2016. Using Green Manures in Potato Cropping Systems. Washington State University Extension Publication FS218E.

High Residue Farming

McGuire, A. 2014. High Residue Farming under Irrigation Series:

> EM071E High Residue Farming under Irrigation: What and Why
>
> EM072E High Residue Farming under Irrigation: Crop Rotation
>
> EM073E High Residue Farming under Irrigation: Residue Management through Planting
>
> EM074E High Residue Farming under Irrigation: Pest Management Considerations
>
> EM036E High Residue Farming under Irrigation: Strip-till

References

Bouman, O.T., D. Curtin, C.A. Campbell, V.O. Biederbeck, and H. Ukrainetz. 1995. Soil Acidification from Long-Term Use of Anhydrous Ammonia and Urea. *Soil Science Society of America Journal* 59(5): 1488.

Clark, A., 2008. Managing Cover Crops Profitably, 3rd ed. USDA, Beltsville, MD.

Cochran, R.L., H.P. Collins, A. Kennedy, and D.F. Bezdicek. 2006. Soil Carbon Pools and Fluxes after Land Conversion in a Semiarid Shrub-Steppe Ecosystem. *Biology and Fertility of Soils* 43(4): 479–89.

Doran, J.W., and T.B. Parkin. 1994. Defining and Assessing Soil Quality. In Defining Soil Quality for a Sustainable Environment, 1-21. J.W. Doran, D.C. Coleman, D.F. Bezdicek, and B.A. Stewart, eds. *SSSA Special Publication* 35. SSSA and ASA, Madison, WI.

Granatstein, D. 2003. Measuring Soil Quality – Initial Considerations. *Sustaining the Pacific Northwest* 1(4): 7–8.

Granatstein, D., and A. McGuire. 2012. Building Soils for Better Crops Audience Feedback. Unpublished Data from Participant Survey at Building Soils for Better Crops Workshop, Nov. 27–28. Moses Lake, WA. Washington State University.

Hefner, M., S. Donaldson, and J. Skelly. 2009. Assessing Soil Quality. University of Nevada Cooperative Extension Fact Sheet-09-17.

Karlen, D.L., M.J. Mausbach, J.W. Doran, R.G. Cline, R.F. Harris, and G.E. Schuman. 1997. Soil Quality: A Concept, Definition, and Framework for Evaluation (A Guest Editorial). *Soil Science Society America Journal* 61: 4–10.

Kramer, J., and J.E. Weaver. 1936. Relative Efficiency of Roots and Tops of Plants in Protecting the Soil from Erosion. University of Nebraska Department of Conservation Bulletin 12. Lincoln, NE.

Loveland, P., and J. Webb. 2003. Is There a Critical Level of Organic Matter in the Agricultural Soils of Temperate Regions: A Review. *Soil & Tillage Research* 70(1): 1–18.

Magdoff, F., and H. van Es. 2010. Building Soils for Better Crops. 3rd ed. USDA-SARE, Beltsville, MD.

McGuire, A.M. 2014. High Residue Farming Under Irrigation: What and Why? Washington State University Extension Publication EM071E.

McGuire, A.M., D. Granatstein, and M. Amara. 2017. An Evaluation of Soil Improvement Practices Being Used on Irrigated Soils in the Columbia Basin. Washington State University Extension Publication TB41E.

Moebius-Clune, B.N., D.J. Moebius-Clune, B.K. Gugino, O.J. Idowu, R.R. Schindelbeck, A.J. Ristow, H.M. van Es, J.E. Thies, H.A. Shayler, M.B. McBride, D.W. Wolfe, and G.S. Abawi. 2016. Comprehensive Assessment of Soil Health Training Manual – The Cornell Framework Manual. 3rd ed. Cornell University, Ithaca, NY.

Sojka, R.E., and D.R. Upchurch. 1999. Reservations Regarding the Soil Quality Concept. *Soil Science Society of America Journal* 63: 1039–1054.

WASHINGTON STATE UNIVERSITY
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MUSTARD GREEN MANURES

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WSU PEER REVIEWED

FS219E

Mustard Green Manures

Farmers are using several types of mustard for their ability to build soil quality and to suppress soilborne diseases, nematodes, and weeds. Described below are the practices typically used by farmers for mustard green manure crops in the irrigated Columbia Basin.

Types of Mustard

There are two types of mustard being used in the Columbia Basin: white mustard (*Sinapis alba*, also called *Brassica hirta* or yellow mustard) and oriental mustard (*Brassica juncea*, also called Indian or brown mustard). See Figures 1 and 2. Commercial varieties are used to produce table mustard, oil, and spices. Blends of the two types of mustard, most with a high proportion of oriental mustard, are often planted for green manuring.

Figure 1. White mustard seed *(Sinapis alba)* on left; Oriental mustard seed *(Brassica juncea)* on right.

Uses

Farmers are using mustard green manures, mainly before potatoes, to:

Suppress soilborne diseases and nematodes. When used as a green manure, researchers (Larkin and Griffin 2007, Ochiai et al. 2008) have found that mustards can suppress some diseases such as Verticillium dahliae and *Aphanomyces euteiches* (common root rot). Mustard green manures have also been found to suppress Columbia root-knot nematodes and may be effective against other types of nematodes (Mojtahedi et al. 1993; Fourie et al. 2016). However, because even low levels of some nematodes puts potato crops at risk of being rejected by processors, mustard cover crops should be used to enhance, not eliminate, chemical control of nematodes. Fall incorporation works best for control of nematodes and soilborne diseases and, oriental mustard may be better for this use than white mustard for disease suppression (Lazzeri and Manici 2001). Research is ongoing.

Suppress weeds. Weed control using mustard green manures has been variable (Haramoto and Gallandt 2004). The level of suppression seems to depend on the combination of mustard type and weed species and on the management of the green manure crop.

Biofumigation. Reductions in the numbers of nematodes, disease problems, and weeds are thought to be due in part to the presence of glucosinolates in mustards (Matthiessen and Kirkegaard 2006).

Figure 2. White mustard *(Sinapis alba)* on left; Oriental mustard *(Brassica juncea)* on right.

When the crop is incorporated into the soil, the breakdown of glucosinolates produces other chemicals that act against pests. These chemicals are similar to the active chemical in the commercial fumigant metam sodium.

Improve soil quality. Regular use of mustard green manure crops, with reduced tillage, has been found to increase soil organic matter levels and water infiltration rates and reduce wind erosion (McGuire 2003).

Crop Characteristics and Requirements

Soils

Mustards tolerate saline soils as well as barley and grow in soils with pH 5.5–8.3.

Temperature

Healthy, unstressed mustard plants can withstand temperatures into the low 20s (°F).

Herbicide Sensitivity

Mustards are sensitive to glyphosate as well as to 2,4-D and various other broadleaf herbicides. They may also be affected by carryover from herbicides used on previous crops.

Growth and Biomass

A mustard cover crop, planted in early to mid-August, will generally be in full bloom by the end of September in the Moses Lake area. Cool temperatures in September and October usually prevent it from producing viable seed before it is incorporated or freezes in late October or November. With approximately 100–120 lb available nitrogen and irrigation, mustards will produce up to 9,000 lb of dry matter per acre, depending on management and temperatures during the growing season (McGuire 2012).

Management

Seeding Dates

The optimal seeding time is during the second week of August; otherwise, up to the end of August is appropriate. With current varieties, planting in July is not recommended, as the mustard will mature quickly and require early incorporation to prevent production of viable seed.

Varieties and Sources

Several varieties and blends of both types of mustard are currently available. Plant seed that has been tested and certified not to be infected with the black leg (*Phoma lingam*) and black rot (*Xanthomonas campestris* pv. *campestris*) pathogens to avoid spreading these diseases. Most of Washington State is now protected by a Crucifer Quarantine to avoid introducing these pathogens on seed. If planting seed in an area where these diseases are established, plant only seed treated with fungicides that are effective against black leg or seed treated with hot water.

The mustards that are currently being used do not have hard or dormant seed. Cover crop varieties may not be acceptable for commercial purposes.

Wheat Straw

If possible when following wheat, leave the standing stubble to be incorporated with the mustard. This reduces the volunteer wheat emergence, avoids nitrogen immobilization by the straw and the resulting need for additional nitrogen, and may reduce winter leaching by immobilizing nitrogen released by mustard residues. See Figure 3.

Seeding Rates and Methods

The following seeding rates are the minimum recommended rates for white mustard green manures. Seeding rates for oriental mustard, which has smaller seed, may be reduced by one third. Some producers are experimenting with higher seeding rates which will produce smaller stems and roots that decompose more quickly when incorporated.

Figure 3. Mustard green manure growing in standing wheat straw.

Drilled. Drill 8–10 lb seed per acre through wheat straw using a minimum or no-till drill, or a drill with offset, double-disk openers.

Aerial seeding. Fly on the day before wheat harvest at 10–15 lb per acre Keep surface wet until crop has emerged after 5–10 days. Rolling or packing the field before irrigation will result in better stands.

Broadcast. Same rate as aerial seeding. This can be done in combination with fertilizer application, followed by a pass of a noninversion undercutter V-sweep implement which also kills existing weeds (Figure 4). Alternatively, use a packer to press seed into soil or, if wheat straw is absent, a light cultivation.

Seeding Depth

For quick emergence, which improves weed control, a depth of 1/8–1/4 inches is recommended for center-pivot irrigated fields, or down to one inch where overhead irrigation is not available.

Figure 4. An undercutter like this can be used to incorporate broadcast mustard seed while also killing weeds.

Seed Cost

Cost of seed is $2.00–2.40 per lb as of 2015. Commercial condiment varieties may be less expensive but may also be less suited for use as green manures. Ask your seed dealer.

Fertilization

Test soil to determine residual soil nitrate available to crop. For optimum growth, 120 lb available nitrogen per acre total (100–140 range) is needed over the season, with sulfur at 6:1 nitrogen-to-sulfur ratio. Early applied nitrogen will help the mustard compete with weeds and volunteer wheat.

Irrigation

To attain maximum benefits, maintain adequate soil moisture throughout growing season. This is critical to keep the mustard plants vegetative as long as possible for maximum biomass production. Stress will initiate flowering and limit biomass production.

