Market Farming with Rotations and Cover Crops: An Organic Bio-Extensive System

by George Kuepper and Staff
at the Kerr Center for Sustainable Agriculture

PHOTO 1. Killed cover crop mulch and transferred mulch on an heirloom tomato trial at Kerr Center’s Cannon Horticulture Plots, summer 2012.

Kerr Center for Sustainable Agriculture
Poteau, Oklahoma
2015
Acknowledgements

This publication and the work described herein were brought about by the past and present staff of the Kerr Center for Sustainable Agriculture, with the help of many student interns, over the past seven years. Throughout, we have had the vigorous support of trustees and managers, who made certain we had what we needed to succeed. A thousand thanks to all these wonderful people!

We must also acknowledge the USDA’s Natural Resources Conservation Service for its generous funding of Conservation Innovation Grant Award #11-199, which supported the writing and publication of this booklet, in addition to our field work for the past three years. We are eternally grateful.

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Report
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This material is based upon work supported by the Natural Resources Conservation Service, U.S. Department of Agriculture, under number 11-199.

Any opinions, findings, conclusions, or recommendations expressed in this publication are those of the author(s) and do not necessarily reflect the views of the U.S. Department of Agriculture.
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About the Author

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His Kerr Center publications include *Heirloom Vegetables, Genetic Diversity, and the Pursuit of Food Security* (along with an accompanying series of reports on variety trials of various heirloom crops); *A Brief Overview of the History and Philosophy of Organic Agriculture; Small Scale Organics: A Guidebook for the Non-certified Organic Grower; Farm Made: A Guide to On-Farm Processing for Organic Producers; Rotations, Cover Crops and Green Fallow on the Cannon Horticulture Project: A 2010 Status Report;* and *Sweet Sorghum: Production and Processing.*

Kuepper has spent his career mostly in the non-profit sector as a researcher, educator, producer, and consultant, including an earlier stint with the Kerr Center in the late 1980s. Before rejoining Kerr Center, he worked for NCAT (the National Center for Appropriate Technology) on the ATTRA Project and served as NCAT’s Midwest Office Director in Lewis, Iowa. There he focused on organic agriculture, specializing on compliance, certification, and transition issues.
Introduction

Mark Twain once said “It’s not what you don’t know that kills you, it’s what you know for sure that ain’t true.” While it may not kill us to believe untrue things, it rarely contributes positively to our understanding of... anything! Those of us who have worked in organic agriculture for many years are much too familiar with this predicament. We have wrestled for many decades with misinformation about organic farming and gardening, some of it unintentionally ignorant, much of it intentionally manipulative – advanced by those with their own agendas.

Among the falsehoods is the relatively benign assertion that organic agriculture first emerged in the 1960s and 1970s – a fabrication of a hippie culture based on misguided philosophy and absent of science. This is entirely untrue! Organic agriculture traces its origins to the 1910s and 1920s, when interests in sustainable farming and the quest for healthy food merged to create a nascent movement. They developed and promoted an approach to growing food called humus farming, which held that producing healthy food required healthy soil, and that the health and vitality of soil is embodied in its diverse soil biology, which nourishes food crops in the way nature does, without the short-cut of soluble chemical fertilizers. The production system revolved around many traditional techniques and strategies long recognized as good biological farming practice, such as crop rotation, cover crops, green manures, animal manures, composting, mulching, and the like. Synthetic pesticides were rejected primarily because they were harmful to soil biology, though questions about harm to humans and the wider environment were already emerging.

Organic production is a system that is managed “to respond to site-specific conditions by integrating cultural, biological, and mechanical practices that foster cycling of resources, promote ecological balance, and conserve biodiversity.”

It was the concern about human health and the wider environmental impact of agricultural chemicals, combined with an emerging countercultural and anti-industrial zeitgeist, that stoked a demand for food that was naturally grown and minimally processed. The organic movement, small though it was, was already in existence and there, to be co-opted and integrated into the countercultural and environmental movements of the time.

Thus, a market was created – one which grew at double-digit speed to a roughly $35 billion industry today. But while this era led to expanded demand for organic food, thereby increasing the amount of land under organic management, consumers and other proponents often lost sight of the critical details and philosophy of organic management. They became more focused on what organic farmers did not do – they did not use pesticides or commercial fertilizers – than on what they did do as stewards of the soil and of the biology that sustains and builds the soil. Consciously or unconsciously, the new message seemed to be, “Just quit using harsh chemicals. Nature will take care of the rest.” This message spawned a number of “organic by neglect” growers, whose output and produce quality was, typically, dismal.

As growers became wiser and more experienced, they realized they needed to do much more. Some became organic “farmer-consumers”
purchasing and substituting commercial organic fertilizers and pesticides not only for the conventional agricultural chemicals they once depended upon, but also for lower-cost on-farm resources and traditional organic practices. Unfortunately, such practices became commonplace, especially among novice organic farmers. “Input substitution” is, first of all, a very expensive way to go about organic farming and gardening, but, more importantly, it continued to miss the importance of managing soil biology, of conserving and nurturing it, which is at the heart of organic farming and makes it more sustainable than conventional approaches.

The management of soil biology in traditional organic farms is achieved, first, through systems thinking and design. Understanding what we mean by a systems approach can be perplexing at first, because many novice, and even some experienced, organic growers, take a “toolbox approach” to organic culture. This means that they treat the techniques and practices in their “toolbox” like isolated wrenches, hammers, and drivers, as single-purpose tools that fix single problems. They fail to see and understand the interrelationships and impacts that these tools – the strategies, techniques, and inputs – have across the field, the farm, and the wider environment, that all their actions and inputs can have both good and bad consequences. To manage well organically, growers need to discern those foundational practices that are needed to make up their system(s) and give them priority over more specific cultural practices and inputs.

FIGURE 1. Beginning growers commonly approach organic production in the same reductionist way as their conventional counterparts. They handle pest control, weed control, and soil fertility as if one is not related to the other, when they, decidedly, are. They evaluate and choose options from their tool box as if one is no more important than another, when in fact, there should be a hierarchy of choices based upon building an effective organic system.

To repeat, one must understand that all organic systems, if they hold true to traditional philosophy, must work to conserve and nurture the biological life of the soil. We believe that a good organic system for market farming, and vegetable farming in general, can be built upon the foundational practices of crop rotation, cover crops, and a relatively small amount of compost. Additional organic practices, while they may be important, assume a less critical role in the design and implementation of the whole system.
In this publication, we will highlight a particular kind of system, one represented by the concepts illustrated in Figures 2 and 3. It is the system we are using for the Cannon Horticulture Plot demonstration at the Kerr Center for Sustainable Agriculture. It is called a bio-extensive system, which is built primarily around a planned crop rotation and creative use of cover crops. We will spend several pages discussing rotation and cover crops, but we will also spend time on other supportive cultural practices, especially organic no-till. Please be aware that, while we are describing these various cultural practices, our successes (and failures, for that matter) result within the whole system. The bio-extensive system, we feel, paves the way for many other practices to be easier and more successful. We will point that out, on occasion, as a reminder! We will, sometimes, speculate on how a particular cultural practice might perform outside of a bio-extensive system. Keep in mind these are our best guesses; they remain… speculation.

While we are describing various cultural practices, such as killed-mulch methods, OUR SUCCESSES AND FAILURES OCCUR WITHIN A WHOLE SYSTEM. While we might speculate on their performance within a different system, it is just that – speculation.
We broke ground on the Cannon Organic Horticulture Plots in November 2007, with the overall goal of creating a research, demonstration, and teaching site for sustainable organic farming on a market-farming scale. Over the years, our activities have included beginning farmer trainings, heirloom vegetable trials, heirloom seed production, bio-intensive gardening, a Native American “three sisters” garden, and numerous student intern projects. The principal demonstration and teaching tool, however, is the organic management system we use to build and maintain our soil, reduce insect and disease pests, and suppress weeds. We designed a bio-extensive model that relies on a well-planned crop rotation, the creative use of cover crops, and supplementary fertilization using mostly on-farm resources.

Coming to terms...

Traditionally, organic farming is a soil-based production system based on conserving and nurturing the diversity of biological life in the soil, and relying on this healthy biology to grow crops in a natural manner. Organic growers do not use most of the common pesticides, herbicides, and commercial fertilizers.

Market farming, as we use it here, is the same as market gardening or truck farming. All of these terms describe small-scale production of vegetables, herbs, and/or flowers that are typically direct-marketed locally through farmers markets, roadside stands, and the like.

Three sisters refers to the traditional Native American polyculture of corn, beans, and squash.

Cover crops are crops planted, not for sale, but to accomplish agronomic benefits. For example, smother crops are cover crops grown to suppress weeds; green manures are cover crops that are plowed in for soil improvement; catch crops are cover crops planted to scavenge soluble nutrients in the soil, preventing them from leaching.

A field is fallow when it is taken out of production for a period of time. Brown fallow involves repeated tillage to prevent weeds from growing on the fallowed ground; green fallow entails growing cover crops on fallowed ground.

Crop rotation is the sequence of crops planted on any field over time.

A bio-extensive rotation is one in which a significant proportion of land is in green fallow each year.4

Zeitgeist refers to the general feeling or thought characteristic of a particular period of time. Adapted from the German, it literally means the spirit of the time.
The Cannon Management Objectives

We set out with two important management objectives to guide us in designing the organic system for the Cannon Plots:

1. **Very low weed pressure.** Weeds remain the toughest challenge for organic growing in the Midsouth. Mechanical control through cultivation, hoeing, digging, and hand-pulling is common fare for organic weed control, but Kerr Center lacks the labor required. Plastic mulch is an option, but we choose not to rely on it. An exceptional approach is needed because bermudagrass (*Cynodon dactylon*) is among the weeds we must manage.

2. **Low external inputs.** Many, if not most, organic market farms in the Midsouth depend on frequent applications of commercial poultry manure to sustain soil fertility. As long as chicken and turkey litter remains abundant and available, this is an excellent resource. However, as synthetic fertilizer prices rise, organic growers may find they must compete with conventional growers for poultry manure, pay much higher prices, and look further afield. The poultry industry has also been known to “pull out” of some communities for various reasons, leaving market farmers and gardeners without a local source for their favorite fertilizer. We chose to design a system that would optimize on-farm resources and not be dependent the poultry industry for fertility.

With these objectives in mind, we ultimately designed a bio-extensive approach to crop rotation; one that relies heavily on the use of cover crops, particularly as green fallow, along with several strategies and techniques for supplementary fertilization and soil-building.

Rotation Planning

Crop rotation refers to the sequence of crops planted on a field, or group of fields, over time. Good rotations are planned to manage soil fertility, pests and diseases, and weeds. Conventional, as well as organic, vegetable growers practice rotation, particularly because it remains the key to controlling a wide range of soil diseases and pests.

> “Crop rotation is at the core of ecological stability on vegetable farms.”

*Vern Grubinger, University of Vermont Extension Vegetable and Berry Specialist*

Most growers practice rotation by ensuring that crops belonging to the same family are not planted in the same field the following season and, perhaps, not for several more seasons after that. The reason is that most diseases and insect pests are “shared” by members of the same plant family, but are much less likely to infect or infest plants from another family. Figure 4 gives an example of this concept involving representatives of four different crop families. Figure 5 goes on to list the most common vegetable families and their prominent members.
The length of rotations (i.e. the number of years that lapse before a crop family is again planted on a field) can be very important. The standard recommendation for most vegetable crops is four years, though rotations up to eight years in length can be found in the organic farming and gardening literature. Generally speaking, the longer the rotation the less likely that spores and over-wintering pests can survive to become a problem. See Figure 6 for the persistence periods of several problematic soil diseases.7

Another reason for planned rotations, particularly on organic farms, is the strategic placement of nitrogen-fixing legume crops, to increase the abundance of that critical nutrient. The scheduling of legumes in rotations and the additional nuances of nitrogen fixation will be detailed in a later section.

**Common Vegetable Crop Families**

- **Brassicas:** cabbages, broccoli, kale, brussels sprouts, cauliflower
- **Cucurbits:** melons, squashes, pumpkins, cucumbers, gourds
- **Legumes:** soybeans
  English peas, beans, peanuts, southern peas, faba beans
- **Alliums:** onions, garlic, chives
- **Solanaceous:** tomatoes, potatoes, peppers, eggplant, tomatillo
- **Umbels:** carrots, dill, fennel, parsley, celery
- **Composites:** lettuce sunflower, artichoke, Jerusalem artichoke
- **Grasses:** broomcorn popcorn, sweetcorn

*Figure 5. Common vegetable crop families and their prominent members.*
Rotations not only help us provide nitrogen and manage disease and insect pests, they also aid in suppressing weeds. This begins through changing what we grow on a field each season. With different crops and cover crops, growers alter the timing and kinds of tillage, cultivation, mowing, mulching, irrigation, and fertilization practices they use. This reduces the available time and space niches that weeds rely on to get well-established. Virtually all rotations provide this benefit to some degree. Bio-extensive design and management, as you will see, goes much further to provide a profound level of weed suppression through a particular kind of rotation.

