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RESEARCH & INNOVATION CENTRE




Mustard Production Guide

A guide for growing mustard as a biofumigant cover crop in Ontario

November 2024

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Introduction

This production guide highlights the best practices for implementing AAC Guard Mustard as a biofumigant cover crop. Combining the benefits of cover cropping with the pest and disease control benefits of a biofumigant crop is an ideal and sustainable way to optimize crop production and improve soil health

Site selection, planting practice and harvesting details for optimizing the biofumigation traits of AAC Guard are described and detailed herein. This comprehensive guide is supported by the findings collected during a field trial at the Vineland Research and Innovation Center's research farm.

Authors

Vineland Research and Innovation Centre is a non-profit organization dedicated to results-oriented horticulture research and innovation. Through an integrated and collaborative cross-country network, Vineland Research and Innovation Centre delivers products, solutions and services that address the challenges and opportunities for Canadian horticulture.

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Benefits to Ontario Growers

Biofumigation is a method of pest and disease control that utilizes the natural compounds produced by certain plants, such as Brassica species, to suppress soil-borne pathogens and pests. Mustard plants naturally produce glucosinolates, which are compounds that, when broken down, release bioactive substances that impact the soil around them. These substances can be toxic to a range of soil-borne pathogens and pests, including nematodes and fungi, and have been observed to inhibit weed seed germination. The biofumigation process helps reduce reliance on chemical treatments and lowers disease incidence.

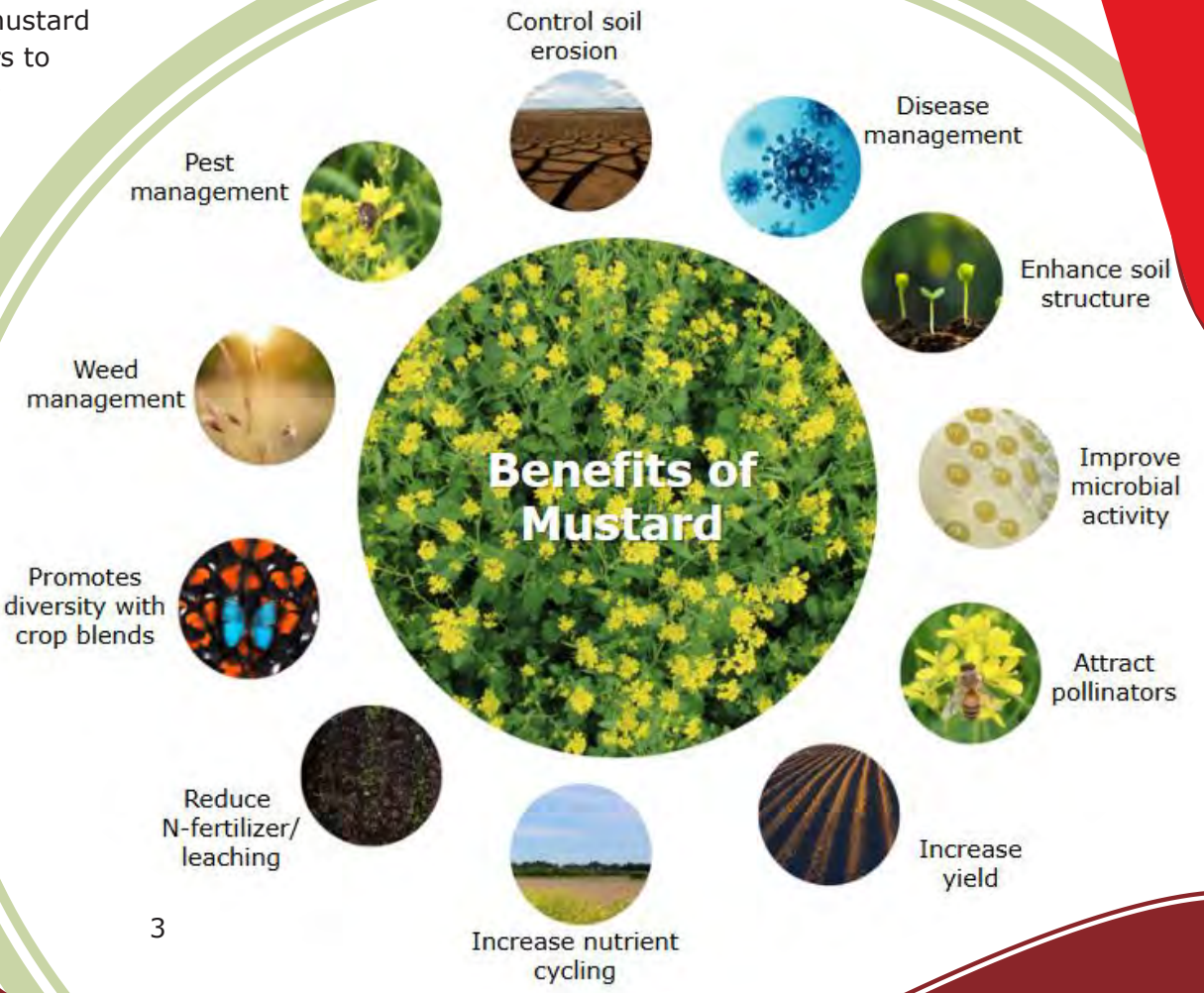
Mustard excels in reducing populations of plant-parasitic nematodes and soil-borne pathogens such as Phytophthora blight, Verticillium wilt, and Sclerotinia, decreasing the need for chemical treatments. Its effectiveness extends to weed suppression, as mustard cover crops can control weed density and germination, potentially reducing or eliminating the need for herbicides.