Weed Control

Because mustard does not compete well early on, weed control may be needed. For best mustard growth, control the volunteer wheat and other grassy weeds with selective herbicides. Broadleaf weeds, such as pigweed, that emerge at the same time as the mustard are difficult to control, although the mustard often outgrows the weeds. In addition, large weeds that may be left after wheat harvest should be controlled before mustard emergence (see the broadcast seeding method in the Seeding Rates and Methods section). Check to see which herbicides are currently labeled for use with mustard.

Incorporation

Irrigation water shut-off, or fall practices such as fumigation, can dictate the timing of incorporation. For maximum biomass production, wait until late October to early November in the upper Columbia Basin, or three to six weeks before spring planting. Flail chopping followed immediately by disking to incorporate into top six inches of soil is recommended for maximum biofumigation effects (Figure 5).

One of the effects of a green manure is to bind soil particles together, enhancing resistance to erosion. However, this is a short-term effect. Therefore, leave sufficient residue—mustard, straw, or both—where wind erosion may be a problem. Do not let soil dry out in the fall because this will inhibit breakdown of the incorporated cover crop.

Figure 5. Chopping and disking of a mustard green manure crop.

Growers of mustards have a responsibility to either incorporate or otherwise kill plants which survive in fields or field borders to prevent potential cross-pollination with seed crops. Compared with spring-incorporated cover crops, fall-incorporated mustards will scavenge less soil nitrogen and therefore may result in nitrate leaching in some conditions. Incorporating the green manure with wheat straw may reduce this risk.

Possible Problems

Insects. There is the potential for increased soil insect populations after incorporation. Incorporate in fall or four to six weeks before planting spring crops to avoid these problems. In very mild winters, when the mustard does not winterkill, green peach aphids may overwinter on mustards. To avoid this, kill cover crop before spring warm-up. Various aphids and loopers can attack mustard, but damage is generally limited in late summer- or fall-planted mustard.

Effects. The effects of mustard green manures may vary due to differences in soil texture, organic matter levels, and quality; crop rotation; mustard variety and growth; initial pest levels; and other biological factors.

Other Resources

Mustard Green Manures, WSU Center for Sustaining Agriculture and Natural Resources

Using Green Manures in Potato Cropping Systems

This is a revision of EB1952E, written by Andrew McGuire and published by WSU Extension in 2003.

References

Fourie, H., P. Ahuja, J. Lammers, and M. Daneel. 2016. Brassicacea-Based Management Strategies as an Alternative to Combat Nematode Pests: A Synopsis. *Crop Protection* 80 (February): 21–41.

Haramoto, E.R., and E.R. Gallandt. 2004. Brassica Cover Cropping for Weed Management: A Review. *Renewable Agriculture and Food Systems* 19: 187–98.

Larkin, R.P., and T.S. Griffin. 2007. Control of Soilborne Potato Diseases Using Brassica Green Manures. *Crop Protection* 26 (7): 1067–77.

Lazzeri, L., and L.M. Manici. 2001. Allelopathic Effect of Glucosinolate-Containing Plant Green Manure on Pythium Sp. and Total Fungal Population in Soil. *HortScience: A Publication of the American Society for Horticultural Science* 36 (7): 1283–89.

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 Sciences* 25: 235–65.

McGuire, A.M. 2003. Mustard Green Manures Replace Fumigant and Improve Infiltration in Potato Cropping System. Crop Management.

McGuire, A.M. 2012. Mustard Green Manure Use in Eastern Washington State. In Sustainable Potato Production: Global Case Studies. Z. He, R. Larkin, and W. Honeycutt, eds. 117–30. Springer Netherlands.

Mojtahedi, H., G.S. Santo, J.H. Wilson, and A.N. Hang. 1993. Managing Meloidogyne Chitwoodi on Potato with Rapeseed as Green Manure. *Plant Disease* 77 (1): 42–46.

Ochiai, N., M.L. Powelson, F.J. Crowe, and R.P. Dick. 2008. Green Manure Effects on Soil Quality in Relation to Suppression of Verticillium Wilt of Potatoes. *Biology and Fertility of Soils* 44 (8): 1013–23.

Use pesticides with care. Apply them only to plants, animals, or sites as listed on the label. When mixing and applying pesticides, follow all label precautions to protect yourself and others around you. It is a violation of the law to disregard label directions. If pesticides are spilled on skin or clothing, remove clothing and wash skin thoroughly. Store pesticides in their original containers and keep them out of the reach of children, pets, and livestock.

ESTIMATING PLANT-AVAILABLE NITROGEN RELEASE FROM COVER CROPS

D.M. Sullivan and N.D. Andrews

HIGHLIGHTS

■ Legume cover crops provide up to 100 lb PAN/a. To maximize PAN contribution from legumes, kill the cover crop at bud stage (early May).

■ Cereal cover crops immobilize up to 50 lb PAN/a. To minimize PAN immobilization from cereals, kill the cover crop during the early stem elongation (jointing) growth stage (early April).

■ Legume/cereal cover crop mixtures provide a wide range of PAN contributions, depending on legume content. When cover crop dry matter is 75 percent from cereals + 25 percent from legumes, PAN is usually near zero.

■ A laboratory analysis for cover crop total N as a percentage in dry matter (DM) is a good predictor of a cover crop's capacity to release PAN for the summer crop.

— When cover crops contain a low N percentage (less than 1.5 percent N in DM), they provide little or no PAN.

— When cover crops contain a high N percentage (3.5 percent N in DM), they provide approximately 35 lb PAN/ton of dry matter.

— PAN release increases linearly, as cover crop N percentage (in DM) increases from 1.5 to 3.5 percent.

■ Cover crops decompose rapidly and release or immobilize PAN rapidly. Most PAN is released in 4 to 6 weeks after cover crop kill.

■ PAN from legume cover crops is usually much less expensive than PAN from organic fertilizers.

■ Values for cover crop PAN listed here are most applicable to winter cover crop/summer vegetable crop rotations in western Oregon and Washington.

Dan M. Sullivan, Extension soil scientist, and Nick D. Andrews, small farms Extension agent; both of Oregon State University

Cover crops provide many benefits: reduced soil erosion, improved soil tilth, and increased soil biological activity, to name a few. Legume cover crops are especially important for maintaining nutrient balance in organic cropping systems because they are one of the few organic inputs that supply nitrogen (N) without phosphorus (P) or potassium (K). Cereal cover crops are planted mainly with two goals: (1) maintaining vegetative cover in winter (to reduce soil erosion) and (2) to take up residual soil nitrate-N from the summer crop that might otherwise leach to groundwater.

A key benefit of cover crops is their ability to supply plant-available nitrogen (PAN) for the following crop. PAN consists of ammonium-N + nitrate-N. The PAN provided by a cover crop can replace purchased N inputs such as fertilizer, compost, or manure. But, to take advantage of this benefit, you need to know how to predict the PAN value of the cover crop. How much PAN is provided? When is PAN provided? What is the best way to predict the PAN-supplying ability of various cover crop species and mixtures?

What is in this publication?

This publication has four sections:

- PAN basics (pages 2–5)
  - — Why cover crop N percentage is a good indicator of cover crop PAN
  - — Other cover crops
  - — When to kill a winter cover crop to get maximum PAN benefit
  - — Estimating PAN
- Applicability of this guide (page 5)
- A site-specific method to estimate PAN: step-by-step instructions on how to perform site-specific measurements to predict PAN from your cover crop (pages 6–9)
- Case studies: Willamette Valley examples addressing frequently asked questions about cover crop management, PAN, and the value of cover crop PAN as an N fertilizer substitute (pages 10–16)

In addition, a series of appendices summarize Willamette Valley cover crop research that supports our PAN estimates (pages 17–21).

PAN basics

Why cover crop N percentage is a good indicator of cover crop PAN

Cover crops may increase or decrease N fertilizer needs for the following crop in the rotation. Because decomposition happens quickly, so does PAN release or immobilization (negative PAN).

PAN released from a cover crop depends on crop species and crop growth stage. In general, green leafy plant tissues have high N concentrations and high PAN. More mature plant tissues (stems) have low N concentrations and low or negative PAN.

Carbon (C) and N dynamics control PAN release. As soil organisms decompose cover crop residues, a portion of cover crop C is lost from soil (as carbon dioxide). The remaining cover crop C is transformed by the decomposition process, yielding fresh soil organic matter with a C:N ratio of approximately 12:1. For a typical cover crop, 60 percent of cover crop C is lost as carbon dioxide, and 40 percent of cover crop C is incorporated into soil organic matter. Most of this decomposition occurs in the first 4 to 6 weeks after spring plowdown.

Nitrogen percentage in a cover crop is strongly related to PAN release following cover crop incorporation, as illustrated in the conceptual example given in Table 1 (page 3).

- For legumes (e.g., common vetch) that are high in N, about half of cover crop N is released as PAN because the cover crop has more N than needed to "build" soil organic matter.
- For non-legumes, such as cereal rye, that contain about 2 percent N in dry matter (DM) during stem elongation, the release of PAN is small, because most of the cover crop N goes into soil organic matter.
- When cereal crops reach the heading growth stage (1 percent N in DM), PAN is immobilized (made negative) by cover crop decomposition because more N is required to build soil organic matter than is present in the cover crop.

Table 1.—Nitrogen fate after rapid phase of cover crop decomposition is completed.[1,2]

Cover crop (%N in DM)	Growth stage	Biomass DM	Cover crop N uptake	N fate	
				N in soil organic matter	Plant-available N (PAN) NH_4-N + NO_3-N
		(lb/a)	(lb/a)	(lb/a)	(lb/a)
Common vetch (3% N)	vegetative	3,000	90	40	50
Cereal rye (2% N)	stem elongation	3,000	60	40	20
Cereal rye (1% N)	heading	8,000	80	107	-27

[1]Rapid decomposition typically occurs during the first 4 to 6 weeks after cover crop plowdown.
[2]Assumptions: Cover crops contain 40 percent C in DM; 60 percent of cover crop C is decomposed (lost as carbon dioxide); all cover crop N is retained (zero N loss); stable soil organic matter has C:N ratio of 12:1; 1% N = 20 lb N/ton DM.

