

# Green Manuring with Mustard; Improving an Old Technology

2003: Andy McGuire, Lauzier Agricultural Systems Educator, WSU Cooperative Extension Grant-Adams Area, WSU Center for Sustaining Agriculture and Natural Resources.

Green manuring, as it used to be called, is the tilling of fresh plant material into the soil to improve the soil and thus the growth of the following crop. It is an old technology, used by farmers since at least the 5<sup>th</sup> century BC. Immigrants brought the practice to the USA from Northern Europe and its use reached a peak in the early 1900s. Since then, most farmers have replaced green manures with synthetic inorganic fertilizers.

Recently, however, innovative farmers are giving this old technology a new look with mustard green manures (Figure 1). In contrast to the low input, low management green manures of the past, mustard green manures require fertilizer, irrigation, and intensive management. They require a current understanding of soil ecology, soil-borne pests, plant biochemistry, and breeding and screening techniques. And unlike synthetic fertilizers, they can improve the soil's physical, chemical, *and* biological qualities.

These multiple benefits are attracting an increasing number of farmers in the Columbia Basin of Washington (Figure 2). They are using mustard green manures, mainly before potatoes, to improve their soils and thereby manage soil-borne pests, control wind erosion, increase infiltration, improve crop yields, and they hope, increase profits.

## Green Manure Research

Up through the 1940s, green manure research was focused on improving the soil's physical characteristics and ability to supply nutrients to crops. Then, as synthetic fertilizers came into use, green manure research faded. In the late 1980s, researchers in the Pacific Northwest began to look again at green manures, but now for soil-borne pest control. Nematodes (Mojtahedi et al., 1993), weeds (Boydston et al., 1995), and soil-borne diseases (Davis et al., 1994, 1996) were all targets of this research, done mainly to improve potato production. Sudangrass, already used in Washington as a cover crop before potatoes, was used, but so were unfamiliar crops like rapeseed, oilseed radish, and mustard.

## Dale Gies' Cropping System

The use of mustard green manures by Columbia Basin farmers can be traced to sugarbeet research done in Idaho in the early 1990s. Several varieties of white mustard (*Sinapis alba*) and oilseed radish were imported for testing as trap crops of the sugarbeet cyst nematode. One of these mustard varieties, Martigena, made its way into the hands of several Columbia Basin farmers who were trying it out as a green manure in irrigated crop rotations. One of these farmers was Dale Gies.

Gies, who farms just south of Moses Lake, took several years to develop his unique [cropping system](#). This system is designed around a two-year rotation of wheat followed by potatoes, with a mustard green manure planted after wheat harvest and incorporated in late October. Reduced tillage, and good water and nutrient management practices are also important system components.

Using this system, Gies can successfully grow potatoes every other year on the same field, which is no small feat. He grows Norkotah potatoes, which are very susceptible to the soil-borne pathogen *Verticillium dahliae*. Basin farmers control this pest using longer rotations, at least 3 years between potato crops, and soil fumigation. However, in spite of his short rotation, Gies harvests above average yields. Until 2001, he still fumigated before planting potatoes, but experimented with omitting the fumigant in parts of fields. In those areas he saw evidence that fumigation might not be necessary in his system. He also noticed improvements in his soil. So in 1999, Gies began working with WSU to verify these observations.

In the past four years of on-farm research, we have measured improvements in soil quality and conducted fumigant replacement trials in Gies' fields. We have also worked to understand and improve the use of mustard green manures. Below is a description of this work.

### ***On-Farm Research***

*Improved soil quality.* Soil quality and soil health are equivalent terms used by researchers and farmers. A healthy soil is one that will support crop growth without soil degradation or harm to the surrounding environment. However, while the concept of soil health is easy to understand, it is difficult to measure. Fortunately there are several indicators of soil health that represent a combination of other soil factors. One of these is infiltration, the process of water entering the soil.