Mustard cover crops offer significant advantages in agricultural management, particularly through their biomass production above and below ground. The high volume of plant material generated by mustard not only aids in soil erosion control but also improves soil health by enhancing organic matter and nutrient cycling. This biomass contributes to a more robust soil structure, fostering better water retention and aeration.

Advantages of Mustard21's AAC Guard Male Sterile Hybrid

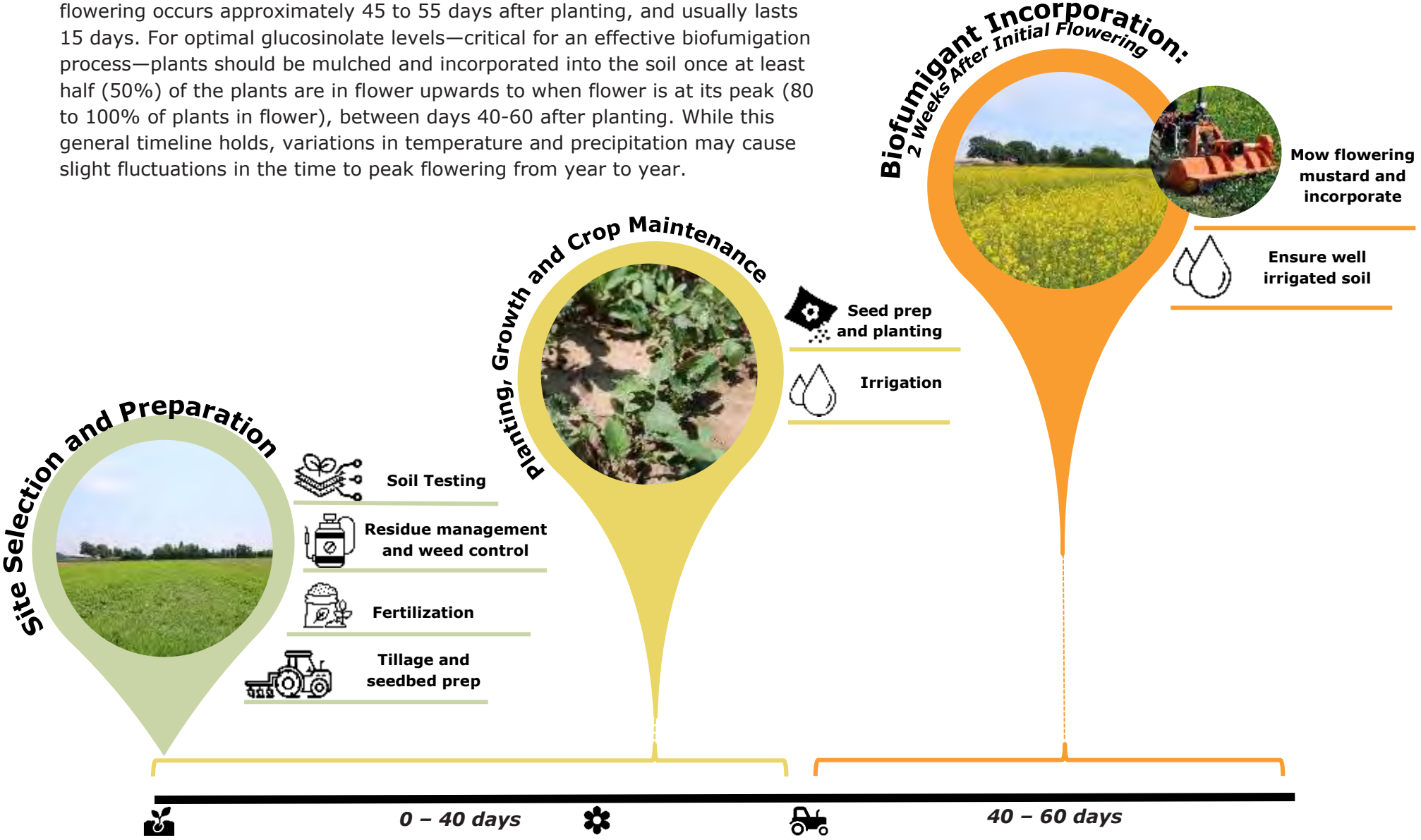
Male sterile mustard hybrid varieties offer additional benefits for biofumigation practices. Unlike fertile varieties, male sterile hybrids do not produce seeds. This characteristic eliminates the risk of these plants becoming weedy, as they cannot reproduce and spread. Consequently, growers do not need to invest time and resources in managing or eradicating leftover plants, simplifying field management and reducing overall input costs.