Cover crop roots contribute only a small amount of PAN for the following crop and are ignored in calculations used in this publication. Research conducted in western Washington showed that Austrian pea and hairy vetch cover crops contained approximately 100 lb N/a above ground, but only 10 lb N/a in roots (Kuo et al., 1997). Roots also had low N in DM (%N less than 2 percent; C:N ratio greater than 20), suggesting that PAN release would be near zero.

Other cover crops

Phacelia is sometimes used to replace cereals as a winter cover crop. Like cereals, PAN from phacelia is positive in early vegetative growth, but is near zero or negative at flowering.

Brassicas provide PAN when killed at flowering growth stage (%N in DM is near 2 percent). Brassica cover crops are atypical in western Oregon vegetable crop rotations because of concerns about cross pollination of Brassica seed crops. Also, Brassica cover crops stimulate soil-borne diseases, such as club root, that can infect Brassica cash crops (cabbage, broccoli, turnips, etc.). Mustard (a Brassica species) is used successfully in eastern Oregon potato rotations.

When to kill a winter cover crop to get maximum PAN benefit

PAN from any cover crop is minimal when the cover crop is killed when it is very small (e.g., in March). For solo cover crops, the best time to kill the cover crop to maximize PAN depends on whether the cover crop is a legume or a non-legume.

- PAN from a good stand of legumes (Figure 1) peaks at budding growth stage (May). PAN declines slowly as reproductive growth continues.

- PAN from cereal residues is positive early in the spring (through tillering, mid- to late March). As stem elongation proceeds (jointing), PAN from cereal residues declines. By the time the flag leaf (uppermost leaf) emerges (Feekes growth stage 8 or Zadoks 37), PAN from cereal crop residue is near zero. When cereal heads are visible (Figure 2), PAN from cereals is negative.

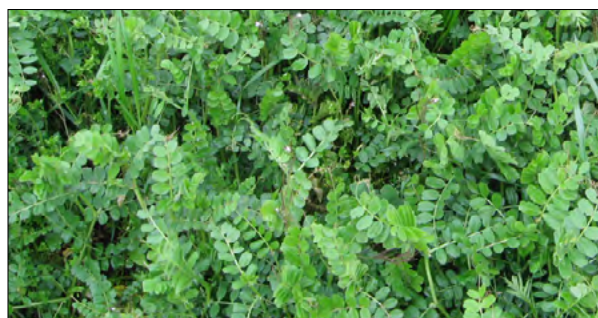To maximize PAN, kill cereal cover crops early, but wait until bud stage to kill legumes.
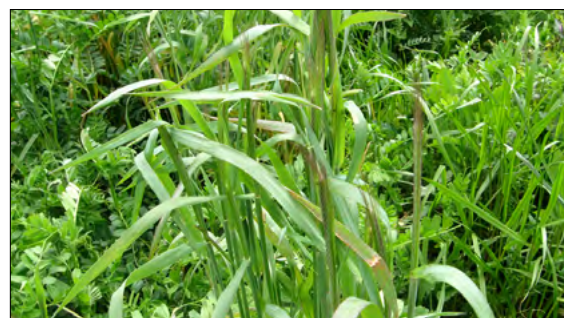

Figure 1.—Common vetch in the vegetative stage.

Figure 2.—This cereal rye has started to head.

In cereal/legume mixtures (Figure 3), the best crop growth stage for maximum PAN benefit depends on the percentage of legume in the stand.

- When the cover crop has mostly legume (75 percent legume line in Figure 4), it behaves much the same as does a pure legume cover crop. However, the PAN from crop residue increases until cereal boot stage (Feekes stage 10; Zadoks stage 45). After cereals reach boot stage, PAN declines.

- When a cover crop has more cereal than legume (25 percent legume line in Figure 4), it follows a similar PAN curve as a solo cereal crop, but negative PAN is usually not seen until the cereal reaches boot stage (around mid-May). A cover crop with at least 25 percent legume can be allowed to grow until early May (boot stage for cereal) without danger of N immobilization (negative PAN).

Seeding legume/cereal mixes instead of a solo cereal crop allows greater flexibility in timing of cover crop kill without consequences of negative PAN.

Estimating PAN

Cover crop N uptake is the total amount of N present in above-ground biomass. Usually, less than half of cover crop N uptake is released as PAN during the first year after incorporation. Figure 5 shows the typical relationship between cover crop N concentration and expected PAN release. Table 2 (page 5) has the same information in a table format.

Photo by D. Sullivan

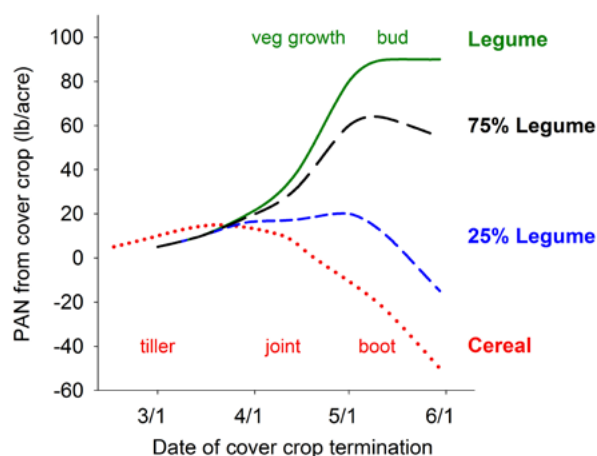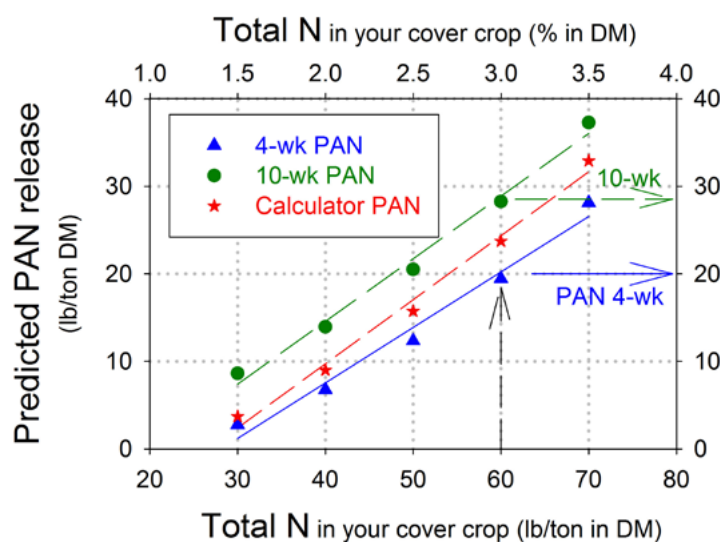Figure 3.—This phacelia is flowering, but the peas are in late vegetative stage.

FIgure 4.—Effect of kill date on typical plant-available N (PAN) release from cereal, legume, or mixed stands. Based on compilation of field data from Willamette Valley cover crop trials. Source: D. Sullivan.

Figure 5.—Predicted PAN release from cover crops. *Instructions*: (1) Find the total N analysis of your cover crop, using either the top (%N in DM) or bottom (lb N/ton in DM) x-axis (using a commercial laboratory analysis or "typical value," page 9). (2) PAN release predictions are made on the y-axis. Four- and 10-week predictions are estimated by incubation of cover crop residue in moist soil at 72°F (Sullivan et al., 2011). Calculator predictions are estimated by the OSU Organic Fertilizer and Cover Crop Calculator (http://smallfarms. oregonstate.edu/calculator).

Table 2.—Predicted PAN release from cover crops. *Instructions*: (1) Look up your cover crop N analysis in one of the left columns (use either the "%N in DM" or the "lb N/ton in DM" column). (2) PAN release predictions are made in the right columns.

Your cover crop total N[1]		Predicted PAN release[2]		
		4 weeks	10 weeks	Calculator
%N in DM	lb N/ton in DM	lb PAN/ton DM		
1.0	20	<0	0	0
1.5	30	3	9	4
2.0	40	7	14	9
2.5	50	12	20	16
3.0	60	19	28	24
3.5[3]	70	28	37	33

[1]Total N analysis of your cover crop sample performed by a commercial laboratory or "typical value" (page 9) for the cover crop. 1% N in DM = 20 lb N/dry ton.

[2]PAN predictions: 4- and 10-week predictions are estimated by incubation of cover crop residue in moist soil at 72°F (Sullivan et al., 2011). Calculator predictions are estimated by the OSU Organic Fertilizer and Cover Crop Calculator (http://smallfarms.oregonstate.edu/calculator).

[3]Few cover crop samples in Oregon studies contained more than 3.5 percent N when sampled in mid-April, so 4- and 10-week PAN predictions are not available from our data. The Calculator gives predictions for higher cover crop %N.

Example:

You sampled the cover crop using one of the harvest methods (page 7) and submitted a composite sample of the cover crop to the lab for N analysis. The cover crop biomass you measured was 2 ton DM/a, and the lab analysis was 3 percent N (60 lb N/ton DM). Using Figure 5 or Table 2, you can see that predicted PAN release from this cover crop is:

- 20 lb N/ton after 4 weeks
- 28 lb N/ton after 10 weeks

This is similar to the 24 lb N/ton predicted by the equation used in the OSU Organic Fertilizer and Cover Crop Calculator. See Appendix A (page 17) for more information on Calculator calibration.

PAN release per acre is calculated as follows:

PAN (lb/a) = cover crop biomass (ton DM/a) x estimated PAN (lb PAN/ton DM)

Example: 2 ton DM/a x Calculator prediction (24 lb PAN/ton DM) = 48 lb PAN/a

Applicability of this guide

The field sampling approaches described to determine cover crop N uptake are applicable to a wide variety of cropping systems.

Research to support our recommendations was performed in the Willamette Valley, where cover crops are normally seeded in fall and killed in spring prior to a summer vegetable crop (see appendices for details).

Compared to results in western Oregon, winter cover crops accumulate less N in western Washington at the same calendar date because of the cooler climate, and some popular Oregon cover crops do not survive the colder winters in western Washington.

Equations used to predict cover crop PAN in this publication (Table 2 and Figure 5) are very similar to those originally developed to predict PAN from Kansas crop residues (see Appendix A, page 17, for details). We expect a strong relationship between cover crop %N and PAN to be found in most locations. However, the timing of PAN release will differ in regions outside of western Washington and Oregon.