The Cannon Plots consist of four main fields in annual rotation as shown in Figure 7. Each field follows a repetitive rotation of “early vegetables » green fallow » late vegetables » green fallow.” The sequence is staggered over all four fields each year, as might be clearer in Figure 8.

**FIGURE 7.** This figure illustrates our basic in-season rotation at the Cannon Horticulture Plots. While some variations may occur due to weather or programmatic needs, we adhere rather tightly to this long-term plan.
“Early vegetables” includes those crops planted or transplanted before mid-summer. They include (but are not limited to) early spring crops like English peas, cool-season greens and brassicas like cabbage and broccoli; crops for early- and mid-summer harvest like sweet corn, beans, southern peas, summer squash, tomatoes, and Irish potatoes; and long-season summer crops like okra and sweet potatoes.

“Late vegetables” includes summer-planted crops for fall harvest like pumpkins, winter squash, fall tomatoes, and beans; and true fall crops like winter greens and fall brassicas. We have been especially interested in planting cucurbits during or after the first week of July. Delaying planting this way starves out much of the local over-wintering squash bug (Anasa tristis) population, and often eliminates the need for additional control measures. Be advised that this only works well where no cucurbits are spring-planted on the farm or nearby fields and gardens.

“Green fallow” describes a season-long cover crop, which we grow in place of a marketable crop. We do this, of course, to enhance pest and disease management, as already described, but more importantly, green fallow is there as the backbone of our weed management and soil building programs! You will soon see how.
FREQUENTLY-ASKED QUESTION:
“Rotation!?!? I have only one small field (1/4 acre) on my market farm. How can I possibly rotate crops??”

While it is sometimes challenging, the best way we know of to start a rotation in a single field or garden spot is to start with a list and a map. List the vegetables that you grow or plan to grow and sort each of them into one of these four categories:

Root Crops: e.g. potatoes, carrots, sweet potatoes, onions, etc.
Leaf Crops: e.g. lettuce, cabbage, kale, mustard, etc.
Fruit Crops: e.g. tomatoes, peppers, sweet corn, squash, etc.
Legumes: e.g. beans, peas, cowpeas, peanuts, etc.

Next, make a sketch map of your garden plot and subdivide it into sections based on these four categories. Write in the crops you will grow in each section. Your map might resemble Figure 9. The next year (year 2), plan to grow root crops where the legumes were planted; legumes where the leaf crops were; leaf crops where the fruiting crops were; and fruiting crops where you had roots. This shift in growing locations should continue in this way thereafter.

To visualize that future, look at Figure 10 to see the rotation as implemented over three years. Understand that rotations like this are ongoing cycles on each field: legume crops are followed by leaf crops, which are followed by fruit crops, which are followed by root crops, which are followed by legume crops, and so on...

**FIGURE 9.** A quarter-acre field subdivided into four smaller planting zones. Notice that each of the zones is planted to a different selection of crops based on the four groupings of root crops, legumes, leaf crops, and fruiting crops.
If you, like most farmers and gardeners, grow more of one kind of crop than another, you may have to make adjustments to such simplified rotations. Take special note of those crops you invest more space in and add additional subplots for them. You might come up with a map that looks something like Figure 11. It is only an example and many variations are possible. What is most important is that, for a single field or plot, the same grouping of crops is not scheduled to be grown following season.

**FIGURE 10.** This figure illustrates a three-year field history for the legume » leaf » fruit » root » repeat rotation.

**FIGURE 11.** A quarter-acre field subdivided into eight smaller planting zones, to more easily accommodate the grower’s mix of crops.
FREQUENTLY-ASKED QUESTION:
“On the Cannon Plots, you lump your vegetables into two groupings of early and late vegetables and don’t seem to concern yourself with plant families. Does that give you enough protection against soil diseases?”

Excellent question! If we were growing a large number of crops of the same family, or an especially large proportion of, for example, nematode-susceptible root crops, our rotation might lead to disease problems in the future. Figure 12 shows such a rotation. Both of the commercial crops belong to the solanum family. If the soil is well-balanced and the biology strong, soil diseases and pests might not become a problem, but the lack of biodiversity makes this rotation a bit risky and we wouldn’t recommend it.

With our Cannon Plots, we actually address your concern, though it is not immediately evident. We begin by growing a rather large diversity of crops, which ensure more crop families to begin with. We go further by mapping the locations of all crops year-to-year to make certain that vegetables of the same family do not follow each other closely. We illustrate how this can be done in Figure 13. In this example, we are actually growing vegetables from only three different families to make things less confusing. Secondly, we have divided each of the fields into north and south halves during cropping years. By tracking the location of the solanaceous crop from two years before (potatoes, for example), we shift the location of the next solanaceous crop (fall tomatoes) to the alternate half. This ensures that we grow solanaceous crops no more than once in four years on any single piece of ground.

![Figure 12. A four-year rotation in which solanaceous crops are planted every other year. There is danger that diseases, nematodes, and insect pest populations could build up over time. More diversity in vegetable crop families is desired, if not needed.](image)

![Figure 13. A strong four-year rotation that includes just three crop families. It illustrates how this might be managed by further field divisions and tracking the field history. (Keep in mind that this is a simplified illustration of a principle. The theoretical market farmer, here, is only producing two different vegetables on each of the fields each year – something he or she would be unlikely to do unless specializing and selling to larger markets.)](image)
A Strategy for Controlling Bermudagrass and Other Summer Weeds

If you study the previous two figures, you will notice that they show one half of the land in green fallow every year. That does, in fact, reflect what we actually do with the Cannon Horticulture Plots each year – take 50% of the land out of production to grow a summer cover crop. That is good land that could be used for other purposes… making money, perhaps?! But it is our intent to spend money and time growing something we don’t market. That might sound unwise, but there is method to this madness, as you will see.

Weed control, as we mentioned earlier, is a major objective of our system. In fact, that understates the circumstances. Bermudagrass was the dominant forage on the pasture we converted to the Cannon Plots; it was about a 50% stand. For readers unfamiliar with bermudagrass, it is a summer perennial grass that spreads aggressively through fast-growing rhizomes and stolons. These reproductive structures can easily grow over and under four-foot sheets of landscape fabric to infest flower and vegetable beds, frustrating anyone unwilling to use glyphosate or similar synthetic herbicides. (These, of course, are prohibited in organic production).

Some organic growers, faced with bermudagrass on new fields, do choose to spray them with glyphosate. This delays organic certification for three years (36 months) from the date of herbicide application. While such practices are allowed when bringing new fields into production, certifiers frown on the notion of taking land in and out of organic status, and are unlikely to approve doing so as ongoing weed management strategy.

In our work, we learned that a rotation that included repeating green fallow, combined with an initial treatment of winter tillage, could effectively suppress bermudagrass, almost to the point of eradication. Thanks to this bio-extensive rotation, along with reasonable use of standard organic weed control practices, we have turned bermudagrass into a non-problem, and reduced all of our other summer weeds to easily manageable levels.

**Coming to terms...**

**Stolons** are specialized plant stems that grow, from the base of the plant, horizontally across the top of the ground. Rooting can readily occur at nodes along the stolon. Strawberries spread using stolons, as does bermudagrass. By contrast, **rhizomes** are underground stems. Neither rhizomes or stolons are roots; both are aerial stems. They can photosynthesize and turn green. Johnsongrass spreads via rhizomes. Bermudagrass has both stolons and rhizomes.

A **propagule** describes any part of a plant that can be used to help it spread or disperse. Viable pieces of rhizomes and stolons can be considered vegetative propagules.

**Flash grazing** – also called **mob grazing** – is the practice of briefly grazing a field with a high concentration of animals.

The **soil food web** is a relatively new term used to describe the relationships of biological organisms (including plants and plant roots) in the soil. We first heard it used in the mid-1990s. Whether Dr. Elaine Ingham coined the term or not, she is often credited as having done so.
How Green Fallow Works for Bermudagrass and Summer Weed Suppression

While bermudagrass seems invincible in the absence of powerful herbicides, it has two vulnerabilities that a bio-extensive system can exploit:

1) Bermudagrass is easily weakened through winter tillage
2) It cannot tolerate shade.

Using bio-extensive management, we take advantage of both of these vulnerabilities. Success is far less likely if the grower exploits one, but not the other, of bermuda’s weaknesses. The Cannon Horticulture Plots are located in southeastern Oklahoma, and we cannot predict, with certainty, how well our approach will work in other environments and circumstances. However, we believe the basic steps and principles we will present are sound and should work elsewhere with some site-specific modifications. The steps we take are as follows:

It is important that bermudagrass control begin in the fall prior to the first growing season.

1) Winter Tillage (i.e. brown fallow).

Bermudagrass is a summer perennial. It is dormant during the winter and re-emerges from roots and other vegetative parts. Undisturbed, it survives southern winters quite easily. However, if tilled up and exposed to cold and dry conditions, a stand can be weakened and thinned. When we first broke ground on the Cannon Horticulture Plots, we did so in November, and followed with repeated diskings through the winter months, with this objective in mind.

We began using a heavy breaking (i.e. offset) disk. Thereafter, we switched to a tandem disk, carefully watching weather forecasts for periods we hoped would be cold and dry. We consciously avoided rototilling, as this can decimate soil structure. In retrospect, we wish we had had access to a chisel plow, field cultivator, or spring-tooth harrow for the subsequent operations. These implements are less likely to create plow pans and are better designed to pull roots and rhizomes to the surface. This is especially true of the spring-tooth harrow – an implement we now use when brown fallow is appropriate.

If weather conditions allow for good and repeated winter tillage, bermudagrass should be seriously weakened and the ground well-prepared for planting a green fallow crop.
in spring. If done reasonably well, you may never need to brown fallow the field(s) again. Green fallow should be all that is needed from then on to ensure bermudagrass control.

A few additional points:

• Do not assume that a single winter season of brown fallow will eradicate bermudagrass without follow-up green fallow. We've observed that enough propagation material generally survives winter tillage to re-establish a spotty but problematic stand. If you do not follow-up with green fallow, consider summer brown fallow, with repeated tillage, or plan on very diligent cultivation and hand-weeding through the summer should you decide to grow crops.

• Do not assume you can establish a competitive and successful green fallow to smother bermudagrass without winter fallow the previous season. We’ve tried and it has not worked very well for us.

• Do a good job with your first winter of brown fallow, so you don’t need to repeat it! Brown fallowed soil is highly vulnerable to erosion and nutrient leaching; you will lose organic matter and soil biology. If you accomplish your objective of controlling bermudagrass, you will be able to keep your fields covered with crop residues or a cover crop every winter from then on.

Following winter tillage, we seed one or more of the annual grassy sorghums as early as the last week in April, or whenever soil temperatures approach 65° F. It’s our custom to seed at or 10% above the recommended seeding rate for the specific type, variety, conditions, and planting method. This helps ensure a thick stand. (For common sorghum-sudan hybrids, 30 lbs/ac. is often recommended for broadcast seeding in our region; therefore, we use about 33–35 lbs/ac.)

To date, we have relied on broadcast seeding, followed by shallow incorporation using a small disk or spring-tooth harrow. Shallow rototilling also works, but is has been less satisfactory and “batters” the soil more than is desirable or necessary.

We have begun to follow this shallow incorporation with rolling, to improve soil-seed contact. We have been using a water-filled lawn-type roller, though a cultipacker or cage-type seedbed roller would certainly be preferred. So far, these
methods have worked adequately, but our stands are seldom as uniform as we’d like them to be. A grain drill would be preferred, but we’ve not found one that suits our small plot work. We have, however, recently acquired a drop seeder, integrated with a cage-type seedbed roller. It looks promising, and we are looking forward to the 2015 season to give it a try.

Grassy sorghum seed sources should be easy to find. Local farmers coops commonly stock one or more kinds. However, be aware that many seedhouses routinely treat sorghum-sudangrass seed with fungicides, making them prohibited for organic growers. In such cases, you may need to special-order untreated seed.