Infiltration is important in irrigated agriculture, especially where center pivot irrigation is used. In these systems, the water application rate at the outside of the circles is often higher than the infiltration rate of the soil. This can result in runoff and ponding in low areas, which can lead to increased incidence of root-rot diseases. Where fertilizers and pesticides are being applied through the water (chemigation), high infiltration rates allow the chemicals to stay where they fall. Good infiltration is also correlated with good aeration, which can reduce soil-borne disease problems.

Green manures can increase infiltration rates, but the effect is not direct. It begins, as with many green manure effects, with the addition of organic matter to the soil. As soil microorganisms digest this organic matter, they produce various substances called soil glues. These glues bond soil particles together into stable aggregates, or soil "crumbs," which allow water to move more quickly into the soil.

We have measured infiltration, on adjacent fields with similar soil textures. One was managed under the Gies cropping system. The other was in a rotation more typical of the Columbia Basin, with no green manures.

Infiltration rates (Table 1) were generally much greater under the Gies cropping system. One exception was after potato harvest on the Gies field and sugarbeet harvest on the adjacent field (2000). Infiltration rates on both fields were measured on soils that had been fluffed up during harvest. In this condition, the infiltration rate for the first inch of applied water was lower in the Gies field than in the adjacent field. However, the situation was reversed when a second inch of water was applied. We believe that the aggregates in the field not receiving green manures were not stable in water. After the first inch of water was applied, they broke down and sealed the soil. Infiltration in the Gies soil was stable, even when a third inch of water was applied. This difference in aggregate stability of the soils was confirmed in later measurements (Figure 3).

*Reduced wind erosion.* Another benefit of increased aggregation due to green manures is reduced wind erosion. Farmers in the Columbia Basin have observed this in fields receiving green manures and research to confirm their observations is on-going.

*Improved nutrient cycling/availability of nutrients.* Because a green manure is returned to the soil, much of the nitrogen that the mustard takes up, whether from fertilizer or residual from the previous crop, will become available to following crops. This is also true for other nutrients. As the saying goes, "feed the soil, and the soil will feed the plants." A rule of thumb for green manures incorporated the same season as the following crop is that 50% of the nitrogen in the green manure will be available. The actual amount depends on the plant composition, soil temperature, soil moisture, and losses due to leaching.

Leaching of nutrients released during decomposition is a risk with mustard green manures because they are incorporated in the fall. This risk may be reduced when the mustard green manure is incorporated with a large amount of wheat straw, which will tend to tie up any available nitrogen in the soil. To do this, farmers must direct seed the mustard through standing wheat stubble. If, however, the wheat straw is incorporated before mustard planting, it will tie up nitrogen and more fertilizer will be required to grow the mustard.

Spring incorporation would lessen the risk of leaching, but farmers prefer to incorporate in the fall for several reasons. First, they do not want to have to deal with a green manure in the spring when there are many other things to do. Second, there is less risk of damage from any soil-borne pathogens that might have been stimulated by the green manure in the short term. Finally, because mustards will not always survive our winters, a spring incorporation of dead plants would not give them the "green manure" effects that are important for pest control (see green manure effects below).

Green manures can also increase nutrient availability through weathering of soil mineral components. This weathering may be caused by the production of acids by microorganisms during the decomposition of the green manure. Research on the nutrient cycling of mustard green manure crops is beginning this year.

*Improved management of soil-borne pests.* Much of the renewed interest in green manures is for their potential to help control soil-borne pests, such as fungal pathogens and nematodes. Often, these pests cannot be controlled well with pesticides and when they can, as with soil fumigants, it is expensive to do so. Mustard green manures offer farmers a management tool for some of these pests.

The fumigant metam sodium is widely used in Columbia Basin potato production for the control of *Verticillium dahliae*, a major cause of the potato early dying complex. Without such control, yield losses of up to 30% can be expected. We conducted fumigant replacement trials to see whether such losses would occur in the Gies wheat/mustard-potato rotation if we did not apply metam sodium.