Crop residue decomposition rate and accompanying PAN release rate are primarily driven by soil temperature and moisture content. Decomposition proceeds two to three times faster at a soil temperature of 70°F than it does at 50°F. Decomposition proceeds most rapidly when soil is near field capacity, and it slows as soil dries.

Local research has not specifically addressed whether the method of cover crop kill (tillage, herbicide, roller-crimper, mowing) affects PAN. Research from other regions suggests that cover crop kill method does not affect the amount of PAN release, but these practices may affect the timing of PAN release.

To evaluate cover crop PAN release in novel climate/cropping/management systems, we recommend using soil nitrate testing to validate PAN release following cover crop kill. To do so, compare soil nitrate-N accumulated over time in cover crop strips versus no-cover-crop strips in the same field.

Using a site-specific method to estimate PAN

The recommended field sampling and analysis method in this publication is based on a whole-plant above-ground sample from a specified area. The cover crop is harvested from a known area in the field, weighed wet, then subsampled. The subsamples are sent to an analytical lab for determination of cover crop biomass (dry weight) and total N percentage (%N in DM).

Advantages of a site-specific method

- Accuracy of cover crop N "credits" is improved, and N fertilization practices can be fine tuned.
- Accuracy of this method has been documented extensively for winter cover crops harvested from March through May in the Willamette Valley.
- A site-specific method is especially useful for mixed cover crop stands.

Cost

- Collecting and weighing four quadrat samples from a field typically requires 1 to 2 hours of labor.
- Laboratory analysis for DM and %N in DM costs $20 to $40 per sample.
- Additional time is required to send samples to the analytical lab, enter data, and use the Worksheet.

Supplies needed

- A sampling frame. The frame can be any size (we use 2' x 2' frames) and can be made from metal, PVC pipe, wood, or any other readily available material.
- A scale with about 20-lb capacity and 0.1-lb accuracy

- A sharp knife or sickle (e.g., lettuce harvesting knife)
- About four large paper bags (e.g., grocery bags) for collecting samples
- A large plastic tub or bag (at least 10-gal capacity) for combining samples
- A 1-gallon zippered freezer bag for submitting the sample

Step-by-step method

Step 1. Select an analytical lab. Because you will be collecting perishable cover crop samples, think about shipping details prior to sample collection. Check with your analytical lab to determine shipping options, sample packaging (paper or plastic), analysis cost, and whether the lab will grind the whole submitted sample (see step 5). We recommend working with a laboratory that will dry and grind the whole sample you submit. Grinding the whole sample prior to subsampling for analysis ensures that the lab analyzes a representative sample (a few grams at most) of your cover crop.

Step 2. Select the cover crop sampling areas in the field (quadrats). It is better to sample a number of representative small quadrats from different parts of the field (Figure 6) than to sample one large area. For most fields, four quadrats will give an adequate estimate of cover crop field weight and species mix. Choose sample areas that represent the species mixture and plant biomass in your field. Record the quadrat area sampled (ft^2).

Photo by K. Pool

Figure 6.—Place the sampling frame in representative areas of the cover crop.

Figure 7.—After working the frame to ground level, cut the plants that root inside the frame (harvest method A).

Figure 8.—Harvest method A, the finished sample.

Figure 9.—Push the cover crop down in one direction (harvest method B).

Step 3. Harvest the cover crop. Cut the cover crop, leaving about an inch of stem above ground. Do not harvest small, low-growing weeds, because they typically have adhering soil. Getting soil into a cover crop sample alters its analysis, inflating DM and reducing N percentage.

The best method for harvesting quadrats depends on the type of cover crop stand. Three methods are described below. Any harvest method can be used that gives you a clean plant sample with a known harvest area.

Harvest method A. Short, upright cover crops can be harvested using a quadrat frame. Work the frame through the canopy to ground level. Sample plants that root within the quadrat (Figures 7 and 8).

Harvest method B. For tall or trailing cover crops, push down the canopy in one direction and cut through the cover crop lying on the ground (Figures 9–10).

Harvest method C. Use a sickle-bar mower or similar harvesting equipment to cut a cover crop strip from the field (Figure 11).

Figure 10.—Cut through the cover crop to sample all plants lying within the frame (harvest method B).

Figure 11.—Using a sickle bar mower to sample cover crops (harvest method C).

Regardless of the harvest method used, combine all of the field cover crop samples in a large bag or container. Clean plastic tubs or bags (at least 10 gal) work well. Avoid crushing or smashing the cover crop into slime. Protect samples from wilting in the sun or getting soaked by rain.

Step 4. Weigh quadrat samples. Weighing can be done in the field with a tarp, tripod, and hanging scale (Figure 12). When it is not convenient to weigh in the field, you may want to weigh samples under a roof on a platform scale. An accuracy of about 0.1 lb is sufficient.

Step 5. Prepare subsample for laboratory analysis. Place the combined field samples on a tarp or clean, flat surface and vigorously mix the sample (Figure 13). Chop or tear apart large plants. When the sample is thoroughly mixed, collect a large handful that fits loosely in a 1-gal zippered freezer bag (half full) and weighs about a pound. This is your lab sample.

It might take a couple of rounds of subsampling to reduce the field sample volume to a 1-gal lab sample volume. If you are not satisfied that you are getting a good mix of species, leaves, and stems, slice the plants into 4- to 6-inch pieces before doing the final subsampling.

Step 6. Ship the sample to the lab for dry matter and total N analysis. Ship the sample so that the lab receives a fresh plant sample. Ship samples with blue ice to keep plastic bags cool in transit, or ship the sample overnight. Generally, it is best to ship the sample early in the week, so it can be processed shortly after arrival.

Step 7. Review laboratory analyses. Tracking cover crop lab analysis values for multiple fields over 2 or 3 years will help you develop a running average that reflects your management system. After you have consistent data for 3 years of cover crops under your management, you may be able to reduce the frequency of lab analyses.

What %N and DM are "typical"?

- Typical mid-April DM and %N for cereals and common vetch are given in the sidebar "Shortcut method" (page 9). Typical DM for phacelia, clover, and rye/vetch cover crop mixtures is shown in Appendix C (page 20).

What range is possible?

- Cover crop N can range from less than 1 percent N in cereals after head emergence to 4 to 5 percent N in very young, leafy plants.
- DM of 10 percent can be present in young, leafy, wet cover crops such as vetch or clover. Dry matter of 20 to 25 percent is typical for cereals after head emergence.

Photo by J. Luna

Figure 12.—Weighing the field sample from all sampled quadrats.

Photo by N. Andrews

Figure 13.—Remove any soil, tear up large plants, and mix the field sample.

Step 8. Estimate PAN using Table 2 or OSU Organic Fertilizer and Cover Crop Calculator.

Table 3.—Worksheet for estimating site-specific plant-available N release from cover crop.[1]

Line no.		Your value	Example: Vetch	Units
1	Area sampled to determine cover crop biomass: *Quadrat area (ft²) x number of quadrats*		16	ft²
2	Number of sample areas per acre: *43,560 ft²/acre ÷ Line 1*		2,723	sample areas/ acre
3	Wet weight of cover crop field sample (lb)		12	lb wet cover crop
4	Percent DM in cover crop: *lab data or your "shortcut" estimate[2]*		15	DM, % in wet cover crop biomass
5	Calculate cover crop DM (ton/a): *(Line 2 x Line 3 x Line 4 ÷ 100) ÷ 2,000*		2.45	ton DM/acre
6	Cover crop total N percentage: *lab data or your "shortcut" estimate (N, % dry wt)[3]*		3. 0	N, % in cover crop DM
7	Plant-available N from cover crop decomposition: *Find your %N in DM in column 1 of Table 2 (page 5), and then find estimated PAN release under the "Calculator" column.*		24	PAN, lb/ton DM
8	Calculate plant-available N for summer crop[4] (lb PAN/acre): *Line 5 x Line 7*		59	PAN, lb/acre

[1]The OSU Organic Fertilizer and Cover Crop Calculator calculates PAN (Line 8) from the input data in lines 1–6.
[2]See sidebar "Shortcut method" and Appendix C (page 20). A closed cover crop canopy retains moisture, so cover crop dry matter is relatively consistent across sampling dates.
[3]See sidebar "Shortcut method."
[4]Typical values for PAN are 30 to 70 lb N/a for winter cereal/legume cover crops killed in mid-April (see Case Study 5, page 15). Check your calculations if your PAN estimate (Line 7) is greater than 100 lb PAN/a. This is the maximum PAN value observed for excellent vetch cover crops allowed to grow to bud stage (total cover crop N uptake = 150 to 200 lb N/a).

Shortcut method

If you prefer to forego lab analysis, you can harvest and measure cover crop biomass (see steps 2–4 on pages 6–8) and use typical values for cover crop DM and %N to estimate PAN. Values below are typical for cover crops collected in mid-April in the Willamette Valley:

Biomass dry matter:
— Common vetch = 12 to 18 percent
— Cereals = 15 to 20 percent
— 50/50 vetch/cereal mix = 15 percent

%N in DM:
— Common vetch = 3 to 4 percent
— Cereals = 1.5 to 2.5 percent
— 50/50 vetch/cereal mix = 2.5 to 3 percent

The %N in cereals varies with field history. Fields that have a history of manure/compost application and/ or legumes in rotation have higher %N in cereal than do fields with history of only mineral N fertilizer application.

We always recommend cutting and weighing cover crop biomass to estimate PAN. Visual estimates of cover crop biomass are not very accurate, especially for multi-species cover crop mixes.

Case Study 1. Cover crop growth: Is bigger always better?

Situation
May can be rainy in the Willamette Valley, sometimes delaying cover crop kill by several weeks. Data shown below came from a field where cover crops were ready for killing in early May. Because of weather delays, however, the cover crop wasn't killed until late May.

Question
What is the effect on PAN of delaying cover crop kill until late May?

Method
Cover crop samples were collected on May 5 and May 27 from the same field, and N concentration in the harvested biomass was measured (lb N/ton DM). Crop biomass (lb/a) increased by about 10 to 20 percent between cover crop sample dates.

PAN was determined via incubation of cover crop samples in moist soil in the laboratory.

Nitrate-N accumulated in soil was measured after 4 and 10 weeks of incubation at 72°F.