3) Mowing or Flash Grazing. Unless early summer weather is exceptionally cool, annual grass sorghums can grow to the height shown in Photo 2 by late June or early July, when seedheads begin to emerge. At or before seedhead appearance, the green fallow crop should be mowed. We use bushhog (rotary) or flail mowers for two reasons:

i. First, one can set either mower to leave long stubble, which we prefer in order for the sorghum to re-grow quickly.

ii. Second, rotary and flail mowers shred vegetation, which encourages faster decay. As a result, minerals will recycle faster and the plant matter offers less of a mulch barrier to the re-growing plants.

Flash grazing (also called mob grazing) is an excellent alternative to mowing, as long as the sorghum is not grazed too short. While ruminants might remove biomass, they return urine and manure, and we can manage the green fallow without using fuel and machinery. Photo 5 shows Kerr Center’s goats grazing one of our green fallow fields in 2012.
4) Mowing or Flash Grazing Redux. Sorghums are especially drought tolerant and, unless conditions are extremely hot and dry, they will resume growing and be ready to mowed or grazed again, by around mid-August. Guidance for how mowing and grazing should be done might vary from #3, above. Read ahead to #5, below.

5) Establish a Winter Cover Crop. At this time, we usually select one of two options:

A. Planting a winter cover crop using standard seedbed preparation. In this instance, we set our bushhog or flail mower as low as possible in order to shred as much of the vegetation as possible, and discourage the green fallow from re-growing. If flash grazing, we would graze it short as well. Mowing or grazing is followed with disking and other operations intended to make a suitable seedbed. Our objective is to seed our winter cover crop between September 15 and November 1.

Be certain to allow at least two weeks to pass between incorporation of green fallow and seeding the winter cover crop, to allow the biomass some time to decay properly. You might want to wait a bit longer if the biomass is especially heavy and conditions are exceptionally dry.

Because of the volume of biomass incorporated into the soil, it is very important that nitrogen-fixing legumes (clovers, vetch, etc.) be in the subsequent winter cover crop mix, along with a fast-growing grass such as oats or grain rye. Grasses are especially important in the fall and early winter, when legume soil cover is sparse and the soil needs extra protection against heavy rainfall, erosion, and nutrient leaching.

B. Establishing a Winter Cover Crop without Tillage. To establish the cover crop without tillage, leave long stubble when mowing or flash grazing the sorghum, as was done earlier in the summer. Allow the sorghum to re-grow again. It will continue to do so until the first significant frost. Fine-seeded legumes, like clovers, can best be broadcast between September 15 and November 1, though later seeding is still likely to work. It is important to rotary- or flail-mow the sorghum so it does not shade out the clover. We believe that this is best done either shortly before frost-kill or immediately after. The objective is to allow sunlight to reach the emerging clover plants.

It is probably not advisable to rely on brassicas for such a seeding. While they are fine-seeded and should germinate easily in these circumstances, they are not leguminous, and their performance would likely be disappointing in the midst of all the high-carbon sorghum residue.

Effective bermudagrass and summer weed suppression requires a dense shading stand vegetation throughout the growing season. Should you choose Option A – establishing your winter cover crop with tillage – be prompt and vigorous with your seedbed preparation. Bermudagrass might re-establish a weak but persistent early-fall stand from any surviving roots, stolons, or rhizomes, if given a chance. Don’t give it that opportunity!

Annual grassy sorghums are not the only alternatives for season-long summer fallow, though we do recommend them when confronting bermudagrass. We are investigating other species as well. Though we’ve not fully assessed their weed-competitiveness, they have most of the characteristics of successful summer cover crops – rapid growth, dense plant canopies, and longevity. The more promising species include:

- **Pearl Millet.** While not growing as tall as the sorghums, pearl millet forms a shorter but remarkably dense leaf canopy. While we have not done side-by-side comparisons, we suspect pearl millet might work as well as the sorghums for suppressing bermudagrass.
• **Crotalaria** (also known as Sunn Hemp). Crotalaria can grow exceptionally tall and dense (see Photo 6). If allowed to reach maximum height, the stems become quite woody. Crotalaria is also a legume that seems to inoculate well with current strains of rhizobia used with cowpea. It does not appear to set seed at our location, which is fortunate. The seed is apparently toxic to birds.

• **Lablab** (also called Hyacinth Bean). Another legume, lablab is well-adapted to the region. It is vining and grows well in combination with annual grassy sorghums.

• **Long-season cowpeas.** Cowpeas are legumes, more closely related to beans than to English peas. Crowders, black-eyed peas, southern peas and, simply, “peas” are terms variously used in reference to specific kinds of cowpeas, or to cowpeas in general. Varieties like “Iron and Clay” (110 days) and “Red Ripper” (90 days) are fast-growing but remain vegetative long into the summer, much longer than “Pinkeye Purple Hull” (65 days) and other popular garden types, which flower, fruit, and drop their leaves relatively early in the season.

• **Sesbania** is another tall-growing southern legume. Unlike crotalaria, it easily sets seed in the Midsouth and can become a weed if not terminated in a timely manner.

Once bermudagrass is under control, there is benefit from using these (or other) cover crops as green fallow. They increase biodiversity and, in the case of legumes, they fix nitrogen. We have begun mixing several grass, legume, and other non-legume species to find compatible combinations.

To this point, our discussion of weed management has focused exclusively on bermudagrass. What about other summer weeds? Fortunately, we have found the effect of green fallow to be equally profound where other summer weeds are concerned. Our overall weed pressure, today, is very low – a fact appreciated by student interns, who spend very little time cultivating and hand-weeding. Rotation with green fallow goes a long way toward suppressing weeds in our system.
Summary of Steps for Converting from Bermudagrass to Organic Vegetables with Annual Grass Sorghum

1. Weaken bermudagrass through:
   a) Winter Tillage (with no delay in organic certification) or,
   b) Glyphosate suppression (36-month transition to organic status required)
2. Establish a weed-suppressive summer cover crop of sudangrass or sorghum-sudangrass as early as conditions allow. Use high recommended seeding rates plus 10%. Or more
3. Mow shortly before seed heads emerge using a rotary bushhog or flail mower—shredding the vegetation while leaving tall stubble. Alternatively, flash graze with ruminant stock, leaving long stubble.
4. Shortly before seed heads emerge again, repeat #3. Leave tall stubble if no fall tillage is planned; leave short stubble if planning to till.
5. Plant a winter cover crop after September 1st when conditions permit.
6. In spring, mow and incorporate the winter cover crop and prepare the soil for planting.
7. Plant or transplant vegetables no sooner than 2 weeks after the winter cover crop has been plowed-in.

Just the FAQs: Session #2

FREQUENTLY-ASKED QUESTION:
“I market garden using raised beds with permanent 3-foot wide, mowed walkways in between. Bermudagrass is a major problem! If I rotate half of my beds to green fallow each year, will I control the bermudagrass?”

Permanent beds and mowed walkways are a welcome environment for bermudagrass, which thrives under mowing – producing stolons and rhizomes that easily travel four feet or more in a season. Even if you control bermudagrass within the beds using green fallow, it will re-invade the following year from the mowed pathways.

One of our cooperating Arkansas farmers, Chuck Crimmins of Crimmins Family Farm, does succeed in managing bermudagrass in his raised beds. He relies on tillage techniques, crop competition, and a string-trimmer, where necessary. Chuck’s tillage methods include using bedding disks to shape the planting bed and leave a clear trench along the edges. Drip irrigation confines watering to his crop and does not encourage the grass in his pathways. To get an edge with crop competition, Chuck transplants and double-crops many of his crops to give them a head start and a shading advantage over invading grasses. Chuck also deep-mulches long-season crops, such as tomatoes, to discourage bermudagrass, but backs this up with the aforementioned string-trimmer when required. Chuck stresses the importance of observation and planned his rotation to ensure that competitive crops are planted in locations where bermudagrass appears to be gaining a foothold. Crimmins Family Farm is certified organic and they have successfully farmed this way for many years. So there are techniques that suppress and manage bermudagrass with permanent bed systems. But keep in mind that Chuck has a long history of market farming. Skill such as his takes time to hone.
FREQUENTLY-ASKED QUESTION: “If sorghum-sudangrass works as a smother crop to control bermudagrass, will it also control johnsongrass?”

Since we have not tried to control johnsongrass (Sorghum halepense) with smother crops as yet, we are hesitant to give a firm answer, but... it is not likely that any of the annual grassy sorghums will work very well. Johnsongrass is a perennial member of the sorghum family. We would expect it to be much more competitive than its annual relatives.

This is only a suggestion, but in 2011 we did have a small infestation of johnsongrass that resulted from an unfortunate decision to use imported mulch. (This was the very last time we brought in mulch from the outside!) We succeeded in eradicating this infestation of johnsongrass more through luck than design. It emerged in a green fallow planting of cowpeas, making it easy to identify and hand-pull. We policed the field diligently that season and the johnsongrass never returned. Through this process, we developed a few notions on how to approach the challenge of converting johnsongrass pasture to organic production, without herbicides. Unfortunately, quite a bit of labor is involved.

We would certainly begin, as outlined in Figure 14, using brown fallow for a full winter, but planting a green fallow crop of soybeans. As we learned, johnsongrass will emerge and top the cover crop, making it easily distinguishable. It can then be hand-pulled – the labor-intensive part. We suggest soybeans rather than cowpeas or lablab because soybeans are non-vining, making it easier to walk through the field and extract the grass. Be certain to pull the johnsongrass before it sets viable seed.

If you keep all emerging johnsongrass controlled by hand-pulling or cultivation, further seasons of winter brown fallow should not be needed. Johnsongrass will continue to emerge from dormant seed in the soil. This will decline with time, but will continue to be an issue in your field. One study of weed seed viability found that 48% of johnsongrass seed remained viable after being buried for five and a half years.\(^\text{12}\)

FREQUENTLY-ASKED QUESTION: “I understand that horticultural vinegar works as well as Roundup® for killing weeds. (I read it on the internet, so it must be true!) Unlike Roundup®, natural vinegar is allowed in organic production. Why can’t I just use vinegar, or one of the other allowed products, to control bermudagrass?”

Vinegar, and all of the organically-allowed materials we are familiar with – mostly herb and vegetable oils and extracts, or soap-based products – are contact herbicides; they “burn” the exposed green plant parts that the spray reaches. If the sprayed weed has just emerged and has little or no root reserves, it may be killed; if not, it will likely recover from the damage. By contrast, Roundup® has systemic action. This means that green stems and leaves absorb the poison and it travels throughout the plant to kill the roots and other underground parts that would easily evade vinegar sprays. Thus systemic action allows Roundup® and related chemicals to kill weeds that contact herbicides merely injure.

Being a perennial, bermudagrass possesses roots and underground rhizomes that are fully shielded from sprays. So contact-action herbicides, like vinegar, will burn the exposed vegetation, but the grass will quickly re-grow.
Feeding the Soil: Green Fallow as Green Manure

We can’t repeat it too often: the guiding principle for organic management is preserving and enhancing the healthy biology of the soil – a complex of organisms and relationships we have come to call the soil food web. It is the soil food web that builds the soil and provides crop nutrition, as well as a basis for natural biological pest control. Organic farmers use many traditional practices – crop rotation, composting, green manuring, crop residue management, etc. – to ensure the long-term diversity and vitality of this food web.

The food energy that powers the soil food web originates with the sun, but nourishes the soil organisms in the form of organic matter. It comes in such diverse forms as crop residues, composts, animal manures, leaves, and so forth. In sustainable organic systems, growers can use green manures to deliver large quantities of rich organic matter by growing it right on-site. Among cover crops, annual grassy sorghums nearly top the list of biomass producers. Seasonal totals of seven or more tons per acre through multiple cuttings are not unreasonable where soils are fertile.

Annual sorghums can also be grown with summer legume companion crops such as buckwheat, lablab, cowpeas, or crotalaria that can fix nitrogen, or non-legumes like buckwheat or sunflower. Generally, cover crop mixes are preferred to single-species plantings. They increase biomass yield and add to biodiversity, and when conditions are unfavorable for one species, another is there to fill the gap, ensuring ground cover and a respectable green manure crop.

In bio-extensive systems, green fallow crops are also green manure crops, providing regular infusions of organic matter. Since we regularly grow these high-biomass green fallow crops within the rotation, we reduce the need to import poultry litter or other organic amendments that would otherwise supply the needed organic matter. This, then, goes a long way in helping us cut down on off-farm inputs, and aids us, particularly, in severing reliance on industrial manure sources – one of our main management goals.
Don’t Forget Winter Cover Crops

Winter cover crops are just as important to a successful bio-extensive rotation as summer green fallow crops. Fields without winter cover risk damage from pelting rain drops and losses from erosion and leaching; growers also miss a golden opportunity to grow organic matter and fix nitrogen during the off-season, when they grow few, if any, commercial crops.