The use of AAC Guard as a mustard biofumigant will allow farmers to increase the biomass of their cover crop, while allowing longer flowering time to enhance pollinator activity compared to other mustard varieties.



Production Timeline

Mustard plants typically begin flowering around 30 days after planting. Peak flowering occurs approximately 45 to 55 days after planting, and usually lasts 15 days. For optimal glucosinolate levels—critical for an effective biofumigation process—plants should be mulched and incorporated into the soil once at least half (50%) of the plants are in flower upwards to when flower is at its peak (80 to 100% of plants in flower), between days 40-60 after planting. While this general timeline holds, variations in temperature and precipitation may cause slight fluctuations in the time to peak flowering from year to year.



Site Selection

Selecting a suitable site for growing AAC Guard as a biofumigant cover crop involves several key considerations. It is essential to evaluate the **soil type and fertility**, as mustard prefers well-drained, fertile soils with a pH between 6.0 and 7.0 for biofumigation to be effective. AAC Guard can grow in soils with 5.0 and 7.5 pH, however soil pH must be above 5.5 for optimal biofumigant results.

It is vital to understand the life cycle of the target pests if you are using them to manage soilborne pests and diseases. Review the **field's cropping history** to understand any pest or disease pressures and to plan crop rotation effectively. Choose a field with pests known to be susceptible to mustard biofumigation (Table 1). In addition, select a site that is free from previous heavy infestations of mustard family diseases. This cover crop should not be used on fields that recently grew *Brassica* crops to reduce the risk of spreading genus specific diseases and pests.

The **timing** of planting is critical; schedule seeding so that the crop will reach peak glucosinolate production by the time it is to be incorporated into the soil. The biofumigant should be incorporated when the pest is present in the upper soil layer (~20 cm deep). While previous research suggests that peak glucosinolate production occurs at peak mustard biomass (between 60-70 days after planting)[1,2,3,] Vineland determined that glucosinolate levels are similar on days 42 and 76 after planting the AAC Guard. Therefore, mustard should be sown about 40-60 days prior to the anticipated arrival of pests and disease (Table 1).

[1] Government of New Brunswick, Ministry of Agriculture, Aquaculture and Fisheries. (2015). *Growing mustard for biofumigation*. [Link].
[2] University of Massachusetts, University Extension. (2015). *Growing Mustard as a Biofumigant Cover Crop*. [Link].
[3] Michigan State University, Extension. (2006). *Mustards – a brassica cover crop for Michigan*. [Link].

Table 1. Crop pathogens and pests vulnerable to mustard biofumigation, the crops susceptible to them and the conditions when they are most active in Ontario. The active period for pests/pathogens may vary yearly, depending on environmental conditions.