Three trials were conducted over two years (1999 and 2000) on loamy sand and sandy loam soils. Mustard green manures were fall-incorporated and potatoes (cv. Russet Norkotah), with and without metham sodium, were planted the following spring. The results (Figure 4) show that the fumigant did not increase potato yields over those produced after without fumigant. Gies could have saved the money spent on the fumigant and harvested the same amount of potatoes. This is one reason that potato growers are interested in the mustard green manures.

However, unlike Gies who grows short season potatoes for the fresh market, 90% of Washington's potato farmers grow longer season potatoes for processing. These potatoes are usually grown in 4-year rotations to reduce problems with *Verticillium*. In 2001, we began to investigate whether we would find the same results with these longer season potatoes in longer rotations.

Our first results (Figure 5) indicate that it is possible to replace metam sodium with mustard green manures in long season potatoes. However, while this first trial gave positive results, other fields (unreplicated plots) on the same farm showed lower yields where the fumigant had been left off. We are now trying to determine whether these conflicting results are due to differences in initial disease pressure, soil properties, management of the mustard, or something else.

## ***Pest Control Mechanisms***

The effects of mustard green manures are the result of multiple mechanisms. Because it is difficult to observe these mechanisms in the soil, our strategy has been to identify, as best we can, the primary mechanisms and the green manure attributes that enhance these mechanisms. We can then manage the mustard to produce those attributes.

In this strategy, we have focused on three groups of mechanisms that stem from different aspects of the mustard green manure; crop rotation effects from growing the crop, "green manure effects" from tilling fresh plant material into the soil, and biofumigation effects from the chemicals in the green manure.

*Crop Rotation.* Before advances in soil science and microbiology, many effects of green manures were combined under crop rotation. Rotating diverse crops can reduce pest problems by changing the environmental conditions in the field. These changing conditions disrupt pest life cycles. In general, rotating crops with different planting dates (spring vs. fall), different growing habits (annual vs. perennial, tall vs. short, fibrous vs. tap roots) or different susceptibility to pests (grasses vs. broadleaves) prevents any one pest from becoming a problem.

Mustards are poor or non-hosts of the Columbia root-knot nematode, a serious pest in potatoes. Although a mustard green manure is probably not grown long enough to reduce nematode number by this mechanism, the poor/non-host status keeps the nematode populations from increasing. These nematodes, however, can increase on weeds in the mustard. Therefore, some farmers choose to control volunteer wheat and other weeds in their mustard crop with selective herbicides.

One rotation related concern of Columbia Basin farmers is that the mustard could cross-pollinate with existing Brassica seed crops. The August planting date of most mustard green manures limits this risk, but farmers growing mustard still have the responsibility to prevent cross-pollination by either incorporating or otherwise killing plants which survive in fields or field borders.

*Green manure effects.* The "green manure effects" include several mechanisms, all the result of the addition of the green manure to the soil. This incorporation of the fresh, green, plant material changes the biology of the soil through a transfer of energy. Energy from the sun, stored in plants, is made available to soil microorganisms through green manuring. As these fungi and bacteria digest the plants, certain species, usually beneficial, increase in number because they are best suited to use this energy. The increased numbers of these beneficial species can then

suppress pathogens through a number of potential mechanisms such as the interference of chemical signaling between the plant and pathogen, predation, parasitism, and competitive exclusion.

Some scientists believe that competitive exclusion is the mechanism that suppresses *Verticillium*. It occurs when the increased number of beneficial microorganisms mentioned above out-compete pathogens for location in the rhizosphere (the area just outside roots) of the following potatoes. The *Verticillium* is thus excluded and cannot infect the crop.

