1.6

Selecting and Using Cover Crops

Introduction: Selecting and Using Cover Crops

OVERVIEW

Cover crops can be a key soil health and nutrient management tool for growers, and can have important implications for pest and disease management. This unit introduces students to the roles and selection of cover crops for organic farming and gardening. Two lectures address the influence of cover crops on the physical and chemical properties of soil, the role cover crops can play in pest management, the benefits and challenges of using cover crops, and the factors to consider when selecting a cover crop for a farm or garden. The in-field demonstration shows students how to estimate the nitrogen contribution of a cover crop. In the hands-on exercise, students will determine the amount of cover crop seed being discharged by a seed drill and learn how to calibrate the drill. The resources section includes an annotated list of print and web-based references for use in selecting cover crop species or mixes for specific regions and agricultural systems, including orchards, vineyards, and urban gardens. Supplemental topics address the role of cover crops in climate change, and offer examples of integrating cover crops into a small-scale organic vegetable farm on California's Central Coast.

MODES OF INSTRUCTION

> 2 LECTURES (1 HOUR EACH)

Lecture 1: Role and definition of cover crops; benefits and challenges of using various cover crops

Lecture 2: Cover crop selection, planting and care; special cases; how to plant; Nitrogen calculation.

> DEMONSTRATION: HOW TO ESTIMATE THE NITROGEN CONTRIBUTION FROM A COVER CROP (1 HOUR)

In this in-field exercise the instructor demonstrates how to collect and dry a cover crop sample and use it to estimate the amount of nitrogen that will available to the crop that season

> HANDS-ON EXERCISE: SEED DRILL CALIBRATION (1 HOUR)

This in-field exercise takes students through the steps of calibrating the amount of seed being discharged by a seed drill

> ASSESSMENT QUESTIONS: (0.5 HOUR)

Assessment questions reinforce key unit concepts and skills.

LEARNING OBJECTIVES

UNDERSTAND THE FOLLOWING CONCEPTS

- The influence of cover crops on the physical and chemical properties of soils and the productivity of crops grown in those soils
- The roles cover crops can play in pest and disease management
- The benefits and challenges to consider when selecting a cover crop for farm or garden use
- The disease triangle: Interactions among environment, pathogen, and plant
- The key steps involved in cover crop planting and incorporation

SKILLS

- How to access cover crop information
- How to evaluate cover crops for specific applications
- How to estimate nitrogen contributions of cover crops

Lecture 1: Definition, Benefits & Challenges of Cover Crops

A. Pre-assessment Questions

1. What benefits can be derived from the regular use of cover crops in a farming system?
2. What role do cover crops play in the management of soil fertility in organic farms and gardens?
3. How can cover crops be used to ensure adequate soil nutrient levels?
4. How can cover crops improve the physical and chemical properties of agricultural soils?
5. What roles can cover crops play in pest management?
6. What are some of the challenges to using cover crops?

B. Why Use Cover Crops?

1. The role of cover crops in organic farming systems

   Cover crops are one of the primary fertility and soil management tools available to organic growers. They are crops grown primarily for soil or ecosystem improvement rather than cash (although some can have secondary uses as fodder), and are most often planted following fall harvest and turned in to decompose prior to spring planting (although this varies depending on climate). Some fast-growing cover crops can also be grown during the cropping season to rebuild nutrient levels and soil organic matter.

   Cover crops can provide a variety of services, from increased nitrogen (N) and organic matter input, to soil protection, to weed and disease suppression. However, they can also have negative consequences if they are managed incorrectly or inappropriate species are selected. These issues are covered in Unit 1.1: Soil Health Management.

2. Cover crop, "green manure," and "catch crop" defined

   Although "cover crop" is the term most widely used for non-cash crops filling any one of several key roles, "cover crop," "green manure," and "catch crop" technically refer to different primary functions of the crops.

   a) Cover crop: Mainly used to prevent soil erosion by covering soil with living plants
   b) Green manure: Crop mainly grown to be turned under for soil improvement
   c) Catch crop: Used to "catch" nutrients left after harvest of a cash crop and prevent nutrient leaching

      Note that these are not mutually exclusive functions. For example, a fall-planted cereal + legume crop that is incorporated the following spring can serve as a cover crop, green manure, and catch crop, and generally will be referred to simply as a cover crop. However, different species and mixes may perform one function better than another.

C. Benefits of Cover Crops

Cover crops provide a range of benefits: alone or in combination, different cover crops can increase soil fertility, boost soil organic matter, limit weed growth, and minimize nutrient leaching and erosion, and more. When selecting cover crops, keep in mind the types of benefits they provide and the needs of your cropping system:

1. Provide nitrogen. Here the best choice would be a legume that is well adapted to your area. Rhizobia bacteria work in symbiosis with legumes to fix N_2 from the atmosphere, and the N becomes available after the plant is incorporated into the soil. It is important that sufficient rhizobia bacteria are present in the soil to give good root nodule formation, and hence N_2 fixation. If it is the first time a legume cover crop has been grown in a field it

is recommended that you purchase the appropriate rhizobium inoculant for the species being planted. Some seed also comes pre-inoculated. A rough guide to estimating the N contribution from a cover crop is shown in Lecture 2 (page 11; excerpted from *Managing Cover Crops Profitably, 3rd Edition,* published by the Sustainable Agriculture Network). A hands-on exercise will help you learn how to perform this estimate in a fall-planted cover crop.

2. Increase soil organic matter (SOM) and improve nutrient availability by increasing soil biological activity. To build SOM you would look for a high biomass-producing cover crop. Possible options include non-legumes such as annual rye grass, cereal rye, triticale, or sorghum/sudan grass. High-biomass legumes such as subterranean clover or woollypod vetch also provide both SOM and N input, as would a mix of cereals and legumes. A cover crop that can grow rapidly in a short time window is also effective: for example, a fast-developing crop of buckwheat grown after early summer harvest that is turned in to break down before late summer planting can boost SOM between crops (see Appendix 1: Cover Crop Seeding Rate & Depth Chart).
3. Scavenge nutrients left in the soil after the cash crop and prevent loss by leaching. To maximize nutrient scavenging the cover crop should have an extensive root system that develops quickly after planting. Non-legumes such as oats, cereal rye, triticale, rapeseed, annual rye grass, and mustards (e.g., c.v. Ida Gold, Kodiak and Pacific Gold) work well.
4. Prevent soil erosion. Here the key is to choose a species that rapidly covers the soil surface. Many of the species that are good nutrient scavengers also provide excellent ground cover. However, while annual rye grass is a good nutrient scavenger, it has fine leaves and is slow to cover the soil surface. Triticale, however, has a prostrate early growth morphology, allowing it to cover the surface quickly.
5. Improve soil structure. Increasing SOM is the key to improving soil structure, so high-biomass species are appropriate here, too. It may be beneficial to include a non-legume to provide organic material that breaks down more slowly after incorporation than a legume alone (the lower C:N content of legumes causes them to break down rapidly in the soil).
6. Improve drainage. Some deep-rooted species can help to break through compacted layers in the soil and improve drainage. The roots of soil-penetrating cover crops also create channels through which water can move as the root systems decompose after death or incorporation; e.g., growers in some systems use "tillage (forage) radishes" to break up compaction (see Mixtures and cocktails: Soil is meant to be covered in Resources). In addition, many grass species with extensive, fibrous root systems add large quantities of organic matter to the soil by sloughing off roots. Such organic matter additions stimulate biological activity and the formation of soil aggregates, which improve drainage. Such grasses include annual rye, perennial rye, and oats.
7. Protect water quality. Protecting water quality includes reducing surface run-off of soil particles and the nutrients bound to them as well as reducing leaching of nutrients through the soil profile. Sediment and nutrients reduce water quality in fresh and marine surface waters and nutrient concentrations can build up in groundwater or aquifers. Species that prevent soil erosion and scavenge nutrients during periods of high rainfall, either alone or in a mix, can help minimize these losses. It is also important to avoid turning in high N cover crops during periods when N is vulnerable to leaching, e.g., when there is little or no crop cover and high rainfall.
8. Provide mulch to conserve soil moisture and/or suppress weeds. A combination of high above-ground biomass and moderate or high C:N ratio residues is desirable (note: 24–30:1 is an ideal C:N ratio; 40:1 is moderate and 80:1 is high). Most legume residues with their high N content will decompose too rapidly to be effective. However, note that mulching to conserve moisture is rarely of use in Mediterranean climates where there is little or no summer rainfall.