**FIGURE 15.** Shows the in-season crops and green fallow, plus winter-season cover crops on the Cannon Horticulture Plots.

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**Coming to terms...**

Winter cover crops are typically those planted in late summer or fall, and occupy the ground through the winter. Many, such as crimson clover and hairy vetch, are annuals, though biennial and perennial species may also be used. Most winter cover crops are one of three types: winter annual grasses, winter annual legumes, and brassicas.

Summer cover crops are usually planted in spring or early summer, and thrive through the main growing season. Summer covers include sorghums, millets, cowpeas, buckwheat, and other species already described as green fallow crops.

Legumes are a large family of plants that include beans, peas, cowpeas, alfalfa, peanuts, clovers, vetch, crotalaria, sesbania, and others. They have the unique capability of fixing nitrogen from the air. Nitrogen fixation is managed through the infection of legume roots by the friendly *Rhizobium bacteria*, which fix and share nitrogen with the host plant in exchange for sugars and other carbohydrates that the plant makes through photosynthesis.

Brassicas are a genus of plants in the mustard family (Brassicaceae). The members of the genus are informally known as cruciferous vegetables, cabbages, or mustard plants. Crops from this genus are sometimes called cole crops. Radishes are actually of the genus *Raphanus*, but are often lumped in among the cruciferous plants, as we have done here.¹⁴

Monocropping or monoculture means growing a single crop species on a field at one time. Polyculture entails growing multiple species within the same field.
Figure 7 depicts our basic bio-extensive rotation as regards the crops grown in the main planting season of late spring through early fall. It does not show winter ground cover. Since we strive to cover every available foot of our four rotation fields with winter cover crops, a more realistic and instructive illustration of our bio-extensive rotation is shown in Figure 15, which details not only crops and cover crops during the main growing season, but the winter cover crops as well. We choose winter cover crop species as we do our summer green fallow cover crops: to help address our management objectives of reducing weed pressure and the need for outside inputs.

When selecting a winter cover crop or, rather, a winter cover crop mix, we generally choose among three main kinds of plants—winter annual grasses, winter annual legumes, and cool-season brassicas.

Winter Annual Grasses. If, for some reason, we were unable to plant winter cover crops on the Cannon Plots, our fields would not remain bare; not for long, anyway. By mid-spring, they would host a mix of buttercups, henbit, and other cool season weeds that thrive in southeastern Oklahoma. In the absence of cover crops, wild, weedy vegetation protects the soil. That’s good but, as we begin growing more early-season vegetables, we don’t want to encourage these weeds to thrive, particularly by letting them set seed. To smother winter and early-spring weeds, we look to winter annual grasses. There are three species we have come to rely on:

- **Grain rye** has been our standby winter cover crop. It is very hardy, covers the ground quickly, produces an abundance of biomass, and matures early. When grown alone, legume cover crops like clover and vetch grow slowly and provide the soil with only sparse cover in fall and winter; a companion or nurse crop of rye remedies this problem. We believe wheat or ryegrass would probably work about as well as rye, though we’ve not tried either as yet.

- **Triticale** results from crossing wheat with rye. It has the winter hardiness of rye, but matures somewhat later in spring. This can be advantageous when trying to synchronize the maturity of a winter grass companion with a winter legume in order to optimize nitrogen fixation or accomplish mechanical killing—matters that we will discuss later.

- We choose varieties of *hulless oats* when we need a grass or grass companion that is killed by cold winter weather. A winter-killed cover crop is usually easier to soil-incorporate early in the spring, and is often grown in advance of early spring crops such as Irish potatoes and brassicas, like broccoli. It also serves as an excellent nurse crop when trying to establish a pure winter legume stand of clover or other legumes; the dead residue continues to protect the soil as the legume grows through the decaying vegetation.15

**PHOTO 8.** This shows a dense mat of winter-killed oats on a field at the Cannon Hort Plots.
Winter Annual Legumes. Growers like to use poultry litter because it is rich in nitrogen. This is one of several reasons they have come to rely on it. In our bio-extensive system, we choose to grow our needed nitrogen with legume cover crops. We accomplish most of this in the winter months. Therefore, our choice of legumes and how we manage them is critical to our objective of reducing inputs like poultry litter. We especially rely on the following:

- **Crimson clover** is an exceptionally good cover crop in our region. It matures early in spring, producing only a modest amount of biomass, but with a good amount of nitrogen. It is easy to mow and plow in, and is possibly the only nitrogen-fixing option if you need to get into the field early. Crimson clover often produces “hard seeds” which take an extra year or two to germinate, so it frequently volunteers in subsequent years, which is usually not a problem. Crimson clover also re-seeds itself easily, which can contribute to the soil seedbank, ensuring that crimson clover becomes a recurrent visitor every spring. **Arrowleaf clover**, by contrast, is later-maturing, but produces a large amount of vegetation, making it an excellent smother crop in late spring and early summer.

- **Hairy vetch** is as reliable as crimson clover in our region. It is just as winter-hardy, matures later, but produces more biomass. All vetches are vining and not always easy to mow, especially with walk-behind equipment. We found it almost impossible to mow hairy vetch with a BCS-mounted sicklebar. Like crimson clover, hairy vetch will also re-seed itself, but less vigorously than crimson clover, or so it seems. We also grew some **purple vetch** and were pleased with it. It grew taller and denser than hairy vetch. However, the seed cost is higher so we’ve not continued to use it. We also tried **chickling vetch** but found it did a poor job of surviving our winter.

- **Austrian Winter peas** typically mature a bit after hairy vetch in our area. It is the only legume we might consider planting without a companion grass. It produces abundant fall ground cover, but only if planted early enough. Like vetch, winter peas are vining and present similar challenges for small-scale mowing. Unfortunately, they are also less winter-hardy. We lost a planting of Austrian Winter peas during the 2013–2014 winter season, which was especially harsh.

- **Bell beans** (also known as faba or fava beans) do poorly as a winter cover on the Cannon Plots. They are not winter-hardy enough for southeastern Oklahoma. However, they might do well if seeded in late winter or very early spring.
Cool-season Brassicas. The brassica family includes a number of species that make excellent winter cover crops, and they have some special uses. Most, if not all, of the species are nematicidal, and work to control those crop pests. In general, we grow brassicas in conjunction with other cover crops to increase biodiversity, provide some early-flowering plants for pollinators, and to loosen the soil.

- **Tillage and oilseed radishes** resemble *daikon radish*. All three produce long stout white tap roots that grow deep to penetrate plow pans. When dead and decaying, radishes leave deep channels into the soil, improving water penetration and air exchange. In our area, we find that radishes complete their life cycles ahead of legume and grass cover crops. This presents no problem that we can see, and may be a benefit since the grasses and legumes no longer need to compete with the brassicas.

- Forage turnips are still rather new to us. So far, however, they look promising and deserve mention, especially since their large roots might provide benefits similar to those of radish. **Mustards** have also grown well here but, like forage turnips, we have not gained that much experience with them as yet. In 2011, we did discover, however, that mustard can be a very effective smother crop for fall weeds (see Photo 11).

- We have grown **rape** as a winter cover crop a few times, but it has never done as well as the other brassica species.

**Winter Blends.** Almost all of our winter cover crops are blends. We rarely **monocrop** (grow just one single species). To increase biodiversity, protect the soil, and reap other benefits, we combine grasses, legumes and brassicas on most of our fields every winter. Some of our guidelines for blending include the following:

- Most winter annual legumes should be planted with one or more of the cool-season grasses. The legumes are slow-growing in fall and leave the soil poorly protected. Grasses grow and cover the soil more quickly, as well as anchoring it. In combination with legumes, they will also generate more biomass.

- To date we have used heavy seeding rates, stating at the maximum recommended rate for both the grass and legume species, and adding about 10% more seed. We’ve done this believing we would improve our stands. We may have been too conservative. One commercial source suggests increasing standard rates by up to 50% when weed control is a primary objective.\(^1^6\)

Reducing seeding rates can be “penny-wise and pound-foolish” if you fail to get the full and needed benefits from your cover crops.
• However, as our soil gets better and our planting skills improve, we might also consider scaling back on seeding rates. This can be of particular benefit for organic farmers, who pay extra-high prices for organic seed. Reducing seeding rates, however, can be “penny-wise and pound-foolish” if you fail to get full and needed benefits from your cover crops. This is especially true if the cover crop is grown for killed-mulch growing – a method we will cover later on. Local Cooperative Extension literature is usually a good place to start when deciding on seeding rates, including how to adjust rates when planting combinations of species.

• When we use tillage radish or other brassicas in blends, we find that four pounds of seed per acre is the maximum amount we can add without turning them into smother crops that eliminate companion legumes and grasses. Plan to seed brassicas at standard high rates only if you want a pure stand, such as when trying to suppress a nematode problem.

• We avoid brassicas in winter blends when the following crop will include very early vegetables. Brassicas can host the vegetable weevil – a cool-season insect pest. If present when the brassicas die, vegetable weevil can infest and wipe out spring cabbage crops, early tomatoes, and a wide variety of other vegetables. As weather warms, the weevil goes dormant, so later vegetable plantings are not at risk.

• Grass and/or brassica species are especially valuable following fertilized vegetable crops or circumstances where compost or manure will be spread in fall. Both species – grasses, especially – are good a mopping up soluble soil nutrients that might otherwise leach from the root zone (i.e. excellent catch crops).

• Alternatively, legume cover crops are most important following green fallow crops of pure or dominant sorghum or millet. These high-carbon green manures tie up soil nitrogen and legumes are needed to ensure an adequate supply for the following growing season.
Ensuring Enough Nitrogen

Nitrogen is often the most-limiting nutrient in crop production, whether organic or conventional. In conventional growing, the major source of nitrogen is soluble synthetic fertilizers. By contrast, organic growers rely on nitrogen-fixing organisms in the soil food web to capture it from the air to make proteins. Other components of the food web then process these proteins and other organic matter to release soluble nutrients to plants over time, at nature’s pace. This reduces luxury consumption by crops – a root cause of some diseases and insect infestations. It also cuts down on the pollution resulting from the use of conventional fertilizers. However, because organic producers – especially those with bio-extensive rotations – rely heavily on cover crops for nitrogen, advance planning and system design is critical to ensuring that adequate nitrogen is made available to all crops.

While we have yet to undertake systematic nitrogen monitoring of our crops and soils, field observations have taught us a lot. So while we hope to set up monitoring protocols within the next few years, we are comfortable making the following observations and recommendations:

- Under conditions where soil organic levels are good, and winter annual legumes can be managed close to their nitrogen-fixing potential, we feel the bio-extensive model is capable of meeting nitrogen needs with little or no supplementation. That said, there are at least two important caveats:
  
  I. Early spring and late fall crops that preclude the planting or optimization of legume nitrogen fixation can require some form of supplementation. Very early vegetables can easily suffer a nitrogen deficiency in a bio-extensive rotation if the previous main-season green fallow crop was a pure or dominant stand of sorghum or millet. The high-carbon residues tie up soil nitrogen and there is not enough time for winter legumes to fix appreciable amounts of nitrogen before they are turned down to build the spring seedbed. Even early-maturing winter legumes like crimson clover, will not fix enough nitrogen before they are terminated. We try to alleviate these nitrogen deficits by using legumes in the preceding green fallow crop. Obviously, we would not do this until we confirmed that bermudagrass was well under control.

PHOTO 12. The picture shows a rye and hairy vetch cover crop in early spring following a green fallow of sorghum-sudangrass the previous summer. Note the thin stand of rye and the dominance of hairy vetch, which suggests limited available soil nitrogen.

PHOTO 13. This picture of a nearby field contrasts well with photo 12 by showing a winter cover crop blend of rye and crimson clover that followed a green fallow crop of cowpeas the previous summer. Here the rye holds its own, sharing the stand evenly with the clover. This points to considerable carry-over of nitrogen from the cowpeas, which stimulates rye growth.
II. Uncooperative weather – of which we can expect more – can undermine the best laid plans.

- Factors that limit legumes or otherwise prevent optimal nitrogen fixation by legumes include, but certainly aren’t limited to: weak or thin stands, poor nodulation, and/or bad timing of termination.
  