Results
Delaying cover crop incorporation until late May increased N immobilization (negative PAN) for phacelia and cereal rye. Late May incorporation of legume cover crops also reduced PAN substantially (Figure 14).

Recommendation
To get the most PAN value from cover crops, we recommend they be killed during the late vegetative growth stage. In western Oregon, this is often the first window of dry weather after about April 15 (about 2 weeks before bud stage for legumes or boot stage for cereals). The PAN penalty for delaying cover crop kill past bud/boot stage (about May 1) is most severe for cereal cover crops.
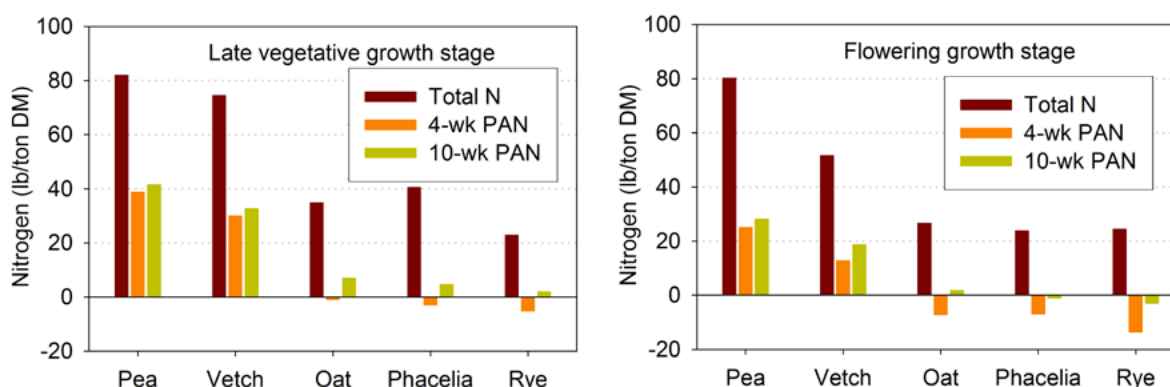

Figure 14.—Delaying cover crop incorporation until late May reduces PAN. Above-ground biomass was harvested on May 5 (left) or May 27 (right) from the same field in the northern Willamette Valley.

Case Study 2. Soil testing for nitrate-N to track PAN

If you don't estimate cover crop PAN by following the method described in this publication, you can use soil sampling to estimate the cumulative effects of the cover crop and soil organic matter on N fertilizer needs.

Most of the PAN released by a cover crop is present in the soil by about 6 weeks after incorporation. Thus, early-season (May/June) soil nitrate sampling can be used to assess N supply for a summer vegetable crop.

Soil nitrate-N above 30 ppm (0- to 12-inch depth) just prior to rapid vegetative summer crop growth is usually sufficient to meet yield goals for vegetable crops (Figure 15). When midseason soil nitrate-N is low, summer vegetable crops may respond strongly to PAN from a winter cover crop (Figure 16). In-season soil nitrate sampling can be used to assess PAN supply in both organic and conventional cropping systems. See the OSU *Nutrient Management Guide for Sweet Corn (Western Oregon)*, EM 9010-E, for more details.

Figure 15.—Lettuce growth did not increase with additional N fertilizer when midseason soil nitrate-N was above 30 ppm. Lettuce field had small plots receiving 0 to 200 lb PAN/acre, but all plants looked the same.

Figure 16.—Table beet growth responded strongly to PAN from a winter legume cover crop (upper half of photo) when midseason soil nitrate-N was low (less than 10 ppm nitrate-N).

Case Study 3. Replacing organic fertilizer N with PAN from cover crops

Situation

From the farmer's viewpoint, the most useful estimate of PAN release from cover crops is a direct field comparison with N fertilizer.

Field research to estimate PAN contributed by winter cover crops has been conducted by OSU faculty at on-farm and experiment station fields. Most of the trials used sweet corn as the test crop and compared PAN from cover crops to inorganic N fertilizer. The amount of inorganic N fertilizer replaced by a typical legume or legume/cereal cover crop (grown to mid-April) was 50 to 100 lb/a.

Question

What is the organic N fertilizer replacement value of vetch and oat winter cover crops?

Method

We present data from a recent trial with organically grown broccoli (Garrett, 2009) to illustrate the field research approach. This trial was performed with an organic fertilizer, feather meal (12-0-0) as the "grower standard" organic fertilizer.

Winter cover crops (oat, common vetch, or no cover crop) were seeded October 3, 2006 and incorporated by tillage May 12, 2007 when cover crops were flowering (Figures 17–19). Three weeks after cover crop incorporation, broccoli was transplanted into the field. Just prior to transplanting, feather meal was applied in rows at rates of 0, 90, 180, and 270 lb feather meal N/a (0 to 2,250 lb feather meal/a). Broccoli was harvested from August 17 through August 30.

Without a cover crop, broccoli yield increased up to a feather meal rate of 270 lb N/a. To determine the organic fertilizer N replacement value of cover crops, N response curves with and without the cover crop were compared (Figure 20, page 13).

Figure 17.—Common vetch (left) and phacelia cover crop (right) in May 2006. Source: Garrett (2009).

Figure 18.—Flail-mowing of cover crops prior to tillage.

Figure 19.—Tillage to incorporate cover crop residue using a power spader.

Results

The common vetch cover crop (biomass = 4,800 lb DM/a; N uptake = 120 lb/a) replaced about 110 lb feather meal N per acre (Figure 20, left).

The oat cover crop (biomass = 7,050 lb DM/a; N uptake = 40 lb/a) increased N fertilizer need. An extra 50 lb feather meal N/a was needed to compensate for PAN immobilized by oat decomposition (Figure 20, right).

In this trial, PAN release from the vetch cover crop occurred earlier than did PAN release from feather meal, because cover crops were tilled into soil several weeks prior to the feather meal application. The earlier release of PAN from vetch was important in this trial because background soil nitrate-N (without fertilizer or cover crop) was very low (less than 10 ppm nitrate-N at transplanting).

Soil nitrate-N testing, performed 5 weeks after transplanting, showed an extra 45 lb PAN/a with vetch versus no cover crop. The OSU Calculator prediction for PAN from vetch cover crop in this scenario was 35 lb/a. Therefore, PAN from vetch observed in this trial was similar to OSU Calculator predictions.

Recommendations

Oat, as grown in this trial (to boot stage) increased N fertilizer need, while vetch (flowering growth stage) reduced N fertilizer need. To overcome N immobilization by oat, we recommend earlier kill of the solo oat cover crop, or seeding of oat with a legume.

Cover crop N from vetch had a high value in the context of this organic farming trial. Feather meal PAN costs about $5 to $6/lb, so the fertilizer cost was reduced by more than $500/a with a vetch cover crop.
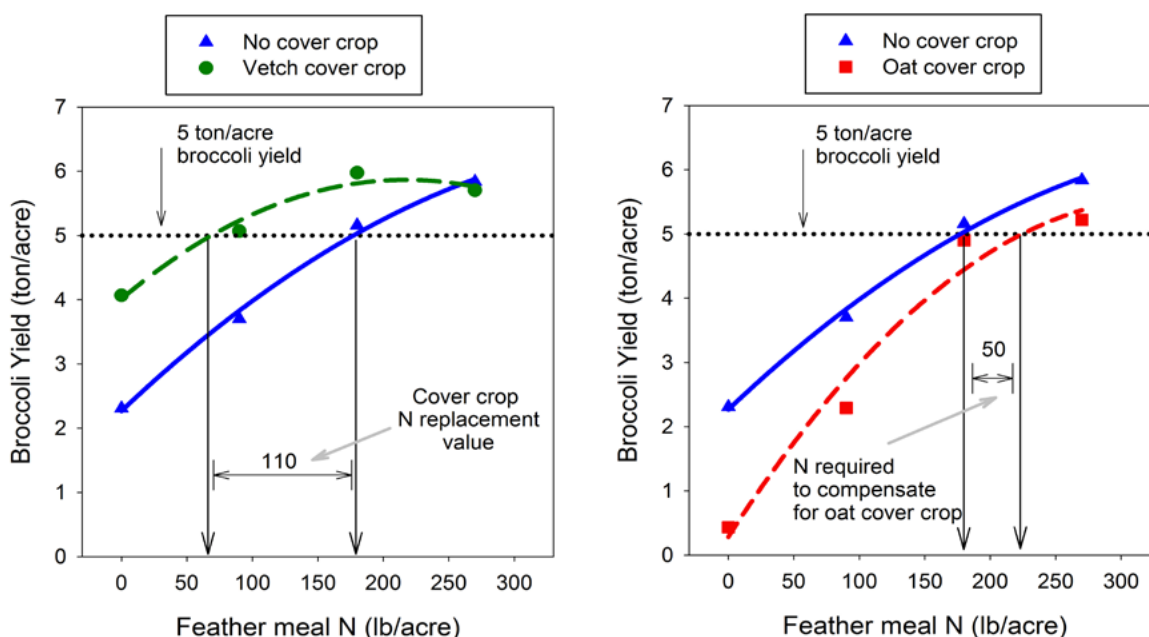

Figure 20.—A vetch cover crop reduces the N requirement for broccoli (left). An oat cover crop increases N required for broccoli (right). Fertilizer equivalency is estimated at a broccoli yield of 5 ton/a.

Case Study 4. Does it pay? Comparing cover crop PAN versus other N inputs using the OSU Calculator

Situation

Legume cover crops can provide a cost-effective source of PAN. The OSU Organic Fertilizer and Cover Crop Calculator can be used to compare the dollar value of N supplied via cover crops with the cost of other N inputs (inorganic fertilizer, compost, manure, or specialty organic fertilizers).

For any source of N input, the Calculator estimates cost per lb PAN, including management costs. When a winter cover crop produces typical PAN (40 to 70 lb PAN/a), the cost of cover crop PAN is usually $2 to $3/lb.

Legume cover crops are typically a more economical source of PAN than are common specialty organic fertilizers such as pelleted feather meal, fish meal, or chicken manure. Cover crop N is typically more expensive than N supplied by inorganic N fertilizers such as urea or UAN solution (urea-ammonium nitrate; 32-0-0) that are used in conventional production systems.