9. Provide habitat for beneficial insects and spiders. Annual cover crops have variable effects in providing habitat for beneficial invertebrates. The effect depends on the particular crop, cover crop and pest, as well as other factors specific to the cropping system. Winter cover crops in California generally have little overlap with summer crops, so may not be good hosts for beneficials that would need to survive until the summer crop is established. Cover crops can provide good habitat for beneficials in perennial systems such as orchards and vineyards, especially when species with food sources such as flowers or extrafloral nectaries (e.g., vetch) are used. Note that to achieve this benefit, you need to consider cover crops as part of a whole-farm plan. While cover crops will attract beneficials, if they have no place to move (e.g., hedgerow or surrounding natural areas) when the cover crops are mown and incorporated, you will lose them and their predation or parasatoid functions.
10. Suppress weeds. Cover crops can reduce weed populations either by outcompeting weeds by earlier or more vigorous growth and dense canopy cover, or by releasing allelopathic compounds that inhibit weed seed germination and seedling growth. However, the ability of cover crops to do so depends on factors such as seeding rate, choice of cover crop, row spacing, early irrigation, planting date, planting method, and use of cultivation during the cover crop growing season. Cover crops that may help with weed suppression include cereal rye, triticale, sorghum/sudan, mustard, and high biomass or allelopathic legumes. A densely-seeded mix of cover crops can also work, providing the canopy closes quickly.
11. Suppress soil borne pests and diseases. Certain cover crops can suppress particular disease or pest organisms. For example, cereal rye, sorghum/sudan, selected rapeseed varieties (e.g., c.v. Humus), and white mustard are known to suppress root knot nematodes and soil-borne diseases such as rhizoctonia and verticillium wilt.

D. Challenges of Cover Crops

Despite their positive attributes, incorporating cover crops into your cropping system can also present challenges, including delaying planting and the financial outlay associated with using cover crops. Impacts can include:

1. *Soil moisture depletion*. Vigorous cover crops that grow late into spring may deplete part of the soil moisture that later crops would use. This depends on the cover crop's maturity and seeding rate, as denser stands have greater water use, as well as the cover crop species. Some deep-rooted or rapidly-growing cover crops may have greater water demands.
2. *Rates of mineralization of nutrients for the subsequent crop*. Winter cover crops are used in part for their ability to scavenge nutrients, particularly N, which are then maintained in their biomass during the rainy season. Whether the cover crop is grown in winter or summer, it takes up and thus immobilizes nutrients, which then need to be mineralized for the subsequent crop. This process can be particularly slow for crops with high C:N ratios. At the same time, a long delay between cover crop incorporation and planting of the following crop can lead to loss by leaching or denitrification or to immobilization of fractions of the N by soil microbes, leaving less N available for the crop.
3. *Delayed planting*. Wet springs can delay the timing of cover crop incorporation as a grower waits until the soil is adequately dried down to drive equipment over and through it, avoiding compaction. Waiting the several weeks needed for the cover crop to be mowed and the residue to dry before incorporation can delay crop planting even further.
4. *Increased weed populations.* As described above, many factors determine the ability of cover crops to suppress weeds. A mismanaged cover crop actually can exacerbate weed problems or the crop can become a weed itself if allowed to produce viable or hard seed or other propagules. Growers might consider avoiding the use of the same cover crop every year, particularly if using a single species, to discourage the build up of populations of weeds that are most competitive with that species.

5. *Increased insect pest and disease pressure.* While some cover crops may help decrease pest and disease pressure, others may exacerbate such problems. For example, many legumes are excellent hosts for nematodes, allowing nematode populations to increase rapidly in the soil unless the cover crop is incorporated before the nematodes complete their life cycle. However, if the timing is correct the legume may actually reduce nematode populations by stimulating the nematodes' emergence and then killing them when the crop is incorporated, with the cover crop acting as a kind of trap crop in this way.

   Some cover crops (including phacelia, Austrian pea, and vetch) are hosts to the pathogen Sclerotinia minor and can have adverse effects on lettuce crops. Fava beans can be affected by Impatiens necrotic spot virus, which can then negatively affect lettuce and radicchio. See *Cover Cropping for Vegetable Production: A Grower's Handbook* (listed in Resources) for a more detailed discussion of current known cover crops and their positive and negative relationships with pathogens.
6. *High percent of cereal biomass.* Even where legumes make up 90% of a legume/cereal blend, you often end up with more cereal biomass than legume biomass. This can be a result of dry weather conditions, which favor the cereals, and soil fertility, where higher fertility and residual nitrogen can favor cereal growth. Thus getting a significant benefit from the higher-priced legume component can be a challenge.
7. *Financial outlay.* Cover crop production costs vary significantly depending on many factors, including seed selection and seeding rate, duration of the cover crop, and methods of planting and incorporation. Production costs include:
   a) Seed purchase
   b) Pre-plant land preparation (discing/ripping)
   c) Planting
   d) Irrigation (if necessary)
   e) Termination (mowing and incorporation). Depending on the amount of biomass produced, soil incorporation and seedbed preparation following cover cropping can be a significant cost in terms of the labor and equipment involved.
   f) Revenue lost while land is out of production

   N contribution from legume cover crops can offset some of the costs of cover crop production. Other benefits, such as improvements in overall soil fertility, tilth, aeration, and water infiltration, are more difficult to quantify, making it difficult to calculate a cost/benefit analysis.

Lecture 2: Cover Crop Selection, Planting & Care; Special Cases; Estimating N Contribution

A. Pre-assessment Questions

1. What are some examples of cool and warm weather cover crop species?
2. What factors must be considered when determining when to plant and incorporate a cover crop?
3. What are some of the techniques for managing weeds in cover crops?
4. What are some of the key pieces of equipment needed to plant and incorporate a cover crop most effectively?
5. How does use of cover crops differ in row crops compared to perennial systems such as orchards and vineyards?

B. Identifying the Cover Crop Planting Niche

1. When and where can the cover crop fit in your crop rotation? What are the climatic and soil conditions at that time? Answering these two questions can help you select the best cover crops for your system.

   Defining when and where the cover crop fits in your crop rotation:

   Timing your field operations to avoid interfering with cash crop production is critical. Determine when your field operations and labor needs are low and resources are available for cover crop management. Once the opportunity for cover crop growth and incorporation is identified then the species selection will depend on the climatic and soil conditions during that window, as well as the goals you're trying to achieve with the cover crop (see Lecture 1.B.). Use the publications and web sites in the Resources section to determine which cover crops will do well in those conditions.
2. Examples of cool weather and warm weather cover crops (see also *Cover Cropping for Vegetable Production: A Grower's Handbook* for discussion of common cover crops by region in California):
   a) Winter cover crops. Most cover crops are planted in the fall to provide cover over the winter months. Examples include: vetches, bell beans (a variety of fava beans), peas, annual and perennial clovers, rape seed and oilseed radish, mustards, and grasses such as oats, annual and perennial rye grass, or barley.
   b) Summer cover crops. When temperatures are high during the summer and if water is available, fast-growing species such as sorghum/Sudan grass and annual buckwheat can provide a good biomass return in a short period.

C. Additional Considerations When Selecting Cover Crops

1. Consider the characteristics you don't want as well as those you do. It is rare that the "perfect" cover crop will exist, so you will need to make trade-offs amongst your goals and the climate conditions during the cover-cropping window.
2. Consider the cost and availability of seed
3. Consider the number and types of field operations required for the different cover cropping options to make a sound economic assessment of the alternatives

D. How to Plant a Cover Crop (see also Supplement 2: Cover Crop Selection, Planting Tips, Tools and Techniques for Central Coast Small-Scale Organic Vegetable Farms)

1. Soil preparation prior to cover crop planting
   a) Soil preparation and timing are critical in order to provide good soil tilth and drainage for a strong, weed-competitive cover crop stand
      i. Avoid working overly wet soil
      ii. Ensure adequate soil particle size, especially for small-seeded crops (mustards, legume mixes) to facilitate shallow planting, good water filtration, and adequate germination
   b) Soil preparation depends in part on the preceding cash crop
      i. Following low-residue crops (e.g., summer squash), only flail mowing and a single pass with an offset disc and ring roller may be needed
      ii. Following high-residue crops on beds (e.g., sweet corn), preparation may re-quire flail mowing and multiple passes with offset disc and ring roller to knock down beds and in-corporate residue
      iii. Following overwintered, intensively managed crops (e.g., strawberries), prep-aration may require multiple passes with an offset disc and ring roller to knock down the beds followed by chiseling or ripping to break up deep furrow compaction created by harvest foot traffic and tractor tires. Multiple passes with an offset disc and ring roller may be needed to break up clods brought to the surface during chiseling and ripping.
   c) If using a tractor-mounted rototiller to prepare ground for cover crops, limit use to a single pass at appropriate soil moisture (not too wet or dry) to minimize soil aggregate dispersal and soil compaction.
2. How to plant: seed drills, broadcast, drill calibration exercise (see Hands-On Exercise)
   a) Seed/grain drills (either no-till or conventional) are the best option for planting cover crops
      i. Seed-line openers facilitate planting into high-residue situations
      ii. Press wheels on some seed drills facilitate planting to moisture
      iii. Adjustable seed drop openers allow the operator set seeding rate
      iv. Drop tubes must be continually monitored for clogging
   b) Broadcast seeding
      i. Plant seed using tractor-mounted, 3-point broadcaster (less expensive than seed drill)
      ii. Requires secondary tillage to improve seed-soil contact and ensure adequate germination, minimize the number of seeds exposed on the surface: disc, springtooth harrow, preferably used with a ring roller or drag bar to improve soil surface uniformity
      iii. Numerous passes with seed opening set smaller than anticipated helps ensure a uniform seed application
      iv. On small acreages (5 acres or fewer), multiple passes with hand-cranked broadcast seeders will ensure uniform seed application
   c) High-density planter