Pest/Pathogen	Crops susceptible to the pest/pathogen	Conditions when pest/pathogen is active in Ontario
Verticillium spp *Verticillium Wilt* A soil-borne fungus that causes wilt and decline in a variety of plants. Symptoms include yellowing and wilting of leaves, often leading to plant death.	Brussels sprouts, cabbage, cantaloupe, cucumber, eggplant, hemp, honey dew, mint, pepper, potato, pumpkin, radish, raspberry, rhubarb, rutabaga, spinach, strawberry, tomato, watermelon.[4,5]	Moist soil and a temperature range of 21-27°C. Most active in the summer months of June, July and August.[5]
Rhizoctonia spp Rhizoctonia Root Rot or Damping-Off This fungus attacks plant roots, leading to poor growth, root rot, and in severe cases, plant death. It is commonly associated with seedling diseases.	Wide variety of crops. Barley, beet, canola, carrot, cereals, cucurbits, field corn, fruit crops, ginseng, hemp, lettuce, oat, ornamentals (woody and herbaceous), potato, radish, soybean, turnip, vegetable crops, wheat.[5,6,7]	Active in a wide temperature range (12-32°C), but optimal at 23-28°C. Most problematic in late spring and summer months of June, July and August.[5]
Fusarium spp *Fusarium Wilt or Fusarium Root Rot* Fusarium fungi cause wilting and root rot in many crops. Symptoms include yellowing of leaves, stunted growth, and poor root development. Some species can also affect grain quality.	Asparagus, barley, beet, broccoli, brussel sprouts, cabbage, cauliflower, cereal grains, cucurbits, eggplant, field corn, garlic, ginseng, lettuce, oat, onion, parsnip, pepper, potato, radish, rye, spinach, sweet corn, turnip, watermelon, wheat.[5,8]	Active when temperatures are 16-30°C and favours moist acidic soils. Fusarium wilt is most severe at soil temperatures of 27°C. Affects most crops in May and June.[5]
Pythium spp. *Pythium Damping-Off or Pythium Root Rot* Pythium fungi are responsible for damping-off disease in seedlings and root rot in mature plants. Symptoms include seedling collapse, root rot, and poor plant growth.	Barley, bean, beet, canola, cucurbits, eggplant, fescue, field corn, ginseng, Kentucky bluegrass, lettuce, mustard, oat, onion, orchard grass, pepper, rye, soybean, squash, strawberry, sweet corn, timothy, tomato, turnip, wheat.[5]	Moist soils with high relative humidity (>90%) and temperatures between 20-37°C. Most active in June, July and August.[5]
Sclerotinia spp. *Sclerotinia Stem Rot or White Mold* This fungus causes stem rot and white mold on a variety of crops. Symptoms include water-soaked lesions on stems and leaves, which eventually lead to moldy growth.	Alfalfa, bean, beet, brassicas, cabbage, canola, carrot, celery, cucurbits, garlic, herbs, lettuce, mustard, pea, pepper, potato, soybean, sunflower, tobacco, tomato, turnip.[5]	Temperatures ranging from 20°C–25°C and continuous leaf wetness (high humidity and/or heavy dews) favour development. Active in June, July, August and September.[5]
Common Scab Caused by Streptomyces bacteria, this disease leads to rough, scabby lesions on tubers, which can affect the quality and marketability of potatoes and other root crops.	Beet, carrot, parsnip, potato, radish.[5]	Warm, dry soils and a soil pH of 5.5–7.5. Optimal temperature for infection is 20-22°C. Most active in June, July and August.[5]
Nematodes Microscopic worms that infest plant roots, causing root damage, reduced nutrient uptake, and overall plant stress. Symptoms include stunted growth and wilting.	Most vegetable crops. Beet, blackberry, eggplant, field corn, garlic, ginseng, lettuce, onion, parsnip, potato, raspberry, rhubarb, soybeans, spinach, strawberry, tomato, turnip.[5]	In Ontario, nematode populations in soil and roots are usually highest in May to June and again in September to October.[5,9]
Wireworm Larvae of click beetles that feed on the roots and tubers of plants, leading to poor plant growth and damage. Symptoms include holes and tunneling in the soil and plant roots.	Bean, beet, carrot, cucurbits, eggplant, field corn, garlic, onion, pea, pepper, potato, sweet corn, sweet potato, tomato, turnip.[5]	Wireworms move to the top of the soil once soil temperatures reach 10°C. Most likely to be present in fields that recently had sod crops or following high grassy-weed pressure. Usually most active in May, June and July.[5]