Question

How does the cost of cover crop PAN compare to the cost of organic fertilizer PAN?

Method

Costs used in the example reflect typical values for a small-acreage farm producing organic broccoli in a 30-acre field with a medium-size tractor (70 hp) and implements in 2011.

Results

This case study shows that cover crop N is less expensive than N supplied by specialty organic fertilizer (feather meal). With a typical vetch cover crop (2.5 ton DM/a and 60 lb PAN/a), PAN costs about $2.30/lb, as compared to more than $5/lb for PAN from feather meal.

Comparison of cost of PAN from cover crop and feather meal

Cost of PAN from cover crop ($2.33/lb)
Cost/lb for cover crop PAN ($2.33/lb) = cover crop expense/a ($140/a) ÷ cover crop PAN/a (60 lb/a)

Assumptions
Expense for cover crop establishment and kill = $140/a (assigns all cost of cover crop to PAN)
   Fall: Common vetch seed + inoculum ($50/a) + drilling seed + one irrigation ($45/a)
   Spring: Flail mowing, plowing, and discing to incorporate cover crop ($45/a)

PAN from cover crop = 60 lb/a
   Vetch cover crop N uptake (150 lb N/a) = 2.5 ton DM/a @ 3% total N in DM
   PAN estimate (60 lb/a) = 2.5 ton DM/a x 24 lb PAN/ton DM

Cost of PAN from feather meal ($5.80/lb)
Cost/lb PAN ($5.80/lb) = product cost/a ($335/a) + application cost/a ($15/a) ÷ 60 lb PAN

Assumptions (to supply 60 lb PAN/a)
   Product cost = $1,000/ton. Complies with USDA Organic Standard
   Guaranteed analysis = 12% total N
   Estimated PAN% (OSU Calculator) = 9% PAN (75% of total N; 0.75 x 12)
   Product rate needed = 60 lb PAN/a x 100 lb product ÷ 9 lb PAN (PAN is 9% of product wt)
       = 60 x 11.1 = 670 lb product

Case Study 5. Comparing PAN from solo vetch versus mixtures

Situation

Both cereals and legumes provide benefits as a cover crop. Although legumes typically provide more PAN than cereals, adding cereals to a cover crop mix may increase the overall benefit of the cover crop.

Question

Is it more beneficial to seed vetch alone, or with a companion crop?

Methods

On-farm research was conducted at northern Willamette Valley farms in 2009 and 2010 to evaluate a solo vetch cover crop versus species mixtures (cereal rye + common vetch or phacelia + common vetch). The PAN evaluation (reported here) was a part of a broader evaluation of cover crop benefits.

Cover crops were seeded in September or early October. If needed, fields were irrigated to provide moisture to the seedbed. Vetch was seeded at 60 lb/a in mixtures and 70 lb/a solo. Seeding rates of the vetch companion crop (rye at 30 lb seed/a or phacelia at 3 lb seed/a) were low enough to allow successful vetch establishment in the fall (Figure 21).

In spring, cover crop biomass was determined using the site-specific quadrat method (Table 3, page 9). Spring cover crop samples were collected April 9 to 30, 2009 and April 15 to May 7, 2010.

Plant-available N (PAN) was determined by incubating chopped cover crop residue in moist soil (20 to 25 percent gravimetric moisture) at 72°F in the laboratory (Figure 22).

Results

Cover crop performance. Cereal rye was a dependable companion to vetch, establishing a stand at all locations. Phacelia established well in the fall, but it winter-killed in four of seven fields, partially smothering the vetch.

Figure 21.—A mixed stand of cereal rye and common vetch at the mid-vegetative stage.

Figure 22.—Cover crop residue prepared at the laboratory for incubation.

Total biomass was similar (3,300 lb DM/a) for solo vetch and phacelia + vetch cover crops. Biomass for rye + vetch was higher on average, at 4,800 lb DM/a.

When seeded alone, vetch accounted for 65 to 70 percent of total cover crop biomass, with weeds accounting for the balance. When seeded with rye, vetch averaged 35 percent of total biomass. Vetch biomass was more variable when seeded with phacelia. Weed biomass was lowest with rye + vetch.

PAN from cover crops. Results are shown in Figure 23.

- Nitrogen concentration in cover crops averaged 3 percent N for solo vetch, 2.4 percent N for rye + vetch, and 2.8 percent N for phacelia + vetch.
- Plant-available N released from cover crop residues was similar for solo vetch or mixtures (40 to 70 lb PAN/a after 10 weeks).

Conclusions

- When cover crops are killed in mid-April, mixtures of vetch with rye or phacelia may provide additional benefits (soil erosion protection, weed control) without sacrificing PAN.
- Rye was a more dependable companion crop for vetch than was phacelia.
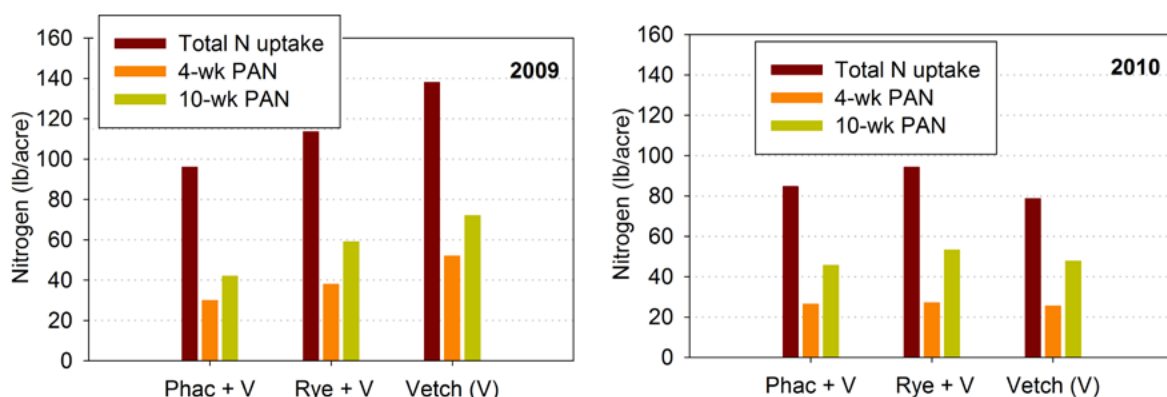
Figure 23.—In 2009, cover crop N uptake ranged from 80 to 140 lb N/a when vetch-dominated cover crop mixtures were killed at a vegetative growth stage in mid-April in the northern Willamette Valley (left). Plant-available N (PAN) ranged from 40 to 70 lb/a. Values for both N uptake and PAN were lower in 2010 (right). Values shown are the average of four field experiments in 2009 and three experiments in 2010. Source: N. Andrews, K. Pool, D.M. Sullivan, and R. Datta (Western SARE project FW09-328).

Appendix A
Cover crop incubations to validate OSU Calculator PAN estimates

Situation

A published regression equation (Vigil and Kissel, 1991) was developed for predicting PAN across a variety of crop residues in Kansas:

PAN (% of cover crop total N) =
-53.44 + 16.98 (cover crop %N x 10)$^{1/2}$

Question

How well does this regression equation predict PAN for Willamette Valley winter cover crop samples?

Method

About 50 cover crop samples were collected each spring (2008, 2009, and 2010) from field plots in the Willamette Valley using the site-specific method (see "Using a site-specific method to estimate PAN," page 6).

Samples were chopped and mixed with moist silt loam or sandy loam soil (Figure 24). Plant-available nitrate-N (PAN) accumulation was measured after 4 and 10 weeks of incubation at 72°F.

PAN (%) was calculated as:

(PAN for cover crop + soil – PAN for soil alone) ÷ cover crop N added x 100
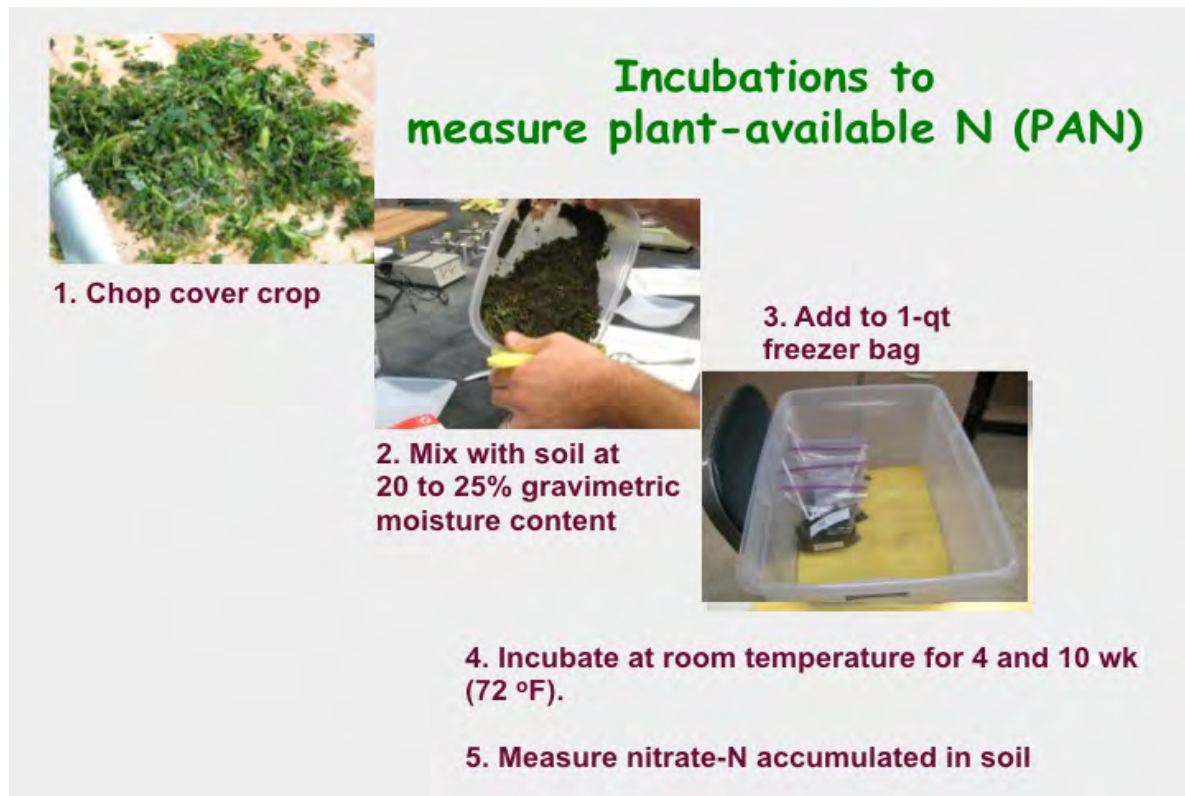
Figure 24.—Incubation method used to measure PAN. Source: D. Sullivan.