There is evidence some green manures are better "food" for the soil than others. Certain Brassica green manures have been shown to increase the total fungal populations while reducing those of *Pythium* (Lazzeri et al., 2001). In the same study, a non-Brassica green manure resulted in increases in both total fungal and *Pythium* populations. The differing results may be due to chemicals in the Brassica crops (see Biofumigation below)

One of the greatest benefits of these "green manure effects" could be suppressive soils. These are soils that should have a disease problem, but do not because certain microorganisms are suppressing the diseases causing agents, whether fungi, bacteria, or nematodes. Suppressing soils have often been the result of growing the same crop continuously for many years. Disease pressure increases at first, but eventually decreases and remains at low levels. Green manures may be a more practical way to build suppressive soils. Different green manure crops have been evaluated for their ability to produce soils suppressive to *Verticillium*, common scab, and other soil-borne diseases (L.L. Kinkel, data not yet published). Canola, sudangrass, and buckwheat were found to be better green manures than other crops in creating these suppressive soils (mustard was not tested).

Although the effects of green manures usually favor beneficial microorganisms, there can be short-term increases in disease-causing *Pythium*, *Fusarium*, and other fungi immediately after the incorporation. This increase does not usually last long, but farmers should wait from 2-4 weeks after incorporating a green manure before planting a crop.

*Biofumigation (allelopathy)*. Biofumigation is the name coined to describe the effects of the chemicals produced by a Brassica green manure crop (Kirkegaard and Sarwar, 1998). It is one type of allelopathy, the chemical inhibition of one species by another.

Plants in the Brassica family, such as rapeseed, broccoli, cabbage, and mustard, produce compounds called glucosinolates in their roots and shoots. They also produce an enzyme called myrosinase, which is normally separated from the glucosinolates. When the plant cells are damaged, by an insect or by a farmer chopping a green manure crop, the glucosinolates and the myrosinase come together. A reaction takes place that produces a mixture of other compounds (Figure 5). Some of these resulting compounds are toxic to soil fungi, nematodes, and even weed seeds. These are the same chemicals make your nose burn when you eat hot Chinese mustard.

One class of these compounds, called isothiocyanates, are very similar to synthetic fumigants, hence the name biofumigation. The active compound in the fumigant metam sodium is methyl-isothiocyanate.

However, biofumigation is not as simple as using metam sodium. There are over 100 different glucosinolates, which produce different degradation products, which have different effects on specific soil-borne pests. Different species produce different glucosinolates. Within a species,

roots may produce different glucosinolates than shoots. Finally, glucosinolate concentrations differ according to plant part, age, health, and nutrition. Despite this complexity, the potential exists to reduce pest populations in the soil through this mechanism (Brown and Morra, 1997).

### **Effects on soil-borne pests**

*Verticillium and other soil-borne fungal pests.* As mentioned before, *Verticillium* is a serious pest in potatoes and controlling it with fumigants is expensive. In the 1990s, it was found that a sorghum-sudangrass green manure could suppress *Verticillium* as well as fumigant (Davis, 1994). Later research showed that other grass green manures, such as barley, wheat, and sweet corn also suppressed *Verticillium*. To do this, it was necessary to produce lots of plant material, 4-5 tons of dry matter per acre, and incorporate it green. The incorporation of dry crop residues, even of mustard residues, does not give the same beneficial effects in terms of pathogen suppression as a green manure. This may be due to competitive exclusion, but whatever the mechanism, it is not exclusive to mustard green manures, and therefore is not due to biofumigation.

Other soil-borne fungal diseases such as silver scurf (Vaughn, 1998) and white mold (Smolinska and Horbowicz, 1999; Pung, 2002) might also be suppressed through biofumigation or a combination of these mechanisms.

*Nematodes.* It is not clear which mechanism is responsible for reducing the populations of parasitic nematodes. Growing a poor or non-host crop will help, but biofumigation and the green manure effects are probably also involved. Whatever the mechanism, rapeseed, sorghum-sudangrass, and white mustard green manures have all been shown to reduce the numbers of Columbia root-knot nematode by up to 90% (Mojtehedi et al., 1993). Unfortunately, this is not sufficient to meet quality standards for processing potatoes. Therefore, in fields infested with the Columbia root-knot nematode in the field, mustard green manures must be combined with fumigants or contact nematicides to obtain the necessary control.