      Tractor-mounted, 3-point high density planter (e.g., those used for salad mix planting) are well suited for planting cover crops on beds free of residue
3. Managing the cover crop to compete with weeds
   a) Optimize seeding density and plant seed uniformly

b) In fall, time planting to take advantage of soil warmth and ensure strong germination; cool soils will reduce germination and favor winter weeds

c) Select cover crops with allelopathic properties (e.g., mustards, cereal rye) that will reduce weed pressure

d) Drill cover crop seed into ground where a flush of weeds (due to irrigation or early rain) has been lightly tilled at the time of weed emergence; plant cover crop seed to residual moisture.

e) Till field where weeds are emerging using a quick pass with a rotary hoe or tine weeder as cover crop seed emerges (blind cultivation); depends on timing of weed and cover crop emergence

4. Cover crop incorporation

a) Timing of cover crop incorporation linked to current and predicted weather, and degree of moisture in the field. Test soil moisture often to determine correct timing.

b) Test moisture using "feel" method (see Appendix 1: Judging Soil Moisture by Feel, in Unit 1.5: Irrigation–Principles and Practices). Moisture level is correct when medium to heavy soils form a ball that can be easily broken apart. If soil "ribbons" when squeezed it is too wet to work.

c) Once correct soil moisture is reached, flail mow cover crop if volume is high and if cover crop is high in C and lignin

d) Mix cover crop residue with soil to facilitate breakdown and bed formation. A mechanical spader is ideal for cover crop incorporation, but expensive.

e) Heavy offset wheel disc is most commonly used for incorporation. Adequate incorporation may require several passes; chiseling after several passes will facilitate the disc's ability to turn soil and will break up compaction cause by the disc.

E. Special Cases

1. Orchards and vineyards

a) Annual or perennial cover crops can be used in orchards and vineyards. Perennial cover crops provide the benefit of year-round cover, but they also need management (particularly mowing) to control weeds and pests, provide wildlife habitat, and prepare for harvest.

b) In California, native cover crops (e.g., perennial bunch grasses) may provide cover without increasing water demand.

2. Garden scale (see Supplement 3: Cover Crops for the Garden, for additional information)

a) Cover crops can be used effectively on a garden or small orchard scale. Fall- and winter-grown cover crops can either be chopped and incorporated to break down prior to bed formation and planting, or skimmed and used as a compost ingredient.

b) Note that it's important to incorporate compost where cover crops are harvested in order to replenish organic matter and nutrients.

F. How to Roughly Estimate N Contribution from a Cover Crop

Most growers do not regularly estimate the total N contribution from cover crops, relying instead on general estimates from sources such as Extension or USDA field stations. However, knowing where the values come from and how you could obtain them yourself can give you an overall deeper understanding of N management in cover crops. Doing an estimate can also help you understand how different cover crops or different parts of your farm are performing in terms of N contributions. Orchards and vineyards

1. Calculate above-ground weight for a given area*:
   a) Cover frame to measure area to be sampled). The number of samples depends on the size of your field and how even the cover crop stand is. Clipping plants from 5 to 10 3 x 3 sq. ft. plots may be representational for a few acres.
   b) Dry for a few days in the sun, a greenhouse, or an oven (150° F) until "crunchy" or brittle
   c) Calculate the dry weight produced in pounds/acre (lbs/ac) as follows:

$$\text{Dry wt (lb/ac)} = \frac{\text{weight of samples}}{\text{\# of sq. ft. sampled}} \times 43{,}560 \text{ square feet}$$

2. Multiply dry weight by the % N content of the biomass (see 4, below) to give total N in cover crop in lbs/ac:

$$\text{Total N (lb/ac)} = \frac{\text{dry weight}}{100} \times \%N$$

3. To estimate how much of the N will be available to the crop that season:

   If conventionally tilled, divide total N by 2

   If left on surface, divide by 2 in warmer climates, by 4 in cooler climates

4. Typical % N contents for cover crop types

   Before flowering:

   Annual legumes: 3.5–4%

   Perennial legumes: 2.5–3%

   Grasses, brassicas: 2–3%

   When flowering:

   Annual legumes: 3–3.5%

   Perennial legumes: 2–2.5%

   Grasses, brassicas: 1.5–2.5%

*From: *Managing Cover Crops Profitably, 2nd Edition,* published by the Sustainable Agriculture Network (see Resources section). Used by permission.

Demonstration: How to Estimate the Nitrogen Contribution of a Cover Crop

for the instructor

OVERVIEW

Through this hand-on field demonstration and discussion, students will learn how to estimate the nitrogen contribution of a cover crop for nutrient budgeting purposes. (See Unit 1.11: Reading and Interpreting Soil Test Reports for more on nutrient budgeting.)

PREPARATION AND MATERIALS

1. If possible, students should have received the lecture portion of this unit covering the biology and functions of cover crops in agricultural systems.
2. Necessary tools and equipment: greenhouse or oven (for drying cover crops), clippers, measuring tape/stick or measuring frame, scale.
3. A mature stand of actively growing cover crops.
4. Demonstrate procedure and then assign each small group the tasks of cutting, drying, weighing, and calculating the nitrogen contribution of the cover crops (in total N lb/ac).

PREPARATION TIME

1 hour

DEMONSTRATION AND DISCUSSION TIME

(2) 2 hour periods

DEMONSTRATION OUTLINE

A. Discuss and demonstrate the collection and calculation of the above-ground weight for a given area of cover crop

1. Demonstrate taking a number of samples from the field: how to use a yardstick or frame to measure area to be sampled, and how to clip the cover crops at the ground level
2. Demonstrate and discuss techniques for sun drying the fresh cover crop material in the greenhouse or in the oven (150ºF) until "crunchy" or brittle

3. After drying material, demonstrate how to calculate the dry weight produced in pounds/acre (lbs/ac) as follows:
   a) Dry weight produced in pounds/acre (lbs/ac) as follows:

      $$\text{Dry wt (lb/ac)} = \frac{\text{weight of samples}}{\text{\# of sq. ft. sampled}} \times 43{,}560 \text{ square feet}$$

   b) Multiply dry weight by the % N content of the biomass (see below) to give total N in cover crop in lbs/ac:

      $$\text{Total N (lb/ac)} = \frac{\text{dry weight}}{100} \times \%N$$

      Typical % N contents for cover crop types

      Before flowering:

      Annual legumes: 3.5–4%

      Perennial legumes: 2.5–3%

      Grasses, brassicas: 2–3%

      When flowering:

      Annual legumes: 3–3.5%

      Perennial legumes: 2–2.5%

      Grasses, brassicas: 1.5–2.5%

      Note: To estimate how much of the N will be available to the crop that season –

      If conventionally tilled, divide total N by 2

      If left on surface, divide by 2 in warmer climates, by 4 in cooler climates–
4. Discuss variables in N availabilty and percentage (above)
5. Discuss the application of the findings to the development of N budgets for farming systems. (See Unit 1.11: Reading and Interpreting Soil Test Reports for more on nutrient budgeting.)

Adapted from: *Managing Cover Crops Profitably, 2nd Edition,* published by the Sustainable Agriculture Network (see Resources section). Used by permission.

Hands-on Exercise: Seed Drill Calibration

step-by-step instructions for students

OVERVIEW

This exercise takes you through the steps needed to determine the amount of seed (lbs/acre) that your seed drill is discharging. Based on this information you can adjust your seeder to ensure that it is discharging at the recommended pounds per acre rate.

PROCEDURE

1. 3-point seed drill (type?) hooked to tractor
2. Row crop area cleared for cover crop planting (100' minimum plus room for turning)
3. Duct tape and cardboard (to make divider in drill hopper)
4. Cover crop seed
5. Flags to mark start and stop location of drill
6. High quality scale to measure seed weight

STEP-BY-STEP INSTRUCTIONS

1. With duct tape and a small piece of cardboard, tape a divider in the drill hopper to effectively "isolate" a single discharge opening at one end of the drill.
2. Disconnect the drop tube where it attaches to the disc opener and allow the tube to dispense seed into a small container or clear plastic bag taped to the tube.
3. Set two flags in the ground alongside a non-paved avenue at 100 feet apart.
4. Place a small amount of seed into the hopper over the drop that you have isolated with the cardboard "dam."
5. Select the gear and RPM that you will be driving in the field—around 3 or 4 MPH.
6. Set the seed delivery opening based on seed rate charts supplied with the drill. If charts are not available you will have to simply estimate an opening width that is just slightly larger than the largest seed.
7. With the drill lined up at the first flag drive the tractor and drill 100 feet to the second flag along the avenue at the selected speed with the drill "engaged" to drop seed between flags. With a three-point drill this is easily accomplished by simply dropping the drill to allow the seed agitator drive wheel to make contact with the soil so that it can "drive" the agitator.
8. When you reach the 2nd flag remove the collected seeds and place them on a high quality scale to get an accurate weight.
9. Count the total number of drops on the drill and multiply the seed weight of the collected seed by the total number of drops. This will give you the total estimated drill output for the 100-foot pass.