Results

Results are shown in Figure 25. As predicted by the Calculator prediction equation, PAN measured via incubation (y-axis, Figure 25) increased with total N in cover crop DM (x-axis).

Most of the PAN was released from cover crops in the first 4 weeks. Measured PAN values were equal to, or lower than, PAN predicted by the Calculator at 4 weeks. After 10 weeks, measured PAN exceeded Calculator predictions. The 4- and 10-week PAN values determined from these incubations were used to develop the linear PAN predictions for "typical" cover crops in Figure 5 and Table 2 (pages 4 and 5). The range in observed PAN at the same cover crop N percentage was about 5 lb PAN/ton DM at 4 weeks and 10 lb/ton DM at 10 weeks (Figure 25).

Because we had cover crops with low N concentration (20 to 40 lb N/ton cover crop DM) in only a few incubations, we do not show that data here. The Kansas regression equation performed adequately for cover crops with low N concentration (Case Study 5 and Appendix B). PAN predictions for low-N cover crops are included in Table 2 and Figure 5.

Our cover crop incubation results are plotted versus a linear form of the Kansas prediction equation in Figure 25. Total N in cover crop (x-axis) was changed from "% total N in cover crop" (Kansas equation) to "lb N/ton in cover crop DM." Units on the y-axis were changed from "N mineralized, % of cover crop total N" to "PAN, lb/ton cover crop DM." We made these unit changes to make the prediction equation more user friendly. A side benefit of the unit change was that the prediction line (Figure 25) became nearly linear, instead of curvilinear (as in the Kansas equation) when cover crop N is 40 to 75 lb/ton DM.

Additional details on validation of the cover crop equation used in the OSU Cover Crop and Organic Fertilizer Calculator can be found in Sullivan et al. (2011).
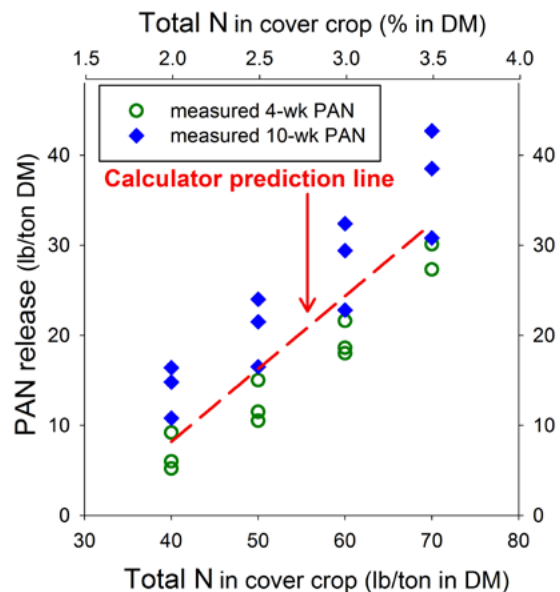

Figure 25.—Plant-available N (PAN) measured in cover crop incubations compared to PAN predicted by the equation used in the OSU Calculator. Variation shown (y-axis) represents measured PAN for cover crop incubations performed in different years (2008, 2009, or 2010). Source: Sullivan et al., 2011.

Appendix B
Using cover crop total N percentage to predict PAN

Situation

In this publication, we use cover crop %N as a predictor of PAN release (Figure 5 and Table 2 on pages 4 and 5). Many other publications use the C:N ratio as a predictor of cover crop PAN. However, because most cover crops contain 40 percent C in DM, the C:N ratio is usually just an indirect way to express crop N percentage. We find %N to be a more useful index of PAN because it yields a linear relationship with PAN, instead of the curvilinear relationship found using C:N ratio.

Question

How do PAN predictions using %N compare to those using C:N ratio?

Method

We collected crop residues from a field site in the northern Willamette Valley on May 5, 2008. To estimate PAN, we added cover crop residues to moist soil for 4 or 10 weeks at 72°F and then measured the accumulated soil nitrate-N.

Results

In Figure 26, cover crop total N (top graph) or C:N ratio (bottom graph) is plotted versus measured PAN for the same cover crop samples. PAN increased with cover crop N percentage (top), and it decreased with cover crop C:N (bottom). The linear relationship observed with %N as the predictor of PAN (top) is easier to interpret than the exponential relationship of C:N versus PAN (bottom). "Break-even" or zero PAN at 4 weeks was observed when cover crop N concentration values were 1.7 percent N (top) or when C:N was 24:1 (bottom).
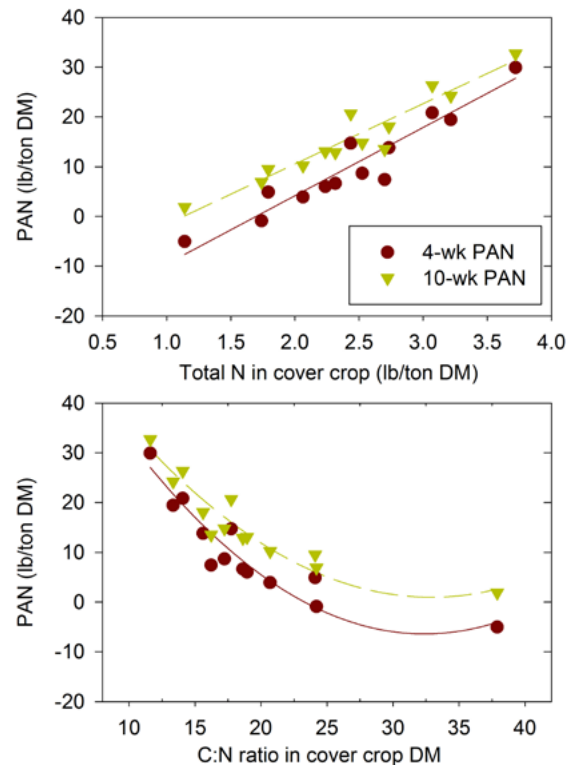

Figure 26.—PAN from cover crop residues (oat + vetch, rye + vetch, and oat + clover) as related to N percentage in cover crop DM (top) or C:N ratio (bottom).

Appendix C
Typical cover crop dry matter percentages

Situation

Dry matter (DM) is one of the measurements needed to estimate site-specific PAN using our worksheet (Table 3, page 9).

Question

How variable is cover crop dry matter among cover crop species and sampling times?

Method

Dry matter percentage in cover crop samples from grower fields in the northern Willamette Valley was determined in 2008–2010.

Cover crop samples were collected using one of the site-specific methods (Method A or B, page 7). More than 50 samples were collected each spring from grower fields just prior to the time of cover crop kill (mid-April to early May). Cereals were in the stem elongation growth stage (April) or near boot stage (early May). Other species were vegetative (April) or starting to flower (early May).

Results

Cover crop DM ranged from 10 to 22 percent, with most samples having 13 to 18 percent DM. Clover had the lowest DM, and cereals and phacelia had the highest DM.

Conclusion

Dry matter values shown in Table 4 can be used to evaluate whether your values for cover crop dry matter (Table 3, page 9) are "typical." These values can also be used as rough estimates when cover crop DM is not measured.

The range in DM found in cover crop samples can be large (10 to 22 percent). Site-specific DM measurement is recommended to improve the accuracy of your PAN estimate.

Table 4.—Dry matter percentage (DM%) in cover crop biomass harvested at vegetative growth stage (mid- to late April), northern Willamette Valley, OR.[1,2]

Year	Cover crop	Number of fields Single species	DM% range	DM% mean
2008	Cereal (oat, rye, or triticale)	4	16–20	18
	Clover	4	10–12	11
	Phacelia	2	17–22	19
	Common vetch	4	13–17	15
	Mixtures			
2009	Phacelia + common vetch	4	12–17	15
	Rye + common vetch	4	14–16	15
	Common vetch	4	12–16	14
2010	Phacelia + common vetch	3	15	15
	Rye + common vetch	3	13–19	15
	Common vetch	3	13–19	15

[1]Data Source: Nick Andrews (PI): WSARE project FW06-301 and FW09-328.
[2]Winter cover crop biomass collected April 16 to May 5, 2008; April 9 to 30, 2009; and April 15 to May 7, 2010. Average biomass yield = 3,800 lb DM/a.

Appendix D
Crop N uptake from diverse legume and non-legume cover crops

Situation

A wide variety of cover crop species is available. Growers would benefit from knowing the typical performance of these species.

Question

How do various cover crop species compare in DM accumulation, N uptake, and N concentration?

Method

Winter cover crops were evaluated for N uptake in field trials conducted in the mid-Willamette Valley from 1992–1995. Cover crops were seeded in September, then irrigated after seeding. Nitrogen uptake by cover crops was determined in mid-April.

Results

A major factor affecting cover crop biomass and N uptake was the winter hardiness of cover crop species. Crimson clover and the vetches were the most consistent legumes in terms of growth and N uptake. Winter wheat and cereal rye were the most dependable cereal cover crops.

Cereal N uptake was 40 to 70 lb N/a (0.8 to 1.2 percent N in DM), demonstrating that cereal cover crops can recover soil N that would otherwise be leached during winter months. Legume N uptake and fixation was 100 to 150 lb N/a (2 to 3 percent N in DM) for most species.