[4] McCain, A. H., Raabe, R. D., & Wilhelm, S. (1981). (*Publication* 2703). *Plants resistant or susceptible to verticillium wilt* (pp. 1–10). Berkeley, California: University of California. [Link]
[5] Ontario Ministry of Agriculture, Food and Rural Affairs. (2024). *Ontario field vegetable guide (Publication 839)*. King's Printer for Ontario. [Link]
[6] University of Kentucky, College of Agriculture, Food & Environment. (2024). *Rhizoctonia diseases in specialty crop production*. [Link]
[7] Ontario Ministry of Agriculture, Food and Rural Affairs. (2017). *Agronomy guide for field crops: Chapter 16. Diseases of field crops* (Publication 811). Queen's Printer for Ontario. [Link]
[8] University of Kentucky, College of Agriculture, Food & Environment. (2022). *Fusarium wilts of vegetable crops*. [Link]
[9] Ontario Ministry of Agriculture, Food and Rural Affairs. (2022). *Sampling soil and roots for plant-parasitic nematodes*. [Link].

Field Preparation

Preparing a field for a mustard cover crop planting involves several steps to ensure that the cover crops establish well and provide the intended benefits.

Soil Testing

Conduct a soil test with an OMAFRA accredited laboratory to check nutrient levels (P, K, Mg, Ca, S), and pH, to identify any nutrient deficiencies. Collect 1 composite soil sample (0-15 cm depth) every acre which should consist of 20 sub samples that zig-zag across your field. Amend the soil as needed based on the test results and accompanying recommendations for mustard/canola. Maintaining a soil pH of 6-7 is essential for biofumigation. If the soil is too acidic when the mustard is incorporated, it will function as a green manure instead of releasing its bio-fumigating properties.[2]

Residue Management

If there are residues from a previous crop, manage them by mowing, shredding, or incorporating them into the soil. This ensures good seed-to-soil contact when planting the mustard crop.

Weed Control

Address any existing weed issues through mechanical cultivation, herbicide application or other weed management practices.

Fertilization

Nitrogen is essential for biomass production, while sulphur is essential for producing glucosinolates in the plant, which form the foundation for soil biofumigation through residue incorporation.[2] Sulphur can be applied alongside nitrogen at a 4:1 to 8:1 nitrogen-to-sulphur ratio.[3] Adequate nitrogen and other nutrients might be present when mustard is cultivated following a fertilized crop. Additional fertilization for your field may be required dependent on nutrient testing results and accompanying recommendations for mustard crop needs immediately prior to planting.[2]

Fertilizers can be broadcasted onto the field prior to sowing the mustard. Typical fertilization rates are 84kg/ha (75lbs/ac) to 140kg/ha (125lbs/ac) depending on the field's history.[1]

Tillage

Depending on the cover crop and field conditions, you may need to till the soil using tilling equipment such as a disc harrow to prepare a seedbed. No-till methods can be used for mustard biofumigation, but the small seeds may not establish well using a no-till drill.[3]

Seedbed Preparation

If the soil bed is dry, irrigate to provide adequate moisture for seed germination. To ensure even planting depth and water distribution, the field can be leveled if necessary. Mustard prefers a firm seed bed which can be achieved by rolling or culti-packing the soil after tilling to ensure good seed-to-soil contact.

Planting

Timing

Growing mustard as a cover crop provides benefits to the soil and cash crop regardless of the season it is planted in, such as improving soil health, nitrogen recovery, feeding pollinators and preventing erosion. For optimal biofumigation results the following seasonal timings should be considered:

Planting mustard as a cover crop in the **spring** is most effective for reducing plant pathogens. Early seeding reduces pests and diseases, increases biomass, enhances crop yield, and elevates soil nitrogen levels.

Sowing in mid to late **summer** often results in poor and uneven stands due to dry conditions and is generally not recommended without irrigation.[1] Hot weather and heatwaves may result in a shorter time to flowering and less biomass compared to mustard grown in the spring.