  - **Weak and thin stands** can be due to unpredictable weather events. On the other hand, they can also be due to miscalculated seeding rates, inadequate seedbed preparation, poor planting technique, low seed quality, and other factors we can control through experience and/or closer attention to detail.
  
  - **Poor nodulation** that can result when the proper *Rhizobium* bacteria is not present to infect the roots of the legume you are growing. There are several different strains of *Rhizobium*. These different strains infect different groups of legumes (see Figure 16). Generally, if legumes from a specific group are growing or have grown on a field in recent years, there are bacteria surviving in the soil that can infect new plant roots. If not, you should inoculate the seed with fresh commercial inoculant. This may be desirable in any case, as new inoculant often contains improved forms of *Rhizobium* that might improve crop or cover crop performance.
  
  - **Terminating** a legume cover crop too early or too late negates much of the benefit. If too early, the plants have not yet fixed much nitrogen; if too late, most of the nitrogen will be sequestered in mature seed and be unavailable. In order to maximize the amount of fixed nitrogen from a winter legume crop, it should be terminated – mowed and/or tilled into the soil – sometime between early- and mid-bloom.

- You can often guess at the composition of a previous green fallow crop by observing the composition of the winter cover crop that follows, but not in early winter. At that time, a winter cover crop grass and legume blend will look much the same whether it follows a green fallow of pure sorghum or millet, or a pure stand of cowpeas, lablab, or another legume. The difference can be seen by mid-to-late spring, however. A winter cover crop that follows a high-biomass sorghum green fallow will become a pure legume stand; by contrast, one that follows cowpeas will have a balanced proportion of grass and legume. This occurs because grasses cannot fix their own nitrogen and are at a disadvantage following high carbon green fallow that ties up much of the soil nitrogen. Under such conditions, only the nitrogen-fixing winter legumes will truly thrive.

- The best way we have found for addressing nitrogen deficits in this system is by adding more legumes to our green fallow plantings. Here are our thoughts and some of the ways we are going about this:
  
  - Switching to a legume green fallow might not be advisable if bermudagrass control remains a significant issue. Some legumes, such as crotalaria and long-season cowpea varieties (e.g., “Iron & Clay”, “Red Ripper”) appear to be very effective smother crops, however, and might do a fine job of suppressing bermudagrass. We simply have not done enough work with them as yet to be confident in a recommendation.
The most important place to schedule a legume green fallow crop in a bio-intensive rotation is in the summer immediately preceding very early vegetable crops and/or following very late vegetables, where winter cover crops might not be grown at all. (See Figure 17.)

Summer legumes need not grow as pure stands. Many grow quite well as companions for sorghums and millets, and biodiversity is always desirable where it can be managed. Over several seasons we’ve successfully grown several combinations of cowpeas, crotalaria, and lablab with annual grassy sorghums and with pearl millet. Many combinations appear possible.

Another area where we lack some experience is in how to best manage long-season summer legumes. Long-season cowpeas, lablab, and crotalaria flower quite late, which might mean that we don’t need to mow them in mid-summer as we do with annual grassy sorghums. It might be better to just let them grow until time to prepare the soil for a winter cover crop.

It can be easy for conventional growers to apply too much nitrogen when using commercial fertilizers. It is also possible to do so when using manure. Organic growers that rely on legumes, however, are much less likely to overdo it. This is because *Rhizobium* bacteria become indolent when there is abundant nitrogen in the soil and fixation slows. This is fortuitous since, along with its other ills, excessive nitrogen reduces soil humus levels by over-stimulating the bacteria that consume it. Growers might observe a short-term benefit with an abundance of available nitrogen, but they are drawing on the soil’s reserves of humus and lose productivity in the long run.

**FIGURE 16.** A depiction of the major *Rhizobium* inoculation groups.
Short-Term Summer Cover Crops

Market growers often have short-term gaps between main crops and cover crops, where the field remains empty for several weeks. In these circumstances, market growers usually choose from among four alternatives:

1. Ignore the field until it is time to plant a winter cover – surrendering it to weeds.
2. Manage the field as brown fallow, i.e. periodically tilling the ground to kill growing weeds and reduce the bank of weed seeds in the soil.
3. Plant a second crop to be harvested later, i.e. double cropping or relay cropping.
4. Plant a short-season cover crop.

While all four options are possible, we are focused on #4 and want to use these brief windows of time to grow additional cover crops. This is of particular value where one’s system has little or no green fallow. In our experience buckwheat and short-season cowpeas, like “Pinkeye Purple Hull,” do a great job of filling niches within the growing season.

FIGURE 17. This illustration shows where one should consider planting very early and very late vegetables, as well as legume and non-legume green fallow crops, in a bio-extensive rotation. Scheduling such as this can reduce the need to supplement with natural nitrogen fertilizers.
**Buckwheat.** As cover crops go, buckwheat is different from any of those discussed so far. It is neither a grass or a legume, nor is it a brassica. Buckwheat is a summer annual broadleaf from the Polygonaceae family, which includes a few crops like rhubarb and several difficult-to-manage weeds like smartweed and knotweed.

Buckwheat has many advantages. It can germinate, bloom, and reach maturity in 70–90 days, and its residue decomposes rapidly, making it well-suited to short time windows. It does well on poorer soils, and is exceptionally good at mineralizing phosphorus and making it more available to subsequent crops. Buckwheat is also an effective smother crop with summer weeds, though only for a brief time. As it reaches seed set, the stand will begin to thin and decline, allowing sunlight to reach the soil surface. The residual mulch, too, is short-lived. We did not find it useful for suppressing bermudagrass.

Buckwheat positively excels as a beneficial habitat plant. Even small plantings support huge numbers of wild and domestic bees. While buckwheat seems to draw mainly pollinator species, close observation reveals other species – predatory and parasitic flies and wasps, for example – that aid in pest management.

Unfortunately, buckwheat is not drought tolerant, and while it grows at moderately-high temperatures, it prefers somewhat cooler summer temperatures to really excel. Its performance can be very disappointing if heat and drought hit simultaneously. When conditions are favorable, though, buckwheat can be allowed to produce seed and, if lightly tilled, re-seed itself, which may or may not be desirable. If you are growing buckwheat in the early part of the summer before a fall vegetable crop, you will want to terminate it before it sets seed, or you might create a weed problem that will persist until frost.
**Short-Season Cowpeas.** Short-season cowpeas have several advantages over buckwheat. They are more drought- and heat-tolerant than buckwheat, while being just as productive on poor soils. They have the advantage all legumes have in that they will grow on nitrogen-starved soils, and they can fix a reserve of nitrogen for a subsequent crop. They have several of the same characteristics we associate with buckwheat, such as short-term weed suppression and attraction for beneficial insects. Flowering cowpeas draw especially large numbers of *Polistes* wasps, which prey upon various species of pest caterpillars.

When needing a short-season cowpea, we are accustomed to using a variety called “Pinkeye Purple Hull,” which reaches harvest maturity in about 65 days. (This contrasts with a long-season cowpea like “Iron and Clay” which matures in about 110 days, making it – “Iron and Clay” – more suitable for use as green fallow.) “Pinkeye Purple Hull” is also popular and easy to find in southeastern Oklahoma. The popularity stems from its delicious flavor and its survivability. (Along with okra, sweet potatoes, and garlic, pinkeye purple hull peas are considered a bullet-proof crop for local gardeners and market farmers.)

If allowed to go to seed, “Pinkeye Purple Hull” will, like buckwheat, re-seed itself to some degree. Therefore, it is smart to kill the cover crop before seed set; at 50% bloom up until early pod fill if seeking optimum nitrogen fixation.
Variations on a Rotating Theme

To this point, we have presented the bio-extensive model as a four-year rotation. This works quite well for us at Kerr Center, helping us meet our twin objectives of weed/bermudagrass management and reduced off-farm inputs. However, it is by no means the only option for growers who have their own goals, objectives, and priorities. In this section we are presenting several alternative system designs to illustrate alternatives for bio-extensive design and how they might meet individual farm needs. While we have not indicated so in the illustrations, please assume, in all these examples, that winter cover cropping is being done and is standard practice.

FIGURE 18. If crop rotation is the core of ecological stability on a vegetable farm, as Dr. Vern Grubinger asserts, the integration of green fallow goes a long way towards making it a sustainable operation. Figure 18 summarizes the trends we’ve either seen or expect to see when a market farm shifts from highly intensive production to bio-extensive management. The trade-off of land for agronomic and environmental benefits is obvious. The question for a grower is how much land ought to be removed from production and cover cropped each year. Though it might be great for the environment, fallowing all your acreage year-after-year is a non-starter. Realistic answers will vary from farm to farm and depend on factors that include land and labor availability, land and labor costs, market pressure, condition of the soil, availability of economical inputs, and the grower’s personal philosophy about how he or she ought to farm.
“Cover crops and cash crops must be intentionally integrated into the rotation, ideally in equal proportions. At a minimum, I’d suggest that a quarter of a farm’s tillable land should be ‘resting’ from vegetable production at any given time if an organic system is to succeed over the long-term.”

Vern Grubinger, University of Vermont Extension Vegetable and Berry Specialist

**FIGURE 19.** This is an example of a 3-field rotation, in which two thirds of the field area is planned green fallow. While highly sustainable ecologically, rotations with similarly high percentages of land “at rest” may not be economical where land costs are high.

**FIGURE 20.** In contrast with Figure 19, Figure 20 depicts a more intensive version of a 3-field rotation in which green fallow occupies only one third of the land area.

**FIGURE 21.** In a similar vein, Figure 21 shows a more intensive version of a 4-field rotation, in which only one quarter of the land is in green fallow. According to Grubinger and others, this is the minimal amount growers should grow to keep a market garden sustainable, but it is less than recommended for a bio-extensive rotation. Also, please note that we took the liberty of suggesting some specific vegetable crops. In one case, it splits the field between okra and sweet potatoes – both long season crops. The two other producing fields feature double-cropping, where one crop is followed by another in the same growing season. We did this to illustrate some further variations.
FIGURE 22. This figure depicts a 5-field rotation, with two fifths of the land in annual green fallow.

FIGURE 23. Here is another variation of a 5-field rotation, where three fifths of the land is in green fallow. Like the 3-field rotation illustrated earlier in Figure 19, such a high percentage of land in rest might be uneconomical except where land costs are low. Where affordable, however, such a rotation should be highly sustainable.

FIGURE 24. The 6-field rotation in Figure 24 is similar to the Cannon 4-field rotation in that half of the land is in annual green fallow. In this example, as in the alternate 4-field rotation (Figure 21), some possible vegetable crops are specifically named. It describes a farm with a production and marketing scheme different from a highly diverse market garden. A grower using the above rotation specializes more, and might be selling into wholesale markets.

FIGURE 25. This 8-year rotation features market garden fields of mixed early and late vegetables, and specialty crop fields for watermelon and sweet potatoes. Fifty percent of the land area is in annual green fallow.
FIGURE 26. Here is a more intensive version of Figure 25. Two additional specialty crops – okra and sweet corn – have been added, and the total land area in annual green fallow is reduced to 25%. Again, this is the recommended minimum for green fallow for a market farm, but not enough to really be a bio-extensive model.

FIGURE 27. Do not feel constrained by the examples we show here! Think outside of the box! Figure 27 depicts a possible plan for a hypothetical operation we are calling “McDermott’s Organic Farm,” which has a plot of land with sandy-loam soil that is ideally suited for watermelons. Watermelons prefer well-drained, sandy loams, but they also benefit from good organic content. The grower subdivides the sandy loam plot into three subfields to accommodate a 3-year rotation, and grows green fallow two out of the three years to ensure enough organic matter for watermelon crops – which she will grow only on one of these three subplots each year. On her other land, which features less promising soils, she marks off four fields to be managed with a 4-year bio-extensive rotation. Here is where she will grow her remaining crops. So what we have is a single farm operation that has two different bio-extensive rotations within it!
Ensuring Long-Term Weed Suppression with Organic Practices

**Backing Up the System.** We have had great success with weed management on the Cannon Plots. We have reduced summer weed pressure significantly and all but eradicated bermudagrass where it counts. We credit this to a well-planned rotation and our use of cover crops, especially as green fallow. This bio-extensive approach has been and remains the backbone of our weed management strategy. That said, this system would ultimately fail if we neglected to also use such basic organic weed control practices such as controlled irrigation, cultivation, mulching, and a number of preventive measures.