Table 5.—Dry matter and N accumulation by winter cover crops in the mid-Willamette Valley, 1992–1995.[1,2]

Cover crop	4-year average		
	Dry matter	N uptake	N concentration
	ton DM/a	lb/a	% in DM
Non-legume			
Humas rapeseed	2.5	60	1.2
Micah barley	1.6	50	1.6
Annual ryegrass[3]	2.6	40	0.8
Monida oats	2.7	50	0.9
Stephens winter wheat	2.7	60	1.1
Wheeler cereal rye	3.3	70	1.1
Juan triticale	3.6	60	0.8
Legume			
Fava bell bean	1.4	60	2.1
Austrian winter pea	2.0	120	3.0
Kenland red clover	2.1	100	2.4
Woolypod Lana vetch	2.2	150	3.4
Karridale subclover[3]	2.4	120	2.5
Hairy vetch	2.5	150	3.0
Common Dixie crimson clover	3.2	120	1.9

[1]Adapted from: Sattell et al., 1999, OSU Extension Service publication EM 8739.
[2]Cover crops were seeded in mid-September and irrigated after seeding. Dry matter and crop N uptake were measured in mid-April of the following year.
[3]Three-year average, 1993–1995.

For more information

Andrews, N. and D. Sullivan. 2010. Organic Fertilizer and Cover Crop Calculator. Oregon State University Extension Service. http://smallfarms.oregonstate.edu/calculator

Burket, J., D. Hemphill, and R. Dick. 1997. Winter cover crops and nitrogen management in sweet corn and broccoli rotations. HortScience 32:664–668.

Burket, J., J. Sandeno, D. Hemphill, and R. Dick. 2003. Cover Crop Nitrogen for Summer Vegetable Crops. Oregon State University Extension Service. EM 8803-E. http://ir.library.oregonstate.edu/xmlui/handle/1957/20217

Clark, A. (ed.). 2007. Managing Cover Crops Profitably (3rd edition). Handbook Series Book 9. http://www.sare.org/publications/covercrops/covercrops.pdf

Cogger, C., A. Bary, and L. Myhre. 2008. Organic Cover Crop Research at WSU Puyallup. Washington State University Puyallup Research and Extension Center. http://www.puyallup.wsu.edu/soilmgmt

Garrett, A. 2009. Improving nitrogen management with cover crops in organic broccoli production. M.S. thesis. Oregon State University, Corvallis, OR. http://hdl.handle.net/1957/12109

Hart, J., D. Sullivan, J. Myers, and R. Peachey. 2010. Nutrient Management Guide for Sweet Corn (Western Oregon). Oregon State University Extension Service. EM 9010-E. http://ir.library.oregonstate.edu/xmlui/bitstream/handle/1957/19064/em9010.pdf

Kuo, S., U. Sainju, and E. Jellum. 1997. Winter cover cropping influence on nitrogen in soil. Soil Sci. Soc. Am. J. 61:1392–1399.

Lawson, A., A. Fortuna, C. Cogger, A. Bary, and T. Stubbs. 2012. Nitrogen contribution of rye–hairy vetch cover crop mixtures to organically grown sweet corn. Renewable Agriculture and Food Systems. http://dx.doi.org/10.1017/S1742170512000014. Also available from authors at http://www.puyallup.wsu.edu/soilmgmt

Sattell R., T. Buford, H. Murray, R. Dick, and D. McGrath. 1999. Cover Crop Dry Matter and Nitrogen Accumulation in Western Oregon. Oregon State University Extension Service. EM 8739. http://hdl.handle.net/1957/15719

Sattell, R. (ed.). 1998. Using Cover Crops in Oregon. Oregon State University Extension Service. EM 8704. http://hdl.handle.net/1957/24506

Smith, R., R. Bugg, and M. Gaskell. 2011. Cover Cropping for Vegetable Production. University of California. Publication 3517. ISBN-13: 978-1-60107-679-3.

Sullivan, D., R. Datta, N. Andrews, and K. Pool. 2011. Predicting plant-available nitrogen release from cover crop residues. In: Proc. Western Nutrient Management Conference, 3–4 March 2011, Reno, NV, pp. 55–60. International Plant Nutrition Institute, Brookings, SD.

Vigil, M. and D. Kissel. 1991. Equations for estimating the amount of nitrogen mineralized from crop residues. Soil Sci. Soc. Am. J. 55:757–761.

Research on which this guide is based

Oregon

1990s. Richard Dick and graduate students (Burket, Sattell, and others) conducted cover cropping trials in the Willamette Valley and investigated the N contributions of cover crops to summer vegetables. Some of this research was reported in OSU Extension publications EM 8803-E and EM 8739.

1993–2009. John Luna conducted on-farm cover crop research with Willamette Valley vegetable growers. Findings were published in reports to the Oregon Processed Vegetable Commission. Luna and graduate student Amy Garrett conducted field trials to study N management in organic broccoli using legume and non-legume cover crops in 2007–2008, publishing results in Garrett's M.S. thesis.

2007–2011. Nick Andrews and Dan Sullivan conducted lab and field research to estimate PAN from cover crops. Field trials were maintained by Kristin Pool, and lab incubations were conducted by graduate student RonJon Datta. Key data from those trials are reported in appendices of this publication. Data from this research were used to support development of cover crop PAN predictions within the OSU Organic Fertilizer and Cover Crop Calculator.

Washington

1990s. Shiou Kuo and collaborators conducted trials at Mt. Vernon and Puyallup evaluating winter cover crops. A number of research articles were published by Kuo and collaborators on cover crop effects on soil quality and N.

2000s. Craig Cogger and collaborators conducted trials at Puyallup and other locations in western Washington to evaluate cover crops in the context of organic cropping systems. Publications by that group are found at http://www.puyallup.wsu.edu/soilmgmt

Section **3**

Additional Online Resources

ADDITIONAL ONLINE RESOURCES...

More Cover Crop Info

Numerous additional publications about mustard green manures are available through the WSU Center for Sustaining Agriculture and Natural Resources (http://csanr.wsu.edu/mustard-green-manures/)

Cover Crops for Home Gardens East of the Cascades (http://cru.cahe.wsu.edu/CEPublications/FS117E/FS117E.pdf)

SARE (Sustainable Agriculture Research and Education) Cover Crop Learning Center (http://www.sare.org/Learning-Center/Topic-Rooms/Cover-Crops)

Cover Crop Calculator (http://www.extension.uidaho.edu/nutrient/CC_Calculator/Cover_Crop_Main_page.htm)

Soil Sampling

A simple guide to collecting soil samples is provided through OSU extension (https://catalog.extension.oregonstate.edu/ec628)

Farmscaping for Beneficials

Farmscaping for Benefitials Resource List - Oregon State University (http://extension.oregonstate.edu/sorec/sites/default/files/resource_list_beneficial_insects_3.2014.pdf)

Many informative fact sheets are available from the Xerces Society:
- Native Pollinators on the Farm: What's in it for Growers? (http://xerces.org/fact-sheets/)
- Farming for Pest Management (http://xerces.org/brochures/)
- Farming for Pollinators (http://xerces.org/brochures/)

Information and resources are available through the OSU Integrated Plant Protection Center (http://www.ipmnet.org)

For natural pest control options organized by crop, there's the Pacific Northwest Insect Management Handbook (https://pnwhandbooks.org/insect)

Want More?

Do your own general search at (https://pubs.wsu.edu)

Food Systems

WASHINGTON STATE UNIVERSITY

Supporting thriving Washington farms, ecosystems, and food economies to provide communities with equitable access to sustainably produced and healthy foods.

Our food systems work is guided by an interdisciplinary team of WSU Faculty, Staff, and critical non-WSU partners. Team members collaborate on initiatives that promote research, implement change, and provide unparalleled educational opportunities for communities, graduates and undergraduates. All of this work is supported through the Center for Sustaining Agriculture and Natural Resources (CSANR) which convenes extension, research, and academics. Find us at **foodsystems.wsu.edu**

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working together to build an equitable and sustainable local food future for all

our local food system

earth · farm · garden · market · kitchen

tilth
ALLIANCE
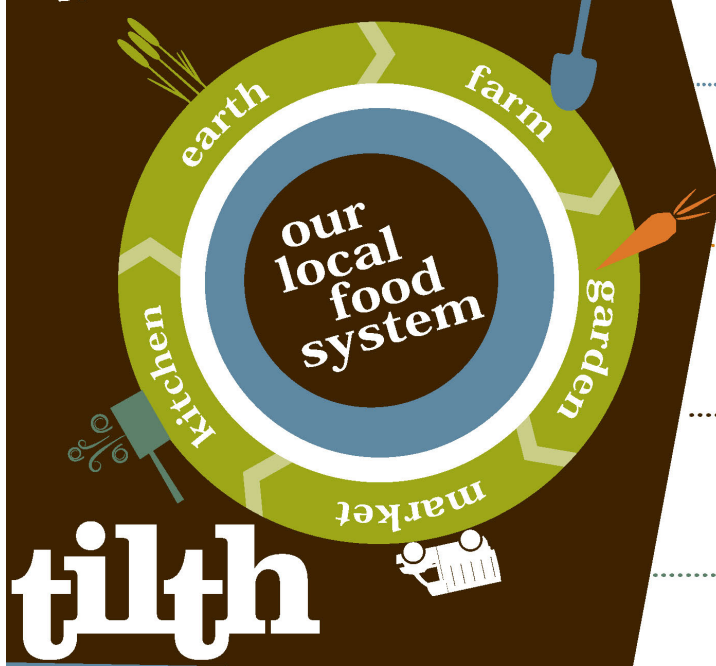
earth

A healthy environment is the foundation for growing healthy food. We enable community members to build healthy soil, restore the environment, manage pests naturally, protect water quality and teach others.

soil and water stewardship training | Garden Hotline Master Composter / Soil Builder training | restoration projects

farm

All farmers need support to thrive. We provide Washington's farming community with peer-to-peer education, connect them with the land they need and support their business enterprises.

farmer-to-farmer education | farm business incubator FarmLink | Tilth Conference | Tilth Producers Quarterly

garden

People who know how to grow food have better health, a stronger connection to the land and more resilience. We teach people of all ages and incomes to grow food.

adult classes | school tours | mobile classroom children's camps | community learning gardens teacher workshops | Tilth Alliance Youth Garden Works

market

Farmers need secure markets, and everyone has a right to food that is good for them and for the environment. We help consumers find local products and get produce into their hands through farmers' markets, community supported agriculture (CSA) and subsidized access for low-income families.

Farm Guide | CSA | Good Food Bags

kitchen

People who know how to cook and understand nutrition are empowered to eat well every day. We share cooking skills, nurtition knowledge and food traditions through classes, events and youth programs.

community dinners | youth cooking clubs | senior meals

tilthalliance.org