Fall-planted mustard is more effective at reducing weed biomass but is less effective in suppressing disease. Fall plantings may also reduce cover crop biomass while lowering soil nitrate levels.[1]

Planting mustard as a **winter** cover crop helps provide soil nutrients, particularly nitrogen, and reduces weed establishment.[10] If considering mustard as a winter cover crop, use seed priming techniques to accelerate germination and improve establishment.[11] Mustard can tolerate cool temperatures, germinating in soils 7-10°C.[2]

Seed Preparation

AAC Guard mustard seeds sold by Mustard21 can be purchased untreated or with a pre-treatment of Helix® Vibrance®, which includes four fungicides and a potent insecticide, providing pest control against threats like Rhizoctonia and flea beetles. For untreated seeds, seed priming, which involves controlled hydration and drying, can increase germination rates, reducing the time to 50% germination by 6 hours in mustard.[11] Rapid germination is especially beneficial in warm, quickly drying soils. The priming procedure is a 3-step process:

1. Surface seed sterilization - dip the seeds in a 5% bleach solution for 30 seconds, followed by a 30 second rinse in distilled water. Blot dry with filter paper.
2. Seed soaking - soak the seeds in distilled water for at least 2 hours in darkness at 22°C.
3. Drying - remove seeds from the water, blot dry and leave to air dry.

[10] Brennan, E. B., Boyd, N. S., & Smith, R. F. (2013). *Winter cover crop seeding rate and variety effects during eight years of organic vegetables: III. Cover crop residue quality and nitrogen mineralization*. Agronomy Journal, 105(1), 171-182.
[11] Snapp, S., Price, R., & Morton, M. (2008). *Seed priming of winter annual cover crops improves germination and emergence.* Agronomy journal, 100(5), 1506-1510.

Planting Practices

When using mustard for biofumigation, it's important to account for the small seed size. Ensuring that your equipment is properly calibrated to handle these small seeds is crucial to avoid over-planting. This not only prevents excessive seed usage but helps save on costs by using only the necessary amount.

Methods

Cover crops can be planted using a wide variety of methods and equipment, which are likely already used or owned by growers. Use equipment and methods that ensure good seed-to-soil contact to improve germination. The most common planting methods are broadcast and drill seeding.

- **Broadcast seed** at a rate of 10-15 lbs/acre. Mustard establishes well if broadcasted and harrowed to a depth of 1/2 inch.[3] After broadcasting, drag the soil to cover the seeds, ensuring good seed-to-soil contact.
- **Drill seed** at a rate of 8-12 lbs/acre. Drill seeding provides better seed-to-soil contact and more uniform germination compared to broadcast seeding. No-till drills can be particularly effective for planting cover crops without disturbing the soil structure. Seeds can be planted 0.25-0.75 inches deep in rows 6-8 inches apart.[2] If the field is wet, avoid drilling until it has dried down.

Vineland's Mustard Planting Practices

Soil preparation

The soil was tilled using a discer (Athens disc, 12-foot for smaller areas) to create an ideal seed bed.

Soil Packing

After drilling, a press reel was used to firmly pack the soil, ensuring good seed-to-soil contact for optimal germination.

Seeding

Rows were spaced 7.5 inches apart, with seeds drilled 0.25 to 0.5 inches below the soil surface.

Irrigation

No irrigation was required due to favorable seasonal conditions. However, during drier periods, minimal irrigation might be needed to support germination while keeping input costs low.

Crop Maintenance

Weeding

Mustard seedlings struggle to compete with weeds, making it important to manage weed pressure effectively. It is essential to start with a field free of weeds, as they can significantly hinder mustard growth. Shallow seeding promotes even and timely emergence.[3] For the best outcomes, address perennial weeds before planting.[3] High seeding rates of mustard alone may not be enough to ensure effective weed suppression. Cover crop mixtures that include a diversity of species can maximize weed suppression and biomass production[12], but have not yet been tested to determine impact on biofumigation benefits.

Irrigation

Adequate soil moisture is particularly important for germination and early seedling establishment; therefore irrigation may be necessary if rainfall is insufficient. Once established, mustard thrives on well-drained soil with adequate moisture.[3] It is not drought-tolerant and performs poorly in waterlogged conditions.[3] Cover crops are often not irrigated by growers for cost-savings. It is important to note that if there is minimal precipitation and high temperatures, mustard plants may begin to flower prematurely. This early flowering can occur before the crop has had sufficient time to develop the desired amount of biomass needed for effective biofumigation. Consequently, the potential benefits of mustard as a biofumigant may be reduced if the crop does not reach optimal growth stages due to insufficient moisture and heat stress. Early planting (in the spring) can reduce these risks.