10. Measure the width of the drill in feet and multiply the drill width by 100 to the get the total square feet of the "trial area."
11. Divide 43,560 (# square feet per acre) by the square footage of your "trial area" and this will give you the total number of "trial areas" within an acre.
12. Now multiply the estimated seed weight from all of the drops by the number of "trial areas" in an acre and this will give you a good estimate of drill output in lbs per acre based on your selected drill opening size.

    You may need to repeat this procedure several times to find the appropriate seed drop opening size to match your desired output in pounds per acre (lbs/ac).

EXAMPLE OF CALCULATIONS

Your grain drill is 7 feet wide and has 13 drops. You select an opening size and run the drill 100 feet at the same gear-ing and rpm that you will be using in the field. You collect seed from the isolated drop and put it on the scale. It weighs 4 ounces (.25 lb).

1. Multiply .25 by 13 giving a total drill output of 3.25 lbs per 100 feet.

   .25 lbs X 13 = 3.25 lbs
2. Now multiply the 7-foot drill width by 100 feet to giving you 700 square feet of "trial area."

   7 feet X 100 feet = 700 square feet
3. Now divide 43,560 (square feet per acre) by 700 to give the number of "trial areas" in an acre.

   43,560 sq ft / 700 sq ft = 62 trial areas per acre
4. Now multiply the number of trial areas by 3.25 lbs to get total lbs of cover crop per acre.

   62 trial areas X 3.25 = 201 lbs per acre

Assessment Questions

1) Define the following terms:

   Cover crop Green manure Catch crop

2) In what ways do cover crops serve to improve or maintain the nutrient availability of agricultural soils?

3) In what ways do cover crops serve to improve or maintain the physical properties of agricultural soils?

4) In what ways do cover crops play a preventive pest management role in agricultural systems?

5) What are the factors to consider when selecting a cover crop for your farm or garden?

Assessment Questions Key

1) Define the following terms:
   - *Cover crop = Mainly used to prevent soil erosion by covering soil with living plants*
   - *Green manure = Crop grown mainly to be turned under for soil improvement*
   - *Catch crop = Used to "catch" nutrients left after harvest of a cash crop and prevent leaching*

2) In what ways do cover crops serve to improve or maintain the nutrient availability of agricultural soils?
   - *Legume cover crops are able to "fix" atmospheric nitrogen (N_2) and convert it into a plant-useable form. Up to 200 lbs/acre of actual N can be fixed by certain species of cover crops. This can be a significant contribution to the N budget of a cash crop. Grains and cereal cover crops with extensive root systems that develop quickly after planting are also able to"scavenge" water-soluble nutrients left in the soil after the cash crop and prevent loss through leaching. Deep-rooted legume cover crops are also able to access normally unavailable nutrients (e.g., P) from lower soil horizons and bring them to the surface through the distribution of the nutrients through their tissues. Such nutrients are then made available to cash crops when cover crops are tilled into the soil.*

3) In what ways do cover crops serve to improve or maintain the physical properties of agricultural soils?
   - *Cover crops help prevent soil erosion. When tilled in, cover crops cycle organic matter through agricultural soils. This cycling of organic matter provides energy (carbohydrates) and nutrients (N) that increase soil biological activity. Through the process of decomposition, soil organisms bind soil particles together forming stable (erosion-resistant) soil aggregates that improve and maintain desirable soil structure.*
   - *Cover crops improve drainage. Some deep-rooted cover crop species can help to break through compacted layers in the soil and improve drainage.*

4) In what ways do cover crops play a preventive pest management role in agricultural systems?
   - *Provide habitat for beneficial insects and spiders: Though not well studied in annual cropping systems, it is clear from research in orchards and vineyards that cover crops provide good habitat for beneficial insects especially when species with food sources such as extrafloral nectaries (e.g., vetch) or flowers are used*
   - *Certain cover crops suppress soil borne pests and diseases, although some also may increase susceptibility of the cropping system to certain pests and diseases*
   - *Cover crops can suppress weeds: Cover crops can reduce weed populations by outcompeting weeds by more vigorous growth and dense canopy cover or by releasing allelopathic compounds that inhibit weed seed germination, although they do need to be managed well to provide these functions and not increase weed pressure*

5) What are the factors to consider when selecting a cover crop for your farm or garden?
   - **Step 1:** *Identify what you want the cover crop to do.*
   - **Step 2:** *Identify where the cover crop can fit in your crop rotation and what the climatic and soil conditions are at that time.*
   - **Step 3:** *Select cover crop species or mix to meet the goals and requirements from steps 1 and 2, considering the characteristics you don't want as well as those you are looking for. Consider the cost and availability of seed and the number and types of field operations required to manage the cover crop.*

Resources

PRINT RESOURCES

Chaney, David, and Ann Mayse, eds. 1997. *Cover Crops: Resources for Education and Extension.* Davis, CA: UC Sustainable Agriculture Research and Education Program (UC SAREP), UC Division of Agriculture and Natural Resources.

A collection of materials that educators will find useful in conveying information about cover crops to farmers and ranchers. The packet includes a variety of materials that may be used in short courses, seminars, workshops, etc. Includes web resources, print publications and articles, cover crop profiles, listings of video and slide sets, and a directory of expertise. Order from the UC SAREP website: www.sarep.ucdavis.edu.

Miller, P. R., W. L. Graves, et al. 1989. *Cover Crops for California Agriculture.* Leaflet 21471. Oakland, CA: University of California Division of Agriculture and Natural Resources.

A concise overview of the common cover crops used in California agriculture. Addresses annual and perennial cropping systems.

Smith, R., R. L. Bugg, and M. Gaskell. 2011. *Cover Cropping for Vegetable Production: A Grower's Handbook.* Publication #3517. Oakland, CA: University of California Division of Agriculture and Natural Resources.

Describes primary cover crop species, including grasses, legumes, mustards and other cool-season and warm-season options. Photos, seeding details, winter vigor descriptions, nitrogen fixation and scavenging, weed suppression and nematode resistance are included for each species. Addresses the effects of cover cropping on water management, pest management and farm economics.

For California growers, the handbook also discusses differences in cover crop use for the Central Valley, Desert and Coastal regions.

Sarrantonio, M. 1994. *Northeast Cover Crop Handbook.* Emmaus, PA: Rodale Institute.

Practical information on the selection and management of cover crop species for northeast agriculture.

Schahczenski, Jeff, and Holly Hill. 2009. Agriculture, Climate Change and Carbon Sequestration. ATTRA–National Sustainable Agriculture Information Service. IP 338. Available free online at *https://attra.ncat.org/publication.html*

Provides an overview of the relationship between agriculture, climate change and carbon sequestration. Investigates possible options for farmers and ranchers to have a positive impact on the changing climate and presents opportunities for becoming involved in the emerging carbon market.

Sustainable Agriculture Network. 2007. *Managing Cover Crops Profitably, Third Edition.* Sustainable Agriculture Network. Beltsville, MD: National Agricultural Library.

Excellent information on the characteristics, costs, seeding rate, and management of different cover crop species. Contains a good introduction to the potential advantages and disadvantages of using cover crops, and how to manage them effectively to minimize unwanted effects. It also provides comprehensive information on the major species used in the U.S. Though geared primarily toward large-acreage cropping systems, the information is readily adapted for smaller-scale systems. Available for download and purchase at: www.sare.org/Learning-Center/Books/Managing-Cover-Crops-Profitably-3rd-Edition

USDA Natural Resources Conservation Services. 2011. *Carbon to Nitrogen Ratios in Cropping Systems*

Two-page handout from USDA describes importance of C:N ratio in feeding soil microorganisms, the effects on soil cover decomposition, and the effects on nutrient cycling. Includes a table of C:N ratios of various crop residues and other organic materials, and their comparative decomposition rates. Available at: http://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/stelprdb1166766.pdf ttp://C_N_ratios_cropping_systems.pdf

WEB-BASED RESOURCES

Brassicas and Mustards for Cover Cropping in Organic Farming

www.extension.org/pages/18643/brassicas-and-mustards-for-cover-cropping-in-organic-farming

Describes the potential benefits of using brassicas and mustards as cover crops. Thoroughly researched with an extensive references section, the article describes species selection, management techniques, and precautions.

Choosing and Using Cover Crops in the Home Garden and Orchard

casfs.ucsc.edu/about/publications/for_the_gardener.html

Orin Martin, manager of UC Santa Cruz's Alan Chadwick Garden, discusses the benefits, varietal selection, timing, planting, and incorporation of cover crops on a home garden and backyard orchard scale. 3 pages.

Cover Cropping Systems for Organically Farmed Vineyards

cemendocino.ucanr.edu/files/17082.pdf

Glenn McGourty, viticulture and plant science advisor for UCCE in Mendocino and Lake Counties, describes management of cover crops in organic viticulture systems. He includes a "top ten cover crop picks" for the region, including several plants not described in this chapter. A 2008 paper by McGourty and colleagues and published in California Agriculture describes self-reseeding annual legumes for untilled vineyards (http://californiaagriculture.ucanr.org/landingpage.cfm?articleid=ca.v062n04p191&fulltext=yes).