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**Coming to terms...**

**Headlands** are areas at the end of farm fields where tractors and equipment are turned around to continue field operations. While these zones are often left bare or in grass, some growers plant it with a few perpendicular rows which, as you’d expect, get well trampled and produce a much lower yield. These are called **headrows.**

**Tilth** refers to a soil’s suitability to support crop growth.

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**Stop Alien Invasions.** Growers have enough trouble with the weeds already in their fields. They don’t need new ones. We would never do it consciously, but sometimes, through negligence or gaps in awareness, we bring alien weeds onto our farms. We may suffer the consequences for a long time thereafter. Heightened vigilance in a few key areas can prevent a lot of weed-caused headaches:

- Examine seed tags for noxious weed seed content. Commercial seed is mostly free of problem weed seed. However, it is impossible to remove all of it, especially from cover crop seed.
- Use caution when bringing off-site manures onto your farm. Weed seed can be found in some bedding materials, in wasted feed, and in the feces. The more you know about the source, the better. Composting is always a wise option if it fits with your overall system.
- Imported mulch material is notorious as a source of new weeds. Hay is especially hazardous and should be avoided completely. As with manure, it helps to know the source.
- Weed seed and propagules can also be introduced on equipment that has been used on other farms. If you are a certified organic farmer, you should already have protocols in place for cleaning such equipment to prevent contamination by prohibited chemicals. Since you will remove any weed seed at the same time, you get a bonus by following the rules.
- New weeds will show up on occasion. You will be fortunate if they appear in an isolated cluster. We accidentally introduced johnsongrass in some imported mulch one year. We were able to remove it because it was clustered in one area of a single field. Waiting for even one year would have been a disaster!
**Avoid Native Uprisings.** New weed seeds and propagules don’t have to come from off-farm. They can sometimes be moved around within a farm.

- Each of the Cannon fields is surrounded by conservation strips with vigorous stands of bermudagrass. Being aggressive, the grass rhizomes and stolons will encroach 3–5 feet into the field along the edges. This does not prove a great problem with bio-extensive rotation because, when the field returns to green fallow the following season, the bermudagrass is pushed back to the border of the conservation strip and never makes a permanent advance into the field. We illustrate this in Figure 28.

- Because of bermudagrass in the conservation buffers, we are obliged to take special care when we work with tillage equipment or cultivators, to **NOT** inadvertently drag rhizomes, stolons, or roots into the field. Equipment with straight or curved shanks are more likely to catch and drag propagules than tillers or disks, but they, too, can pull propagules from bermudagrass, johnsongrass, or other perennials further into your field (see Figure 29).

**FIGURE 28.** Bermudagrass advances into fields in those years when vegetables are grown. The infestation is pushed backwards in alternate years by green fallow cover crops and tillage operations.

**FIGURE 29.** The tractor driver shown is engaging or “dropping” the cultivator before completely clearing the conservation strips. As a result, he catches bermudagrass rhizomes and stolons on the cultivator shanks, and drags them into the field where they can root and re-infest the site.
Re-infestation of this sort is undesirable, but it can be rectified under a good bio-extensive rotation with weed-suppressive green fallow. If a re-infestation is severe, however, it might be wise to brown-fallow the field the following winter, to once again ensure supremacy. You do not want to risk ongoing weed issues!

To prevent this sort of re-infestation in the first place, get in the habit of waiting to drop or otherwise engage cultivating equipment until the edge of the conservation strip or field edge is cleared. An alternative approach entails maintaining an internal buffer of four to six feet at the headlands where neither crop nor bermudagrass is permitted to grow. You have the option of tilling the weed-free zone or planting it to an annual smother crop. Figures 31 and 32 illustrate this later on.

- Sometimes weed seed can already be present in the soil, just waiting for the right conditions to emerge. Tilth, soil biology, and fertility play important roles in weed management. Weeds can be indicators of conditions in the soil where these factors have gone awry; some of our more problematic weeds warn us of anaerobic conditions, poor drainage, and the excesses and deficits of minerals. Sometimes what we think are new weeds are, instead, “sleepers” that just woke up to an alarm bell.

This is often the case with flushes of weeds that emerge following applications of poultry litter. Organic and conventional growers alike long assumed that weed seeds were introduced in the litter, as they can be with other livestock manure. However, numerous studies have proved this to be incorrect. Compared to cattle and other livestock manures, poultry litter is remarkably free from viable weed seed. This is due, in good part, to avian digestion – the gizzard grinds any weed seed introduced in feed, making it non-viable when excreted. The weed flush results from some biological or chemical factor in the litter that awakens dormant weed seeds.

Drip Irrigation to Control Weeds. Once again, because we fail to apply systems thinking, we seldom recognize that managed irrigation can also be a tool for weed management. This is one of several reasons why we prefer to use drip irrigation. Sprinklers apply water broadly, stimulating weeds in the inter-row area. Drip irrigation restricts water application to the crop row, encouraging those plants to develop quickly and compete more effectively with un-watered weeds. It goes without saying that this works especially well in drought years. By late summer, weed emergence in inter-row zones can be almost nil, while irrigated crops next to them are flourishing.

PHOTO 15. Drip irrigation concentrates water in the crop row, providing less stimulation of weeds in the inter-row area.
Opportunities for Conservation Tillage

Tillage is the bugbear of organic farming and gardening. Every time we disturb the soil through tillage and cultivation, we reset the soil biological clock – we tear fungal networks apart, kill earthworms and destroy their burrows, encourage bacteria to consume precious humus, and reduce biodiversity. We also pay for it with time through crusted soil, anaerobic conditions, erosion, nutrient leaching, and poor drainage, all of which result in plant disease, problem weeds, and disappointing crops.

We often argue that most organic soil-building and conservation practices are, in the end, primarily compensating for the deleterious effects of tillage and cultivation. It’s no surprise, then, that it takes a long time to see significant improvements in cultivated crop land. This is especially true in southern states where mild winters and hot summers make it extra-challenging to build soil humus levels.

Though tillage and cultivation are traditional practices, we need to recognize that they violate our basic principle to conserve and nurture the soil food web. Still, most organic farmers rely on these techniques and we cannot simply abandon them without viable alternatives. In this section we will discuss several alternatives that we are working to incorporate into Cannon’s bio-extensive rotation to reduce both tillage and cultivation.

**Coming to terms...**

Though the terms are often used to mean the same thing, we use the term **tillage** primarily to describe mechanical field operations that prepare ground for seeding and transplanting (e.g. plowing, disking, spading, subsoiling, rototilling, double-digging). We use **cultivation** for in-season tillage done mainly to manage weeds within a growing crop, but also to break surface crust and aerate soil. Row-crop cultivators of various types are common to large-scale cultivation; hoes and wheel hoes are common on small-scale farms.

**Conservation tillage** is defined as any tillage or planting system in which at least 30% of the soil surface is covered by plant residue after planting to reduce erosion.\(^{20}\)

**Mulching** entails covering the soil with natural and/or synthetic materials to conserve moisture, moderate soil temperatures, protect soil structure, suppress weeds, or achieve other agro-nomic benefit. Natural organic mulches include straw, wood chips, ground leaves, hay and similar non-synthetic materials. Synthetic mulches are typified by rolled plastic, which is allowed in organic production as long as it is removed at the end of the season.\(^{21}\) Various biodegradable mulches are coming into the marketplace at this time and the National Organic Program (NOP) will regulate their use. Do NOT assume that all biodegradable mulches are allowed for organic production.

**Transferred mulches** refer to natural vegetative materials grown elsewhere on the farm, which are gathered and used to mulch crops in nearby fields.

**Organic no-till** is a popular term used to describe crop production using little or no tillage or cultivation, and with no prohibited herbicides. **Killed mulch** methodology is a currently popular approach to organic no-till. It entails growing dense cover crop stands, killing that vegetation, and leaving it in place as crop mulch. While conventional growers typically use synthetic herbicides for no-till, organic growers use mechanical means or weather extremes to **terminate** cover crops.

**Crimper-rollers** are a tool for mechanically killing cover crops prior to planting or transplanting. **Rolling** is the shorter and more convenient term to describe **crimping-rolling**.

Grasses are in the **boot** when the seedhead has grown several inches up inside of the stem. The head is not visible without peeling away the outer leaves.
Transferred Mulches

Mulching vegetables with organic materials is a tried and true horticultural technique for both conventional and organic growing. Mulch conserves moisture, protects soil from winds and heavy rainfall, suppresses weeds, encourages soil organisms, and adds nutrients as the material decays. Many gardens and market farms employ the practice, usually buying-in straw or scrounging local materials like shredded leaves, pine needles, or well-rotted hay.

Bio-extensive rotations offer growers the opportunity to gather needed mulch from cover cropped fields. It requires a bit of planning to make sure that at least one cover crop is at a suitable stage for mowing, drying, and transferring to another part of the farm. A bit more thought is needed to ensure that the source and the destination are close to each other, so minimal time and effort are spent transporting mulch.

Sourcing and transferring mulch on your own farm addresses several hazards of importing it from elsewhere:

- Imported organic mulches are sometimes contaminated with weed seed and other propagules like bermudagrass stolons. This is especially true with hay. Hay mulch can also be an excellent vehicle for johnsongrass seed. If you harvest mulch from your own fields, you eliminate the hazard of introducing new weed species and, by timely mowing and harvest, can ensure that you don’t further-propagate any native ones.

- Some off-farm mulch materials may also be contaminated with herbicides like picloram and clopyralid. Conventional farmers and ranchers use these to control broadleaf weeds in hay and pasture. They readily damage most garden crops. They are a particular problem because many formulations have very long half-lives and can even survive composting.

- Commercial mulching materials can be expensive!

Some growers have created simple but elegant systems revolving around imported organic materials and deep mulching. The late gardener Ruth Stout is recognized for this approach on a gardening scale. Emilia Hazelip developed “Synergistic Gardening” – an organic no-till model based on permaculture principles. In the Midsouth, Patrice Gros has devised a machine-free mulching system suitable for market farms (see Resources).

Killed Mulch Methods

There are two common means for mechanically killing cover crops: mowing and rolling. We have invested and continue to invest considerable time evaluating killed-mulch methods, and have fully integrated mow-killing. It is standard practice when we grow transplanted crops such as tomatoes, peppers, or eggplant. We also use it routinely for squash and pumpkins, whether we transplant or direct-seed the crop. We have less experience with rolling, but enough for some observations. Both methods, we have found, require experience, observation, and understanding to be successful.
Bio-extensive management is superbly compatible with killed-mulch methodology. We grow cover crops as standard practice and need only to tweak our methods for no-till application. The bio-extensive rotation also ensures low weed pressure, which improves the chances of success with killed mulches.

To start, use extra care when establishing your cover crop. Vigorous, dense stands with plenty of biomass are critical to making the killed-mulch methods work. You should use higher-than-recommended seeding rates and plant as early possible within recommended time windows. If a cover crop stand is thin at the time you need to terminate it, you might be better off treating it as a green manure, unless you can transfer additional mulch from within your system. Importing additional mulch is also a possibility as long as you understand the hazards and can bear the cost.

To build an effective killed-mulch layer, your objective should be to grow as much biomass as possible so that the resulting mulch will be thick and weed-suppressive. This can be challenging when growing early-spring vegetables. Seedbed preparation is done before cover crops grow to a stage where they can be mechanically killed. The logical option here is winter-killed cover crops, such as hulless oats. For growing late-spring and early summer crops, fall-planted grass and legume cover crop blends (described earlier) seem to work fairly well, but there can be complications.

The first complication relates to termination time windows. With annual grasses such as grain rye, wheat, or triticale, plants must reach the “boot” stage before they can be mechanically killed. Grasses are in the boot when the seedhead has grown several inches up the stem – the head not being visible without peeling away the outer whorl of leaves. To mow-kill grasses, it is necessary to sever the stem below the seedhead to kill the plant. Mowing at earlier stages of growth does not kill annual grasses.

On the backside of the time window, annual grass termination should be done no later than the late milk or early dough stages. In milk, seedheads are emerged, pollination is completed, and individual kernels easily exude milky sap when squeezed. In early dough, squeezed seeds will not exude sap, but will feel soft and sticky. From the milk stage onwards, the plant is transferring much of its nutrition into making the seed, so optimum termination should be between boot and early milk, but no later than early dough, when the maturing seeds become viable and you risk creating a weed problem. The value of the mulch to the soil as it breaks down also decreases with maturity after seed set.