[12] Ranaldo, M., Carlesi, S., Costanzo, A., & Bàrberi, P. (2020). *Functional diversity of cover crop mixtures enhances biomass yield and weed suppression in a Mediterranean agroecosystem*. Weed Research, 60(1), 96-108.

Pest and Disease

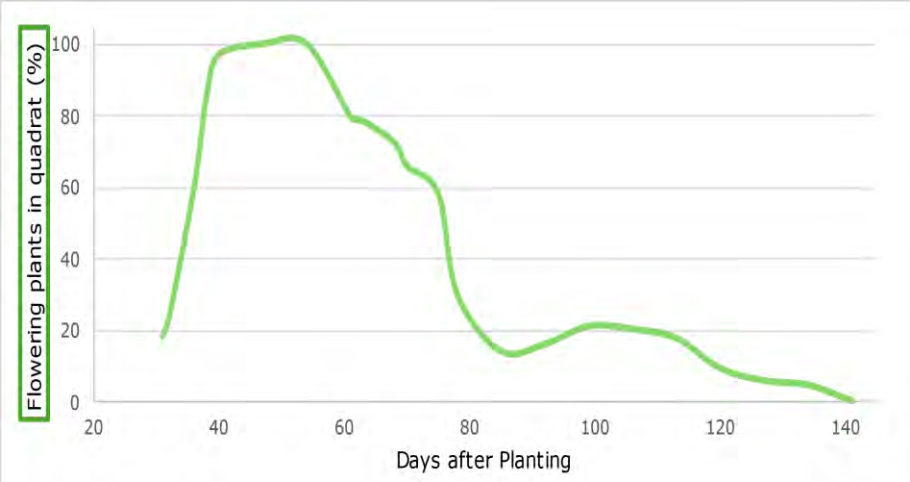
Growing mustard as a biofumigant cover crop will not require the intensive pest management of commercial crops because they are not destined for human consumption, can tolerate more damage, may increase biofumigant potency under stress and can serve as nurseries for beneficial insects.[13]

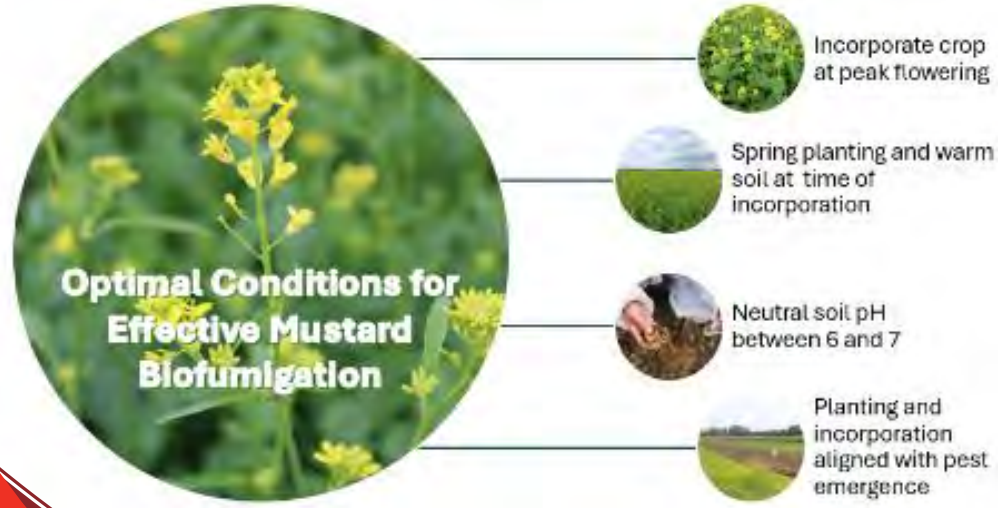
Mustard is vulnerable to many of the same pests that affect commercial brassicas (eg. cabbage and broccoli), including Japanese beetle, cabbage cluster caterpillars, center grubs, aphids, whiteflies, thrips and nematodes. Another significant pest of mustard is the diamondback moth larvae, which feed on the leaves, flowers, and green seed pods. Flea beetles can be damaging at the seedling stage, but the plant will generally outgrow vulnerability to this pest. Establishing a firm seed bed in fertile soil promotes vigorous seedling growth and is the most effective defense against flea beetle damage.[3,13]