Cover Crops Topic Room, Sustainable Agriculture Research and Education (SARE)

http://www.sare.org/Learning-Center/Topic-Rooms/Cover-Crops

This informative website offers educational materials on a variety of topics, including cover crop selection and management, crop rotations, economics, and pest management. Especially useful are the short videos of growers describing their experiences with cover crops.

Diverse Cover Crop Mixes for Good Soil Health

www.nrcs.usda.gov/Internet/FSE_PLANTMATERIALS/publications/nypmssy11419.pdf

Paul Salon, a plant materials specialist with the USDA, discusses the pros and cons of using various mixes of cover crops species, particularly in relation to no-till systems in the Northeast.

Estimating Plant Available Nitrogen (PAN) Release from Cover Crops

ir.library.oregonstate.edu/xmlui/bitstream/handle/1957/34720/pnw636.pdf

This publication developed by Oregon State University researchers provides a step-by-step guide to estimating the N contribution of cover crops. It also includes a variety of informative case studies, including replacing organic fertilizer N with cover crops, and comparing the plant available nitrogen (PAN) of various cover crops used alone and in mixes.

Inoculation of Legumes for Maximum Nitrogen Fixation

extension.psu.edu/plants/crops/forages/successful-forage-establishment/inoculation-of-legumes-for-maximum-nitrogen-fixation

Penn State University publication describes techniques for inoculating legumes, factors affecting N fixation, checking roots for inoculation, and "emergency" inoculation techniques.

Mixtures and Cocktails: Soil Is Meant To Be Covered

www.ctic.org/media/pdf/Cover%20Crops/Mixtures%20and%20cocktails.pdf

Steve Groff of Cedar Meadow Farm describes his use of cover crops, including tillage radish, to build soil organic matter on the farm. Originally published in the Journal of Soil and Water Conservation.

Overview of Cover Crops and Green Manures

attra.ncat.org/attra-pub/summaries/summary.php?pub=288

Excellent resource from ATTRA covering the principal uses, benefits, limitations, and economics of cover crops. Includes extensive references and resources.

Perennial Cover Crops in Orchards and Vineyards.

www.yolorcd.org/documents/perennial_cover_crops.pdf

Agricultural Water Quality Best Management Practices handout outlines management and costs of cover crops in orchards and vineyards.

Plant Cover Crops

http://plantcovercrops.com/

Dave Robison, a cover crop and forage agronomist in the Midwest, keeps a blog about cover crops. While most posts are pertinent to his home region, some have excellent crossover for growers throughout the country.

Soil Quality for Environmental Health: Cover Crops

soilquality.org/practices/cover_crops.html

Developed by the Agricultural Research Service scientists, this introduction to cover crops addresses the question of why to use cover crops, the effects on soil health, and practical "how-to" information on selecting, planting, fertilizing, and terminating cover crops.

UC Sustainable Agriculture Research and Education Program (UC SAREP) Cover Crop Data Base

www.sarep.ucdavis.edu/database/covercrops

Contains a thorough cover crop database, with quantitative information on specific cover crops, and two slide shows covering the use of cover crops for annual and perennial farming systems. The database includes valuable cover crop information such as pounds of nitrogen fixed, seeding rates, suggested timing for seeding, etc. Focuses on California and other similar climatic situations. Includes photographs.

VIDEOS

Brennan, Eric. Agriculture Research in High Value Organic Systems.

www.youtube.com/user/EricBrennanOrganic

Eric Brennan, a USDA Cooperative Extension Specialist with Monterey County, has created a series of informative and entertaining videos on cover crops and the issue of organic versus conventional comparisons.

SUPPLEMENT 1

Cover Cropping and Other Agroecological Practices Benefit Farms in the Face of Climate Change

There is nearly universal scientific and cultural consensus that climate change is having a significant effect on our planet and on many climate-related activities, including agriculture. Agriculture is also a major source of greenhouse gas (GHG) emissions, accounting for 14% of GHG emissions worldwide.[1,2] How farmers will satisfy the demand for food as the global population increases while mitigating agriculture's impact on climate change is the key question facing growers and policymakers around the world.

Currently, there is mounting evidence that suggests sustainable agriculture practices, exemplified by those used in agroecological systems, provide an opportunity to achieve the dual goals of feeding a growing population and shrinking agriculture's carbon footprint, in addition to the social benefits of increased food security and stronger rural economies. This is in contrast with industrial-scale conventional systems that rely on fossil fuel-based fertilizers, pesticides, and heavy tillage and look to genetic engineering to help plants cope with climate change, e.g. by develping drought-resistant crop varieties, which themselves require high inputs of fertilizers and pesticides to produce optimally. Agroecological systems, on the other hand, can mitigate climate change by reducing fossil fuel use.and employing farming techniques that reduce GHG emissions by sequestering carbon in the soil.

Of the range of practices in an agroecological system that address issues related to climate change, cover cropping is perhaps the most effective. As climate change continues to affect weather patterns and cause more frequent and severe weather events, protecting against soil erosion will become increasingly important. Cover crops provide an effective mitigation strategy by protecting soil against water- or wind-driven erosion.

Cover cropping also provides other climate-related benefits, including: an on-farm source of fertility, less dependence on fossil fuels and their derived products, and adaptability and resilience. Most of all, while the specific species, timing, and primary purpose of a cover crop vary geographically, the principles behind their cultivation are universally applicable and their benefits universally available.

The use of a leguminous cover crop to fix nitrogen in the soil over the wet season for the next season's crop is widely recognized as an effective fertility management tool. According to an FAO report on agriculture in developing countries, using cover crops in a maize/pigeon pea rotation led to increased yields and required less labor for weeding than continuous maize cropping systems with conventional fertilizer use.[3] Nitrogen-fixing cover crops also greatly reduce, if not eliminate, reliance on off-farm sources of fertility, thus reducing the overall carbon footprint of the farm while maintaining high fertility levels in the soil. Note that even organic fertilizers have a high embedded energy cost as they are mostly derived from manure from

1 IPCC. 2007. Climate Change 2007: Mitigation. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, Chapter 8-Agriculture. Cambridge, United Kingdom and New York, NY, USA Cambridge University Press.

2 Branca, Giacomo, Nancy McCarthy, Leslie Lipper, and Maria Christina Jolejole. 2011. Climate-Smart Agriculture: A Synthesis of Empirical Evidence of Food Security and Mitigation Benefits from Improved Cropland Management. Mitigation of Climate Change in Agriculture Series 3. Rome, Italy: Food and Agriculture Organization of the United Nations (FAO). *http://www.fao.org/docrep/015/i2574e/i2574e00.pdf*

3 Silici, Laura. 2014. Agroecology: What it is and what it has to offer. IIED Issue Paper. International Institute for Environment and Development, London. Available online at: *http://pubs.iied.org/pdfs/14629IIED.pdf*?

animals raised in confined feedlots, so the ability to grow one's fertility needs on farm is important across different agricultural systems.

Cover crops are not only a mitigation strategy for climate change, but also a cost-saving measure. Synthetic fertilizer costs have steadily increased over the last half-century, causing hardship for farmers in developing countries especially where fertilizer prices are already two to three times the world price. Organic farmers are less vulnerable to price shifts in fertilizer, but can equally benefit from the reduced need for compost as a result of cover cropping. By saving seeds from their cover crops, farmers can close the loop in their cover crop management, save on annually purchased seed, and develop strains well-adapted to local conditions. Fertility management systems based on cover crops insulate conventional farmers from increasingly frequent spikes in fertilizer prices and provide organic farmers with a cheap and renewable source of fertility.

Adaptation and resilience is also crucial to farmers' long-term success in the face of unpredictable and disruptive effects from a changing climate because so much of agriculture depends on constantly changing climatic conditions. Added to climate change are increasing input prices and a growing demand for food that put pressure on farmers to maintain high yields while paring down on costs. Cover crops can provide farmers with the flexibility they need by protecting topsoil from wind and water erosion, storing a reliable supply of nutrients to the soil, and minimizing costly weeding requirements. For many resource-poor farmers who maintain livestock, cover crops provide a path to financial independence and food security as they can be grown both for soil fertility and livestock feed.

Cover crops as part of a climate mitigation strategy also make sense at every scale of agriculture. Large conventional farms require consistently high yields to stay profitable as they often operate on razor thin margins. To achieve this goal, these farms rely heavily on fossil fuel-based sources of energy and fertility. Whether used on conventional or organic farms, cover cropping not only reduces farm emissions, but also contributes to the biological health of the farm's aggressively cultivated soils. Many organic farms at all scales already use cover crops as part of their fertility management program, contributing to the sustainability of the overall system. Subsistence and small-scale farmers in developing countries who do not already practice cover cropping can benefit greatly in production and climate-related sustainability from adopting locally relevant techniques. And finally, low-cost, locally available sources of fertility are vital to the viability and success of urban agriculture projects that rely on cost minimization and closed-loop systems since external resources are not as readily available or economical in cities.

SUPPLEMENT 2

Cover Crop Selection, Planting Tips, Tools & Techniques for Small-Scale Organic Vegetable Farms on California's Central Coast

This supplement to the cover crop lecture addresses the various steps involved in using cover crops on small-scale organic vegetable farms on the Central Coast of California. Although the information is targeted to the Central Coast region, the techniques and approaches are applicable to many settings.