Annual legumes are most vulnerable to mechanical termination once they flower, and especially at full bloom. It is between 10% bloom and full bloom that nitrogen content of legume vegetation is at its maximum. A legume’s value as weed suppressive mulch and for soil improvement also declines with seed set. Ideally, companion legumes will flower within the grass termination window, so that both can readily be killed to maximum benefit.
Killing Cover Crops by Mowing

Small growers generally have up to three kinds of mowing machines: rotary or bushhog mowers, flail mowers, and sicklebar mowers.

1. **Rotary/bushhog mowers** are not well-suited for killed-mulch applications. They are not designed for close mowing, the distribution of cut vegetation is uneven, and the cover crop is mangled and shredded, encouraging rapid decomposition. Since longevity is desirable with killed mulches, we consider rapid decomposition an undesirable trait.

2. **Flail mowers** also shred vegetation, but they can be set closer to the ground to ensure better plant kill. Flail mowers also distribute the shredded material much more evenly than rotary mowers. This makes flail mowing the most recommended option for mow-kill, especially for larger-scale operations, where the costs of labor to re-distribute the killed mulch can be high.

We also use a flail mower for small-scale work. There are models designed to mount on two-wheel walk-behind tractors, like our BCS. It works much easier, however, when the cover crop blend includes clovers, and not vining legumes like the vetches or winter peas.

3. **Sicklebar mowers** are seldom recommended for mow-killing cover crops because large uncovered strips are left in the field (see Photo 17), requiring hand-raking to ensure even ground coverage. However, in circumstances where the grower anticipates moving the cut mulch for some purpose, the sicklebar is an excellent choice. Unlike either rotary or flail mowers, sicklebars cut plant stems at only one spot; they do not mangle or shred the vegetation, making it easy to hand-or machine-rake, and/or gather with a hay fork. Also, sicklebars cut very close to the ground, ensuring good termination. For all of these reasons, we use the sicklebar mower a lot, both for killing mulches in situ and for mowing them to be transferred. However, know that it can be almost impossible to mow vetch or winter peas with walk-behind sicklebar mowers. The cut vegetation clogs the mower and balls up, leaving VERY large areas uncovered.

**PHOTO 16.** Using a BCS-mounted flail mower to cut a cover crop.

**PHOTO 17.** A BCS-mounted sicklebar mower cutting a sorghum-sudangrass cover crop. Sicklebar mowers leave un-mulched strips which are clearly visible in this photo.
Kerr Center’s heirloom tomato trials are a good example of how we use mow-kill methods. When planting the winter cover crop ahead of tomatoes, we generally use grain rye or triticale, plus crimson clover. We mow-kill the cover crop several weeks ahead of transplanting because the grass and legume covers reach optimal termination times well ahead of transplanting time. We transplant heirloom tomatoes on or about May 1 in southeastern Oklahoma. By that time, soil temperatures have usually reached and exceeded the minimum of 65°F recommended for tomatoes.23 Because we have low weed pressure, the delay does not cause problems. Still, we would prefer to terminate the cover crop and transplant sooner. Choosing triticale helps with this since it matures a bit later than grain rye.

In our first trial season, 2009, we simply sickle-bar-cut our winter cover crop and hand-raked it into windrows where drip irrigation tape was laid and tomatoes were hand-transplanted through the mulch. The “stubbled” ground served as pathways throughout the season. Foot traffic kept most weeds suppressed.24 That first trial season was exceptionally wet, however. Though we did not lose any plants and yields were good, crop quality was second-rate. The fruit was watery and lacking in flavor, and shelf life was poor. To remedy this, we later modified our scheme to allow for planting ridges, which would allow the soil to drain better.

To do this, we again used a sicklebar mower to terminate the cover crop. As before, we again raked the mulch into concentrated windrows. However, this time we raked the residue to the row middles, rather than onto the intended plant row. We then used a rotary plow attachment on the BCS tractor to build planting ridges. We found that two to three passes with the plow formed robust planting ridges and left much of the inter-row – about one third to one half of the total ground area – undisturbed. We then laid drip tape and promptly raked the windrowed mulch back over the ridged ground. We completed these preparations as quickly as we could to reduce soil damage from the elements. If you must till, the less time you leave the soil uncovered, the better. Sun and wind can be devastating to exposed organisms.

PHOTO 18. Hand-raking a sicklebar-killed cover crop using a wooden hay rake.

PHOTO 19. The 2010 heirloom tomato trial at the Cannon Hort Plots. Note that the plants are growing on ridges, mulched with the residue of a killed winter cover crop grown on the same ground.
We have also used mowing to kill summer cover crops in preparation for direct-seeded fall pumpkin trials. If planted around July 1 in southeastern Oklahoma, most early and mid-season pumpkin varieties will be ready for Halloween and harvest season markets in fall. If no spring cucurbits were grown earlier in the season, we will also have low squash bug populations, as we said earlier.

Because excess rainfall is usually not a concern, here, in late summer, we don’t feel the need to make planting ridges for fall crops, as we’d done for spring-planted heirloom tomatoes. We proceeded much like we’d done with our first non-ridged tomato trial. We mowed the cover crop with a sicklebar, laid drip tape, and raked the mulch into a wide windrow. We then direct-seeded pumpkins, gourds, and winter squash, through the mulch.
In our experience to date, crotalaria and pearl millet stand out as especially good prospects as mow-killed mulches. The legume – crotalaria – grows tall and dense, making it very weed suppressive. It produces a large amount of biomass and proves an excellent, deep, late-season mulch. When cut close to the ground, crotalaria showed little tendency to regrow. Pearl millet is a much shorter plant than crotalaria, but it produces a very dense canopy of leaves, resulting in thick and durable killed mulch. If cut close to the ground, it, too, does not appear to regrow.

Cutting cover crops close to the ground appears to be an important factor, as well as stage of growth. In 2014, we grew crotalaria and pearl millet, as well as annual sorghums, cowpeas, and lablab, as green fallow crops. When mowed with a bushhog, ALL of these species re-grew. As we learned and continue to re-learn, nature has its own way about things and you can’t make many assumptions!

**Killing Cover Crops by Rolling**

Crimper-rollers are large, weighted, cylindrical drums with corrugated surfaces, made of welded steel plates. When pushed or pulled through a field, they press the cover crop down and the steel plate edges break plant stems, accelerating plant death. The plates on a crimper-roller are usually arranged in a chevron pattern to eliminate bouncing and side-tracking problems that other, simpler mounting patterns would produce.

We have less experience with rolling than with mowing, but have learned quite a bit that we will share. While the crimper / roller is a simple tool, there is a lot to know if you want to make it work properly.

To begin with, the roller must be heavy enough. If too light, stems will not be adequately crimped. Experts recommend two hundred pounds per linear foot of cylinder. More than one pass with the implement – perhaps two or three – might also be needed in some instances to get the job done. Be sure, if you make additional passes with a crimper / roller, that you do not reverse direction; continue in the same pattern and direction that you used for the first pass.

The art and science of roll-killing a cover crop is more exacting than it is with mowing. Rolled crops are still rooted in the ground and have the means to re-grow if given a chance. Termination windows are narrower for rolling than for mowing. For example, you can be easily mow-kill rye and other winter annual grains in the boot stage. By contrast, rolling rye at this stage tends to simply lay it flat, with plants resuming growth from that position. The optimum termination stage to roll grasses appears to begin at milk and continues to dough; roll legumes when they are in full-bloom- to-early pod fill. Waiting longer increases the risk...
that the plants could produce viable seed that might become a weed problem later.

Because termination windows narrow for rolling, there is some argument for planting single-species cover crops. Then the grower does not need to find a compromise kill date that works for two or more species. This is likely, however, to reduce the total amount of biomass in the cover crop, making it less successful as mulch. The best solution, of course, is availability of more kinds and varieties of cover crops for growers to experiment with to find blends suited to their farms.

An intermediate strategy we have just begun to explore entails seeding winter annual legumes with hulless oats. We would expect the oats to winter-kill, but the legume to grow to be roll-killed later. This is clearly a compromise, since the oats does not produce any further biomass past mid-winter. However, it does produce a good mat of vegetation in fall, and this might be a workable compromise, especially if backed up with mulches transferred from elsewhere on the farm.

**Small-Scale Planting and Transplanting into Killed Mulches: A Technology Gap?**

Not all vegetable crops are suited to killed-mulch production. Transplanted crops seem to do the best. Direct-seeding works fine for most large-seeded vegetables like squash, beans, and cowpeas. Those requiring fine seedbed preparation, like lettuce and carrots, are not likely to fare as well.

Large-scale growers have access to a wide-range of no-till seeding equipment, and no-till transplanters for full-sized tractors are being developed. Small market farmers, who depend on small tractors, walk-behind equipment, and/or a single draft animal, find they have far fewer equipment choices when it comes to planting and transplanting.

At Kerr Center, we use a lot of small-scale technology for planting and transplanting. These
include various push seeders, jab planters, and jab transplanters. All of these speed up operations and make them easier, while not being as costly or horse-power dependent as larger-scale equipment. As we trend towards no-till culture, we have found that few of these tools adapt well to use in untilled soil. Instead, we have often needed to use more basic, labor-intensive, garden-scale tools planting and transplanting. These include dibbles, warren hoes, hand trowels, and such. Traditional technologies such as these are perfectly suited for some crops on some small farms. The lack of intermediate-scale technology, however, is certainly a barrier to expanding use of killed-mulch methods on organic market farms.

We have begun to investigate some alternative technologies and methods for planting and transplanting into killed mulches – technologies that we consider appropriately-sized and -priced for small-scale organic farms. It is early days yet, but we have a few observations:

• **Jab-Type Planters and Transplanters.** These are low-tech and low-cost. They work quite well in tilled soil, but are disappointing, if not impossible, when the ground has not been prepared. One exception may be the GreenSeeder, which is being developed for third-world use.\(^2^8\) No matter how well jab planters work in no-till culture, however, they will always be limited when it comes to crops that are close-drilled. Commercial market growers would likely find them too tedious and slow for many crops.

• **Strip-Till.** Strip-tillage entails creating a narrow, prepared seedbed in otherwise undisturbed ground. There are many large-scale designs that do this quite well, especially for agronomic crops like corn,
soybeans, and cotton. Some use rolling coulters to cut through residue, followed by planting shoes built to divert field trash; still others use fluted coulters that both cut through residue and till a narrow strip of soil just in front of the planting shoe. As yet, we have not seen such tools scaled down for market farm use. Not being engineers, we are not certain it might even be done, though preparing the planting strip and seeding probably need to be two different operations. That is the assumption we have made.

We have attempted to make tilled strips using the rototiller attachment on our BCS 853. We remove all but the center two sets of tines to make a five-to six-inch wide seedbed. This has worked fairly well in plant stubble that is cut short if the residue is raked aside. It does not work when cut or rolled residue is left in place; the residues quickly wrap around the tines, bringing everything to a halt. Depending on conditions and the planting operation to follow, more than one pass with the tiller appears desirable, if not necessary.

Mechanical drilling or precision seeding into strip-tilled soil can be problematic. Narrow strip-tilled rows will still harbor some crop residues which catch onto the planting shoes of push planters. We found a solution in the optional disk opener available for the Jang push seeder. It is not hindered by light residues, but the soil must be tilled and loose; it is NOT a no-till planter!

PHOTO 28. The South Korean-made Jang Seeder comes with a standard planting shoe, which works extremely well in tilled soil with no residues. Where crop or cover crop residues remain, they typically gather and accumulate on and around the shoe and slow seeding operations.

PHOTO 29. Growers can purchase an optional disk opener to replace the standard planting shoe on Jang Seeders. The disk opener works quite well in light residues, but still requires prepared soil. The disk opener does not convert the Jang Seeder into a no-till planter.
Living Mulches

Covering the soil with organic mulch is good for crops and for soil – providing protection and nutrition for soil biology, while reducing water loss and suppressing weeds. Even better, however, are living, growing plants; plants that continue to fix carbon, attract microorganisms, and cycle nutrients – so-called living mulches.

The best living mulches are those that are non-aggressive, do not compete with crops for sunlight or water, and are perennial – never requiring tillage or cultivation. There are a few legumes, grasses, and forbs that meet these criteria for perennial fruit and nut production; they are not as easily found for annual vegetable systems.

At Kerr Center, we have modest expectations for living mulches. We are happy if we discover any compatible annual cover crop we can grow between rows of vegetables to suppress weeds and protect the soil. Buckwheat seems the most promising candidate to date.

We have already made mention of growing buckwheat between rows of tomatoes. The buckwheat covers the inter-rows, but is gradually trampled underfoot during harvest and other operations. While this is an example of living mulch, only a few plants mature and flower and it is not very impressive.