*Weeds.* The rapid growth of mustard can shade weeds and reduce their growth. After incorporation, biofumigation is probably the mechanism that later suppresses germination of small weed seeds (Al-Khatib and Boydston, 1999). Crops seeded too soon after the incorporation of a Brassica crop can also be damaged.

### **Mustard Management Strategies**

As mentioned before, there are certain attributes of a mustard green manure that will enhance the effectiveness of the mechanisms that lead to improved soil quality and pest control. Farmers can manage the mustard to produce these attributes if they have the information they need to make good decisions. Table 2 shows these desired attributes, the mechanisms that they affect, the related management decisions, and the information available to help farmers make these decisions.

Table 2

<b>Desired Attributes</b>	<b>Mechanisms affected</b>	<b>Related Management Decisions</b>	<b>Information Available</b>
High biomass production	Green manure effects	Species/variety selection	<a href="#">Green manure variety trial results</a>
	Biofumigation	Planting date/method	<a href="#">Mustard fact sheet</a>

	Improved soil quality	Seeding rate Production inputs	<a href="#">Planting date trial results</a> <a href="#">Mustard nitrogen response trials</a>
Incorporation of fresh biomass	Green manure effects Biofumigation	Incorporation timing/methods	<a href="#">Mustard fact sheet</a> <a href="#">Using green manures in potato cropping systems</a>
High conversion of glucosinolates at incorporation	Biofumigation	Incorporation timing/methods	<a href="#">Mustard fact sheet</a> <a href="#">Using green manures in potato cropping systems</a>
Poor or non-host status to Columbia root-knot nematodes	Crop rotation	Species/variety selection	<a href="#">Mustard fact sheet</a> <a href="#">Green manure variety trial results</a>
High glucosinolate concentration	Biofumigation	Species/variety selection Production inputs	<a href="#">Green manure variety trial results</a>
Glucosinolates effective against targeted pests	Biofumigation	Species/variety selection	<a href="#">Green manure variety trial results</a> <a href="#">Mustard fact sheet</a>

## **Cost**

The cost of a mustard green manure, as grown on the Gies farm, is shown in Table 3. Because a green manure is used to improve the following crop, its cost should be viewed as part of the production costs for that crop. Increases in crop yield and quality, and potential decreases in nitrogen or pesticide needs, will all be factors in determining the worth of a green manure. In addition, the value of improved soil quality, in both the short and long-term, though difficult to estimate, should be considered.

The calculation is more straightforward where the mustard green manure replaces a fumigant. Where this is possible, substantial savings can be realized (Table 3).

## ***Green manures in Cropping Systems***

Mustard green manuring is not an isolated practice. It must be integrated into a cropping system to produce the maximum benefits. Systems that reduce tillage, avoid compaction, and control erosion will help maintain soil quality gains that come through green manure use. And good management of water and soil fertility will ensure that gains in soil-borne pest control will not be lost to waterlogged soils or over-fertilization.

## ***The Future of Green Manuring***

The demand for food, and thus the need for quality soils will only increase. And although improved synthetic fertilizers and pesticides will continue to be important, they, by themselves, do not build soil quality. It will be through green manuring and other practices that increase or

conserve soil organic matter that we will maintain and build our soils, just as it has always been. What will change is the attention we pay to green manuring.

If we continue to improve this old technology by applying our growing knowledge of soil ecology, plant pathology, plant breeding, biochemistry, horticulture, and agronomy there are many possibilities. Crops bred for green manure use. Rotation of green manure crops. Prescription green manure blends. Even genetically modified green manure crops. These could be the future of green manuring if we choose to pursue them.

In 1927, Pieters wrote in his book Green Manuring; Principles and Practice, "Much is known of what goes on in the soil when organic matter is added, but much still remains to be learned." Although we have learned much since then, the same could be said today. The soil still has secrets. There are still processes in plants that we do not understand. If we continue to increase our knowledge of both the soil and plants, green manuring could again become a common practice.

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