Soil Preparation

In many ways planting a cover crop is similar to planting a cash crop. Good soil preparation is critical: it provides good soil tilth and drainage and allows for accurate and uniform seed placement. The time and effort that go into soil preparation prior to cover crop planting are directly related to the quality and uniformity of the cover crop stand and its ability to outcompete weeds, establish a strong, deep root system, and produce optimal biomass.

Factors to consider when preparing ground for cover crop planting include:

- cropping and tillage history
- soil type
- time of year
- soil moisture content
- type and amount of residue to incorporate
- planting method (broadcast or drill)
- type and seed size of cover crop to be planted (i.e., cereal, legume, mustard)
- method of covering
- extent of soil compaction
- timing in relation to predicted rainfall events

Timing is often the single most important factor in determining the extent of ground preparation prior to cover crop planting. If there is adequate time between cash crop removal and cover crop planting this can be a good window to get in and level field ends. These "unleveled" field ends result from soil movement during discing, bed shaping and cultivation passes throughout the production season and can result in non-uniform drainage and puddling issues that will directly impact cover crop stand uniformity and weed growth.

Generally speaking the smaller the cover crop seed size the more care required to prepare a good seed bed with adequate soil particle size. This will facilitate shallow planting depths, good water infiltration and uniform germination. Cereal cover crops generally require less intensive soil preparation, are less sensitive to depth of planting, outcompete weeds better and can handle compaction better than the mustards and legume mixes.

Soil preparation will depend in part on the preceding crop:

- following low-residue crops with minimal compaction and low residual moisture (e.g., winter squash), preparation may only require flail mowing and a single pass with an offset disc and ring roller to adequately prepare the ground for either drilling or broadcasting cover crop seed (see discussion of both techniques, below)
- following high-residue crops grown on beds (e.g., sweet corn), preparation may require flail mowing and numerous passes with an offset disc and ring roller to knock down the beds and sufficiently incorporate the residue prior to planting cover crop
- following overwintered, intensively managed crops (e.g., strawberries), preparation may require multiple passes with an offset disc and ring roller to knock down the beds followed by chiseling or ripping to break up deep furrow compaction created by harvest foot traffic and tractor tires

Breaking up deep furrow compaction with chisels or rippers often brings large clods to the surface. It may take multiple passes with an offset disc and ring roller to break apart the clods and prepare the ground for cover crop planting. In severe cases, especially on soils that tend to compact easily, overhead irrigation may be needed before tilling to moisten the clods enough to facilitate their dispersal.

Many smaller farms rely on tractor-mounted rototillers to prepare ground for cover crop planting. When rototillers are used it is important to be mindful of issues related to aggregate dispersion and compaction. Rototillers are best used as a "single pass" implement when soils are not too wet and not too dry.

Cool Season Cover Crops: Selection and Timing

In areas of the Central Coast where winter rainfall typically exceeds 25 inches per year, and especially on sloped ground, cover cropping in annual vegetable cropping systems is highly advisable to protect non-cropped soil from both erosion and nutrient leaching.

Based on numerous studies the optimum time for planting winter cover crops on the Central Coast is mid October. In our mild winter climate we can plant cover crops as late as January, however the best results in terms of weed suppression, stand uniformity, and biomass production are from cover crops planted in mid to late October or early November.

Depending on rainfall patterns it is often critical to get winter cover crops planted prior to the onset of heavy winter rainfall. Cover crop ground preparation and planting are best accomplished when soil is dry enough to work without the risk of compaction, which can result in poor drainage and clod formation. This is especially important on heavier soils.

Because timing is critical, growers need accurate long-range weather forecasts to help determine when to prepare ground and plant fall cover crops. Timing these operations is directly related to soil type and rainfall amounts, so each farm will have a different set of criteria on which to base ground preparation and planting schedules: the heavier the soil and the greater the rainfall, the tighter the window for fall planted cover crops. There is often a very tight window between cover crop planting and harvest of fall crops which, coupled with the potential for significant rain events, can add considerably to the excitement.

COOL SEASON COVER CROP MIXES

Selecting optimum cool season cover crop mixes is challenging since there are so many factors involved. The optimum mix provides early and uniform stand establishment, good weed competition, and minimal pest and disease pressure. It "catches" potentially leachable nutrients, does not lodge or fall over in high wind and heavy rainfall events, does not set viable seed prior to incorporation, fixes nitrogen, does not get too carbonaceous prior to incorporation and is relatively easy to incorporate and quick to break down once incorporated. The ideal mix also improves overall soil health and helps form stable soil aggregates by providing adequate amounts of carbon as a food source for the soil microbial communities.

There are many commercial mixes available that come close to meeting most of the above criteria. A good standard mix that has proven successful at the Center for Agroecology & Sustainable Food Systems (CASFS) Farm on the UC Santa Cruz campus over the past 20 years is a 50/50 mix of bell beans and lana vetch with no more than 7% (by weight) cayuse oats, planted at a rate of about 175 lbs per acre with a no-till drill.

Other considerations in fall cover crop mixes:

- Common or Purple vetch work well and are often less expensive than lana vetch, although lana vetch does seem to be the best vetch for our region in terms of hardiness and overall vigor.
- Peas make a nice component in a legume mix, but our experience at the CASFS farm is that they are more prone to root rot when compared to the vetches and bell beans, especially when soils are wet at time of germination.
- Cayuse oats are much slower to initiate flowering and are therefore much easier to incorporate in the spring compared to the cereal ryes—especially in higher rainfall areas on heavier soils. When the oats are planted at a percent (by weight) much greater than 7% they will often dominate the legumes. With an oat-dominated cover crop spring incorporation will be difficult and the time required for breakdown after incorporation will be much greater compared to the legume- dominated mixes.
- Cereal ryes are excellent weed suppressors, but start to initiate bloom much earlier than cayuse oats. Once flowering is initiated they have a high C:N ratio and can therefore be difficult to incorporate. If using rye, the advantage of AGS104 rye compared to Merced rye is that it has a much higher resistance to rust fungus.

When using specific legume species for the first time in a production system it is advisable to inoculate the seed with the specific microbial inoculant for that species. When planting the seed through a drill or broadcast seeder it is best to order the seed

"pre-inoculated" rather than attempt to inoculate it yourself since it is necessary to get the inoculant to "stick" to the seed using various methods that usually involve wetting the seed. Some growers simply shake the dry inoculant over the seed as it is being dumped in the seed hopper, but this may not provide the best results. Once established in a cover cropped field the rhizobial bacteria will persist as long as the legume species specific to that bacteria are planted frequently.

Mustards also work well as a winter cover crop; they suppress weeds effectively and are easy to incorporate in the spring. Recent research also suggests that chemicals released from the mustards following incorporation can suppress some nematode species, they are less effective at controlling soilborne diseases. Because they are sensitive to less than optimal soil conditions such as poor drainage and compaction at the time of planting, mustards tend to be good indicators of soil conditions.

When drilled, mustards do well at a planting rate of about 20 to 30 lbs per acre. Because mustard seed is so small it can be challenging to set a drill to plant less than 30 lbs per acre unless the drill has a specially designed "small seed" delivery mechanism. For this reason it is common for growers to broadcast mustard seed and incorporate it with a very shallow harrow or ring roller.

Nitrogen Contribution from Cover Crops

Nitrogen made available to plants through "fixation" of atmospheric nitrogen from legume cover crops is an important consideration when selecting winter cover crops. As a general rule legume residue, at time of incorporation, can produce about 3,000 pounds per acre residue on a "dry weight" basis. The nitrogen content in most legume cover crop residue, at time of incorporation (full bloom), is typically about 3%. Based on these numbers a typical legume cover crop would contribute about 90 pounds of nitrogen to the soil. About half of this nitrogen becomes plant available though microbial "mineralization" during the first year following incorporation. Based on these estimates a cropping system following the incorporation of a legume-dominated cover crop could receive 45 pounds of plant available nitrogen that could be utilized by a "cash crop" following the cover crop.

Legume cover crops typically have a higher level of N than is needed for the formation of soil organic matter and it is this excess N (estimated at 50%) that becomes plant available soon after incorporation. The remaining N goes into soil organic matter and is slowly released over time through microbial decomposition..

Warm Season Cover Crops

There are many options available for mid- and late-summer cover crops in the Central Coast region. Water use and "land out of production" are the two biggest challenges with summer cover crops, but in a diverse system they can provide good weed suppression and nutrient cycling, and can significantly improve soil tilth and aggregation when planted in rotation with mixed vegetables.

The two most commonly used summer cover crops in our region are annual buckwheat and sudan grass. Buckwheat is the fastest-growing summer cover crop, and when planted at a high enough density and irrigated up, annual buckwheat will out grow and "smother" most of the fast-growing summer annual weeds such as pigweed and lambsquarter.

Once incorporated, buckwheat residue breaks down easily, allowing for seedbed preparation soon after incorporation. Growers always comment on the noticeable improvement in soil quality following buckwheat.

Note that buckwheat is not very drought tolerant and therefore must be sprinkler irrigated at least every 7 to 10 days on the central coast. If planting buckwheat with a drill, a good seeding rate is around 60 lbs per acre. If broadcasting, increase this amount to 80 lbs per acre.