Mustard is susceptible to Alternaria leaf spot, Black Rot, downy mildew, white mold, white rust, mosaic virus, bacterial soft rot, bacterial brown rot.[3] When mustard is grown continuously as a cash crop, disease risk is highest, but as a cover crop grown for only about 6 weeks, disease pressure is minimized, especially when planted in rotation.[3]

[13] Queensland Government, Department of Agriculture and Fisheries. (2020). *Brassica Biofumigant Cover Crops: Managing soilborne diseases in vegetable production systems*. [Link].

Incorporation of Crop Residue





Once the mustard crop has reached mid to peak bloom, approximately 40-60 days after planting, it is ready for mowing and incorporating into the soil to maximize biofumigant properties. During this flowering window, biofumigant compounds are at their optimal level.

In the research trial conducted at the Vineland farm, we identified no significant difference in biofumigant levels in the plants in July (day 42 post planting) and August (day 76 post planting).

The average values of the measured biofumigant compound across plots was 12 mg/g dry weight in July, and 13 mg/g dry weight in August.

Growers do not need to mow and incorporate as soon as peak flowering occurs, as we identified that there is about a three-week timeframe within which to achieve optimal biofumigation.

Mowing, Incorporating and Sealing:

Mow the crop:

Between 40 and 60 days after planting, when the plants are in mid to peak bloom (and biofumigant levels are at their highest), mow the crop completely. For optimal mulching of the crop residues, use equipment such as a flail or rotary mower.

Incorporate the residue into the soil:

80% of the biofumigant gas is released within the first 20 minutes of mowing.[1] Immediately after mowing, incorporate the crop residue into the soil. Recommended incorporation equipment includes a chisel plow, rototiller or heavy disc, aiming to thoroughly mix crop residue into the top 15-20 centimeters of the soil.

Seal the soil surface to ensure optimal fumigation:

Gently compact the soil using equipment such as a heavy board, roller, or culti-packer to trap the mowed residue and biofumigant gas within the top 15-20 cm of soil.

Allow the field to rest for optimal fumigation:

Do not disturb the field for two weeks after incorporation and sealing to allow the crop residue to break down. Do not disturb the field

Helpful Tips:

Prior to mowing, incorporation and sealing, ensure the field soil is moist:

Moist soil will encourage the biofumigant to be trapped more effectively when incorporated and will optimize its effectiveness. Irrigate dry soil before and after mowing and incorporating.

Although soil should be moist, heavy rainfall after incorporation can reduce soil Nitrogen due to leaching; therefore, plan incorporation according to local weather forecasts.

Incorporation should be done in the morning or evening when temperatures are lower:

Aim to incorporate mustard into soil when soil temperatures are at their coolest in the summer, but over 10C.

If the average daily soil temperature is below 10°C, a longer rest period after incorporation may be needed for plant material to break down.[1]

Additional Considerations

Winterkill: Most mustard varieties are susceptible to winter kill, meaning they generally do not survive harsh winter conditions. However, some varieties may endure mild winters causing growers to invest additional time and money into controlling or eradicating leftover plants. For those that do survive, using a male sterile hybrid variety offers significant advantages. These hybrids do not produce seeds and pose a significantly reduced risk of becoming weedy.

Labour needs: It typically requires just one person to prepare and plant a one-acre field with mustard. This same individual can also handle the tasks of mulching and using a discer to incorporate the plant biomass into the soil immediately afterward In terms of tillage and preparation costs, the expenses for mustard are generally in the same range as those for wheat.

Comprehensive approach: Although mustard biofumigation can help reduce disease, weed, and insect pest pressure, it should not be viewed as a stand-alone solution for these management challenges, but instead an important part of an integrated approach to support crop health.

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[2] University of Massachusetts, University Extension. (2015). *Growing Mustard as a Biofumigant Cover Crop*. [Link].

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[12] Ranaldo, M., Carlesi, S., Costanzo, A., & Bàrberi, P. (2020). *Functional diversity of cover crop mixtures enhances biomass yield and weed suppression in a Mediterranean agroecosystem.* Weed Research, 60(1), 96-108.

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