Sudan grass is also a good summer cover crop and is relatively easy to grow.

The advantages of Sudan are that it can be mowed and incorporated 40 days after planting when the plants are in full bloom (before the weeds have set hard seed) and it is a good weed competitor. Sudan grass grows best during very warm weather, so during cool foggy periods its growth may be less than optimal for good biomass production and weed suppression.

At the CASFS farm we have had good luck intercropping vetch and sudan grass as a summer cover crop. The advantage of the intercrop is that if the weather is unseasonably warm during the initial growth stage the sudan will dominate and, conversely, if the weather is unseasonably cool the vetch will dominate. In either scenario the cover crop will provide good biomass and weed suppression. Typically, when intercropping two different species it

is advisable to plant each at half the recommended seeding rate. If planting a sudan grass/vetch mix with a drill, a good seeding rate is around 20 lbs per acre of each seed type. If broadcasting, increase this amount to 30 lbs of each per acre.

AGS104 rye or Merced rye will both germinate well and provide excellent weed suppression when grown as summer cover crops in our region, and can be mowed numerous times to keep biomass manageable and to knock off developing seed heads of escaped weeds. Cereals like rye and oats are typically drilled at around 80 lbs per acre and broadcast at between 100 and 120 lbs per acre. Residue breakdown and subsequent seedbed preparation will depend on the length of time the rye, sudan or vetch covers are allowed to grow prior to termination. Sudan grass can be drilled at 40 to 50 lbs per acre and broadcast at 60 lbs per acre. The higher the seeding rate the finer the stem will be and the easier the breakdown will be at time of incorporation.

Cover Crop Planting Methods

DRILLS

The best tool for planting cover crops is either a no-till or conventional grain drill. Depending on the scale of operation, either three point (7 to 8 feet wide) or wider pull-behind drills (10 feet or wider) can be used.

All grain drills have single or double disc seedline openers, which facilitate planting into high residue situations often encountered when cover crops are planted following high residue cash crops such as corn or broccoli. Some drills, such as the no-till drills, have press wheels that run behind the disc openers, which help to re-establish capillarity to aid in bringing deeper soil moisture up to the seed; this feature greatly facilitates planting to moisture. The press wheels, which can be adjusted with spring tensioners, also facilitate accurately setting the planting depth, which is a critical factor as well when planting to moisture. Accurate seed depth is also easily set with a drill and information on how to set depth can be found in the operator's manual. Drills typically put down seed lines spaced from 6 to 7.5 inches apart, providing a close enough spacing for good early cover crop canopy closure, which will greatly reduce weed competition during the critical early cover crop establishment phase.

Drills typically have adjustable seed drop openers that allow for some level of accuracy in setting seeding rates. It is advisable to "calibrate" a drill to improve the accuracy of seeding, and thus avoid either over planting and running out of seed or under planting and having seed left over (see Hands-On Exercise: Calibrating a Seed Drill).

Drills are fast and efficient at field planting cover crops once the proper seed delivery rate has been determined. The double disc openers seldom clog, but it is not uncommon for clogging to take place in the drop tubes especially when the drill is being used to plant large seeds at a high rate. The drill operator must continually monitor the output of the drops to ensure that no clogging is taking place. It is advisable to check drop output visually from the tractor seat at the end of each pass.

Another common problem is for the disc openers to pick up field trash (especially flags and berry bed mulch pins) that can jam the openers. The drill operator must also be cautious about not allowing the drill to move backwards while soil engaged, as this will often clog the openers with soil. A clogged drop is easily detected in the field since seed from the clogged tube will start to overflow at the top of the drop tube near the hopper, and a mindful operator will notice this overflow while running the dril. When using the drill after it has been parked for extended periods it is critical to blow out each of the drop tubes with compressed air or high-pressure water to clear out spider webs and other debris that can cause clogging.

When going into a field with the drill it often takes several feet of ground wheel operation for the seed to make its way through the delivery mechanism, down the drop tubes, and into the soil in the slot opened up by the disc opener. For this reason it is always advisable to make a final perpendicular pass along both edges of the field, filling in the areas that were potentially skipped as the drill entered and exited the field.

BROADCAST SEEDING

If a drill is not available the next best option is to broadcast the cover crop seed with a relatively inexpensive, three-point tractor mounted broadcaster. Small-scale growers planting out small areas (5 acres or less) can effectively broadcast cover crop seed using commonly available and inexpensive hand cranked broadcast seeders.

Seeding rates are challenging to set with broadcast seeders. Depending on the area to be broadcast it is often advisable to set the seed opening smaller than anticipated and make numerous passes over a field to improve overall uniformity of seed application. Note that it is important to measure out your field sizes and estimate the acreage prior to broad-

casting so that you know exactly how much seed needs to be broadcast on each block. Recommended seeding rates are typically increased by 30% when cover crops are broadcast and harrowed, compared to drilling, to compensate for the lack of seeding depth uniformity.

Once the seed is broadcast at the desired rate the grower must go back over the field with some type of secondary tillage implement to improve soil/seed contact to ensure adequate germination and minimize seed exposed on the surface. Secondary tillage implements commonly used to cover broadcast seed include spring tooth and spike tooth harrows and three point rototillers.

Implement choice will often depend on the amount of residue in the field, since spring tooth and spike tooth harrows tend to bring residue to the surface, which can negatively impact cover crop stand establishment. The drawback to rototillers is that they are best operated at much slower ground speeds than other types of harrows, so covering large areas can be time consuming.

Discs can also be used to cover broadcast cover crop seed but setting the correct depth is critical to avoid placing the seed too deep and/or over mixing the soil. Tandem discs are better than offset discs for covering broadcast cover crop seed since they tend to move less soil and are less aggressive. If available it is advantageous to pull either a ring roller or drag bar behind the disc or spring tooth harrow when covering cover crop seed to leave a uniform soil surface.

When broadcasting and harrowing cover crop seed it is inevitable that some seed ends up getting buried too deep and some seed may be left on the surface where it is less likely to germinate due to either bird feeding pressure or inadequate moisture.

Other Planters

Tractor mounted, three-point, high-density planters commonly used for salad mix can also be used to seed cover crops and can provide an extremely high level of uniformity and accurate seed depth. These planters are best suited for planting on beds that are free of residue. And although cover crops are most commonly planted on flat ground when drilled or broadcast, planting on beds definitely has advantages, especially if the grower already has a high density planter capable of planting a single wide bed on a standard spacing of either 60 inches or 80 inches on center. The biggest challenge with this type of seeder is that they are not well suited to high residue situations.

Weed Management Strategies

Growers have several effective tools for dealing with weeds in cover crops. Perhaps the best tool is selecting the optimum seeding density and having the ability to plant uniformly, in terms of both density and seeding depth, in mid to late October for fall planted cover crops, when soil temperatures are conducive to quick cover crop germination; this allows the cover crop to effectively out compete weed seeds. Timing in relation to soil temperature is critical for success since cooler soil temperatures later in the fall will favor the success of winter weeds over the cover crops. Soil temperatures are not an issue with summer planted cover crops.

Other weed management tools include the use of cover crops known for their ability to outcompete weeds through allelopathy. Good examples of these include mustards and many of the cereals—most notably cereal rye—when planted as monocrops. Though effective at outcompeting weeds, growers must be mindful of the challenges of spring incorporation of cereal cover crops when planted as pure stands.

Although often difficult to achieve, one of the most effective winter cover crop planting strategies for good weed management is to drill cover crop seed into ground that has had a flush of weeds from either a light overhead irrigation or early rainfall event in the fall. Light tillage with a spring tooth cultivator or under-cutter bar at time of weed seed emergence will knock out the newly emerged weeds. If done correctly the cover crop seed (bell beans/vetch and oats) can then be planted into residual moisture and will germinate without additional rainfall or irrigation. This scenario will provide a strong and weed free legume/cereal mix cover crop stand. This technique is dependent on the use of a drill for planting (see above). Soil moisture is critical as well since too much moisture will have a potentially negative impact on soil compaction.

An effective way to deal with emerging weeds in a newly planted cover crop is to go over the field very quickly with either a rotary hoe or a tine weeder just as the cover crop (legume/cereal) is emerging. This technique is referred to as "blind" cultivation and can effectively clean up a weedy cover crop field. If the timing is right the cultivation from the rotary hoe or tine weeder will not negatively impact (or only minimally impact) the emerging cover crop seed but will effectively disrupt, kill and/or desiccate the newly emerged weed seeds that are much smaller and closer to the surface than the drilled cover crop

seed. This technique depends entirely on timing in terms of the stage of development of the cover crop and the stage of development of the weed seeds as well as soil moisture. Tine weeders work best when they can be run perpendicular to the drill lines—particularly on soils prone to crusting.

Incorporating the Cover Crop

On the Central Coast of California incorporation of high residue cover crops can be extremely challenging. Because of our mild maritime-influenced winters and relatively high rainfall rates (typically 20 to 40 inches per year), a legume/cereal mix cover crop may produce 2 to 3 tons per acre of residue calculated as "dry weight." The average weight per acre of a standing legume/cereal mix cover crop just prior to incorporation can be over 20 tons per acre (wet weight). At time of incorporation this residue typically has a very high moisture level and, depending on the level of maturity, can be carbonaceous and lignified. Because of these conditions it is advisable to flail mow the residue prior to incorporation to break up the stems into manageable sizes to facilitate incorporation into the soil.

Timing of incorporation is directly linked to soil moisture and the level of maturation of the cover crop. Every spring is different and cover crop incorporation timing often involves a lot of guessing about potential rainfall patterns and soil moisture and cover crop maturation dynamics. A standing cover crop can transpire a tremendous amount of water and soil moisture can vary at different depths, making incorporation decisions challenging.

The best method for determining incorporation timing is to walk the field with a shovel and dig numerous holes and "feel" soil moisture at various depths throughout the field. In medium and heavy textured soils you want to be able to form a ball of soil in your hand and then break it apart easily. For this exercise it is important to get soil from at least 8 inches deep. If the soil "ribbons" easily when squeezed between your thumb and index finger it is probably still too wet to work (see Irrigation unit for more information on judging soil moisture by feel). Optimum soil moisture is critical for good incorporation and breakdown; in average rainfall years early April is commonly the best time for incorporation in the Central Coast region.

After flail mowing the residue needs to be mixed with the soil to enhance microbial breakdown and facilitate seedbed formation. The best tool for this is a mechanical spader.

Spaders are ideal for cover crop incorporation for many reasons. When operated in optimal soil moisture conditions spaders have minimal impact on soil aggregation and create almost no compaction compared to other primary tillage tools. Spaders are capable of uniformly mixing the cover crop residue into the tilled zone (roughly 12 inches with most spaders) while at the same time leaving the soil lofted and well aerated, allowing for ideal conditions for microbial breakdown of the residue.

Spaders also have two major drawbacks: they are expensive, and they require very slow gearing and high horse power (HP) to operate; 10 horse power per working foot of spader is the basic requirement depending on soil conditions and depth of operation. They run at a very slow ground speed, often in the range of .6 to .8 mph. Thus a 7-foot wide spader requires 70 HP and takes between 3 and 4 hours to spade an acre. Although time consuming, the results are impossible to replicate with any other tillage options now available.

If a mechanical spader is not available the next best and probably most commonly used tool for cover crop incorporation is a heavy offset wheel disc. Depending on the size and weight of the disc multiple passes are often required for adequate incorporation. Chiseling after the first several passes will facilitate the disc's ability to turn soil and will also help break up compaction from the disc.

SUPPLEMENT 3

Cover Crops for the Garden

Just as cover crops are an important source of organic matter and nutrients in row crop fields, they also play a critical role at a garden scale.

A cover crop is any plant cover used to protect, and of course, cover, the surface of the soil and to prevent erosion. This includes the effects of foliage to shield the soil from the "explosive" impact of rain hitting an exposed soil, as well as the binding and holding power of roots to prevent erosion. While there are many domesticated cover crops (principally, but not exclusively, legumes and annual grasses), weeds are also an effective cover crop.

Taking it a step further, a green manure is a cover crop that is chopped up and turned into the soil. Chopping the cover crop into small pieces increases the surface area of the incorporated biomass, which translates to faster decomposition by soil microbes.

Green manuring has two main benefits:

1. When incorporated at the succulent stage (pre-flowering) the crop decomposes quickly and acts primarily as a fertilizer for the following crop, usually spring or summer vegetables,
2. When incorporated at a more mature stage (half to full bloom) with a higher carbon content, it adds to the organic matter content of the soil. In this instance nutrients are stored in the reservoir of humus and released slowly over a number of years.

While this is not a strictly delineated process, both approaches provide a food source for soil organisms, a fertilizer, and a way to build organic matter in the soil. You tend to use the first approach on established soils to fertilize crops, and the second on developing soils to build organic matter and improve structure, i.e., to build the "body" of the soil.

Cover crops with the job of effectively trapping or catching nutrients and preventing them from leaching downward in the soil profile are known as trap or catch crops. For example, broadleaf mustards and canola tend to take up nitrogen, calcium, and phosphorous, and concentrate them in their leaves, thus preventing leaching during the rainy season. Legumes are effective in this regard as well.

Thus, cover crops/green manures offer numerous benefits; they can

- Improve the physical properties of a soil, particularly the enhancement of aggregation and development of a "crumb-like" structure.
- Increase soil's organic matter content, which feeds soil microbes and stores nutrients in a non-leachable form and releases them slowly over time.
- Protect the soil surface and prevent erosion.
- Improve water infiltration and retention as well as drainage.
- Provide a "feedstock" for soil organisms.
- Break up hard pans and reduce compaction via the "bio-drill" effect of the deep tap roots of legumes, mustard, chicory, daikon radish, etc., and—in the top foot of soil—via the fibrous roots of annual grasses.
- Cycle nutrients.
- Provide habitat and food (in the form of pollen and nectar) for beneficial insects, i.e., provision the "3 P's": pollinators, predators, and parasitoids.
- Offer a rest or "fallow" period for soil, with little or no disturbance for 5–7 months (fall through spring). This also allows for an increase in earthworm populations, among other benefits.
- Reduce or eliminate the need for purchased fertilizer.
- Increase nitrogen levels in the soil. Through the use of legume species (vetches, bell beans, clovers, etc.) atmospheric nitrogen can be "fixed" and left in the soil to fertilize subsequent crops.

Materials and Methods

Typically, annual cereals (grasses such as oats, barley, or annual rye) and legumes (vetches, bell, or fava beans) are used in tandem.

The grasses are referred to as "nurse crops." That is, they germinate quickly (within 3–5 days)

and provide leaf cover for the soil surface and soil-holding action via the roots until the slower-emerging legumes get established (7–10 days). The grasses have a fibrous, shallow root system that "works" the surface soil (to approximately one foot deep) and is amazing in terms of its ameliorating effect on soil structure.

The legumes feature a deep taproot (bio-drill) that breaks up compaction at depth as well as shallower, fibrous root systems. Some of the legumes, notably vetches and bell beans, are amazing biomass producer (6–8 feet of top growth). Legumes also fix nitrogen, as noted above.

At plow-down time, the combination of the grass and legume contributes to a balance of carbonaceous material (grasses) and nitrogenous material (legumes), which results in an optimal formula for both organic matter increase and immediate fertilizer effect.

The ideal time to incorporate a cover crop as a green manure is prior to the grasses flowering and when the legume is 25–50% in bloom. Note that legumes make 70–80% of their growth in the last 20–30% of their growth cycle.

Soil Preparation and Seeding

Soil preparation can be as simple and easy as skimming the soil surface, irrigating, waiting 3–5 days for dry down, broadcasting or scattering the seeds on the soil surface, and raking them in with quick, short strokes using a bow rake (not a leaf rake), moving in one direction—either to or fro, but not both—to cover the seed. Mulch with straw or leaves, then water. Let the plants grow, then plow down in late February–early April.

On a garden scale, seeding so as to have 8–10 plants/square foot is adequate. This is actually a light scattering of seeds. An admixture (by weight, not volume) of anywhere between 60–90% legume and 10–40% grass should suffice.

A density of 20–30 seeds per square foot is adequate for planting around fruit trees. Some legumes, such as vetch, are vines and will recognize the tree as a trellis and wreak all kinds of mayhem as they intertwine and shade flowers and leaves in the spring. The grasses are also often hard to eradicate in handworked systems.

Appendix 1: Cover Crop Seeding Rate & Planting Depth Chart

COVER CROP	SEEDING RATE PER ACRE DRILLED	BROADCAST	SEED DEPTH
Bell Beans	100 lbs	150 lbs	1"
Vetch	75 lbs	100 lbs	3/4"
Peas	100 lbs	150 lbs	3/4"
Cereal Grain	80 lbs	110 lbs	1"
Small Grass Seed	20 lbs	30 lbs	1/4"
Clover	20 lbs	30 lbs	1/4"
Mustard	20 lbs	30 lbs	1/4"
Sudan/Sorgham	40 lbs	50 lbs	1/2"
Buckwheat	75 lbs	100 lbs	1/2"

Note: These seeding rates and depths are approximate. The higher the seeding rate the higher the density and the better the weed control.

SEEDING RATE FOR LEGUME CEREAL MIX

Mix: 50% Bell Beans/50% Vetch + 7% Cayuse Oats (by weight)

Drilled rate: 150 to 175 lbs per acre
Broadcast rate: 200 to 250 lbs per acre

Appendix 2: Carbon to Nitrogen Ratios & Percent Nitrogen of Various Cover Crops

MATERIAL	C:N RATIO
Rye Straw	80:1
Oat Straw	70:1
Rye Cover Crop (mature)	40:1
Rye Cover Crop (vegetative)	30:1
Rye Cover Crop (immature)	15:1
Bell/Vetch Cover Crop	15:1
Crimson Clover	15:1
Compost	30:1
Corn Stalks	60:1
Sawdust	250:1

PERCENT NITROGEN

MATERIAL	C:N RATIO
Vetch	3.5
Rye (immature)	2.0
Rye (mature)	1.0
Bell/Vetch/Cereal Mix	2.5