On the other hand, we have also grown buckwheat as living mulch in sweet potatoes, which makes a much more interesting case. We typically grow sweet potatoes using standard seedbed preparation techniques, and finish by building shallow, clean-tilled planting ridges. After transplanting the sweet potatoes, we’ve make two cultivations using wheel hoes and hoes, before the plant canopy closes.

In 2012 – the last year of our heirloom sweet potato trials – we immediately seeded the inter-rows with buckwheat following the first cultivation. The buckwheat quickly outgrew any weeds and produced a superb beneficial insect habitat, especially for honeybees and other pollinators. By using drip irrigation only in the crop row, we ensured that the sweet potatoes did not have to compete for moisture and could keep pace with the fast-growing cover crop.

Buckwheat worked well because its growing season is brief. Before it could compete with the sweet potatoes it went to seed, thinned out, and was overwhelmed by spreading sweet potato vines. In our estimation, the living mulch did not adversely affect sweet potato yield or quality in any way. We saved only one cultivation, but consider the benefits to soil, biological pest control, and pollinator support as more than significant.
Back to Bioextensive Basics

Most of our attempts at organic no-till have been fruitful. We credit much of the success to the bio-extensive model that undergirds our whole system. The planned rotation with winter cover crops, green fallow, and supportive cultural practices set the stage well by reducing weed pressure and nurturing the soil food web – the source of nutrition and bio-control for our crops.

We are not suggesting that killed mulches and living mulches will not work without bio-extensive management. We do believe, however, that these methods not only fit well into a bio-extensive system, but that its benefits reinforce and help ensure the success of organic no-till practices, in part by allowing us a much wider margin of error. This is especially true with regard to weed control. You can get by with less mulch and back-up hand weeding when overall weed pressure is low.

We credit our successes with mulch, killed mulch, and living mulch methods to our ongoing bio-extensive management.

Just the FAQs: Session #3

FREQUENTLY-ASKED QUESTION:
“What do YOU think the minimal percentage of green fallow should be for an effective and sustainable bio-extensive rotation?”

Setting aside considerations of market pressure and land cost for the moment, we feel the minimum proportion needs to be about 50% or more, to gain all the benefits we ascribe to bio-extensive management. Vern Grubinger, whom we’ve quoted earlier, suggests a minimum of 25% for long-term success. He may or may not have intended that guideline for bio-extensive systems and, if he did, it might well be sufficient in the northeastern United States. In the Midsouth, however, with our propensity to deplete organic matter, and our higher weed and pest pressure, 50% is probably more realistic, especially if you want to call your system “bio-extensive.” In fact, as we speak with more and more market growers in the region, we hear that many already allot about 50% of their ground to annual cover crops; they may or may not refer to their systems as bio-extensive.

FREQUENTLY-ASKED QUESTION:
“I really like the notion of organically-allowed herbicides. Would it be possible to use natural vinegar or one of the other allowed herbicides to kill mulch for a no-till planting?”

In theory, yes, but there are challenges. These contact herbicides require good coverage of the plant to thoroughly kill its top growth. And since effective killed mulch applications require a dense cover crop, it would be difficult to achieve a good result. Furthermore, it would certainly require a high volume of potent spray, thus using a lot of product. Since organic herbicides are not very cheap at present, it might simply be uneconomic.
FREQUENTLY-ASKED QUESTION:
“I was planning to kill my rye cover crop very early in spring so I can no-till transplant broccoli. What tool will work best, a flail mower, a sicklebar mower, or a crimper-roller?”

None of the above! The cover crops we have discussed can only be mow- or roll-killed as they approach maturity. In the case of rye, the seedhead must be in the boot for mow-killing, milk or early dough stage to roll-kill. Rye does not reach that stage that early in spring.

The most practical option, here, is to treat your rye cover crop as a green manure. Till it in as soon as you can and do standard seedbed preparations. In the future, you could consider seeding a winter-killed hullless oat variety instead of rye. You might then plant or transplant into the resulting residue, though its weed suppression may be somewhat short-lived.

FREQUENTLY-ASKED QUESTION:
“What if I follow your advice but I still get a weak cover crop stand? Will I have to abandon any hope of a mulch-based system that year?”

We have had that experience ourselves. In such instances, we have gone ahead with killed-mulch preparations, but supplemented with transferred mulch from elsewhere on our plots.

FREQUENTLY-ASKED QUESTION:
“When I’m using transferred-or killed-mulches, how much mulch is enough?”

One source recently suggested about two and a half to four inches of mulch to ensure good weed control.34 We have gotten away with a bit less but, as we have repeated quite often, we achieved a high degree of weed suppression through bio-extensive management, and not needing such a thick a mulch is one of the benefits that have accrued.

FREQUENTLY-ASKED QUESTION:
“Can I completely eliminate tillage and cultivation using killed-mulch methods?”

Keep your expectations more modest for now. Killed mulch methods can and will go a long way towards reducing tillage and cultivation, but complete elimination is not likely for most of us. There are many challenges, including perennial weeds that thrive in untilled ground, and rodents, which love continuous cover. In southeastern Oklahoma, we have also found that the number of fire ant mounds increased wherever soil disturbance decreased. But remain optimistic! Researchers are refining killed mulch methodology and, with time, many more of us might dispense with tillage entirely.

FREQUENTLY-ASKED QUESTION:
“I noticed that your living mulch of buckwheat was allowed to go to seed. Since it is recommended as a smother crop, won’t the buckwheat become a weed problem for you next year?”

This has not happened to us. Buckwheat seed that germinates in the current year will be killed either through fall tillage or frost. Any seed that overwinters to germinate in spring will become part of the green fallow mix – a definite benefit and not a problem! So far, we are not aware of significant buckwheat emergence in the second year following seeding.

The situation and its constraints can vary quite a bit, though. We have grown buckwheat under circumstances where it was either trampled and did not produce seed (heirloom tomatoes), or where it produced seed without subsequent emergence due to crop competition (sweet potatoes). In either case, re-seeded buckwheat caused us no problems. We know, however, that it has that potential and do not plant it in places or under circumstances where it might become a weed.
Supplementing Fertility in a Bio-Extensive System

A New Mindset. For many organic growers, annual applications of manure and/or compost are the primary means for fertility management – providing both organic matter and plant nutrients. Bio-extensive management engenders a different mindset and strategy for soil fertility. In bio-extensive systems, we plan for green manure cover crops and crop residues to provide the bulk of required organic matter, and legumes to provide the nitrogen. These inputs are grown on the farm.

Where we are likely to need off-farm supplementation is for the remaining mineral nutrients – phosphorus, potassium, calcium, sulfur, magnesium, and the micronutrients. This is not to say that growers cannot or should not use manure, compost, and other organic materials to supplement soil fertility. Instead, it suggests that growers may have a wider set of options with a bio-extensive system, such as applying needed nutrients in rock mineral form. Under certain circumstances, this has a clear advantage, as clarified in the following example.

Many organic market farmers in the Midsouth rely on industrial poultry litter for fertilization. (So do many conventional farmers, for that matter.) The rates of application are commonly based on nitrogen response. Unfortunately, the phosphate content of poultry litter is high relative to nitrogen, and treated fields receive a surplus of phosphorus. After several years, the build-up of excess phosphorus begins to pollute surface waters and causes nutrient imbalances in crops. In a bio-extensive system, where most or all of the nitrogen is provided by cover crops, it is easier to add only those nutrients needed. At Kerr Center, we are determining those needs through soil testing.

Soil Testing. Soil audits (also called soil tests) are imperfect means for measuring how well a soil can deliver nutrients to crops, but they are among the few reasonably-priced tools we have. In our role as a research and demonstration entity, we sample and test our fields annually. Organic growers with sound rotations and nutrient cycling should not need to test that frequently. In fact, many traditional organic farmers and gardeners in the past chose not use soil testing because they believed their natural approach eliminated the need for monitoring soil chemistry; that the biology of the soil would attend to crop nutrition in its own way and time. They may have been correct. Still, a regular pattern of audits over time is a good idea, if only to identify extreme deficits or excesses. Besides, most organic certifiers require
soil or plant tests to satisfy the requirements of National Organic Standard that producers “main-
tain or improve the physical, chemical, and biolog-
ical condition of soil...”

Soil Biology and another New Paradigm. That some organic growers would assert that their systems can sidestep conventional agricultural paradigms about soil fertility and crop health may seem a bit naive and romantic. However, research in soil biology in recent decades might vindicate the organic traditionalists. Researchers like Dr. Elaine Ingham have discovered that plants deliver about 50% of their photosynthate to their roots to be shared with beneficial bacteria, fungi, and other organisms in the rhizosphere. Among these microorganisms are some that aid in making soil nutrients available to plants and aid in absorption. They further learned that plants modify these exudates to attract and nourish those soil organisms that they need most at different stages of the plant’s growth.

These findings have led to a number of assertions, including:

1. That plants are capable of controlling the microbiology of their own root zones through tailor-made exudates;

2. That thousands of years’ worth of crop minerals are stored in most soils in both available and complexed forms;

3. That supplemental mineral fertilization might not be needed because plants can grow populations of those microorganisms needed to extract otherwise unavailable nutrients from the parent soil material.

These assertions are controversial, of course, especially since they suggest that supplemental fertilizers of any kind are largely superfluous!

It will take some time for soil scientists to sort out these claims and give us more guidance on how to manage fertility in biologically-based, organic systems. In the meantime, we feel the following observations and practices are relevant:

- Our bio-extensive organic system, with its regular contributions of organic matter from winter cover crops, summer green fallow, and recycled crop residues, is friendly to soil biology. It becomes even more friendly when we integrate more organic no-till practices.

- Our view of compost and its importance to the Cannon system is changing. Traditionally, we considered its value in terms of nutrient and humus content only. We now see compost’s greatest value in the numbers and diversity of beneficial organisms it harbors. When applied, the compost inoculates the soil with additional organisms that may not already be present, but are desirable. As a result, we now produce less compost, but pay more attention to the resulting quality. A further reason we can reduce compost production is that we use it to make aerated compost tea – a means for extracting and growing the populations of beneficial organisms present in compost. When we spray these on soils and crops, we get much of the inoculation benefit we seek when applying the compost, itself.

- We continue to supplement with small amounts of organic fertilizers. They are especially helpful for growing very early crops like lettuce in late winter and early spring. When outside temperatures and the soil are cold, microorganisms are not very active and there is very little release of nitrogen and other nutrients. Furthermore, most winter annual legumes will not have reached the stage where they are fixing much nitrogen. So supplying some nitrogen at this time can be a smart move. This is one of the few circumstances where soluble sodium nitrate might be the best choice. An alternative might be foliar fertilization.
using fish-based fertilizer. Remember, if very early crops follow a non-legume green fallow of sorghum or pearl millet, for example, nitrogen supplementation can be even more important, since soil reserves are surely bound up in the breakdown of high-carbon biomass.

• Choosing to supplement fertility, especially nitrogen, in a bio-extensive system, is a judgment call. As indicated, we do some, but very little. It can be costly and certainly redundant if you grow lots of legumes and have established a rich and diverse biological community in your soil. But many of us have a long way to go on that score!

• We have discussed killed mulch methods, and want to point out where nutrient supplementation might be warranted...or not. Nutrient availability, including release from the mulch, can vary with the cover crop, place in rotation, and the technology applied. Generally speaking, if mulch remains on the surface of the soil and is not incorporated, little nitrogen is bound up, no matter the composition of the residue or its carbon-to-nitrogen ratio.

1. If the crop is following a green fallow of pure grass, like sorghum-sudangrass, sudangrass, or pearl millet, consider some early nitrogen supplementation, since much of the soil reserve will be bound up in decomposition.

2. If the cover crop was rich in legumes, it will break down much faster than one that was composed of non-legumes. If mulch decomposition occurs quickly, there are nutrient benefits for the growing crop, but it is unfortunate if you were hoping for long-season weed suppression.

3. If you shred the mulch with a flail mower, expect more rapid decomposition and nutrient release. Alternatively, if you roll the cover crop or cut it with a sickle-bar, breakdown will be slower.

Just the FAQs: Session #4

FREQUENTLY-ASKED QUESTION:
“You write about using natural rock powders. What materials are you referring to, specifically?”

Natural rock powders include such common materials as ag lime, dolomitic lime, and gypsum, and less-common ones such as rock phosphates, greensand (glaucnite), granite meal, and glacial gravel dust. They are not treated with acids or otherwise chemically processed. What processing they receive is usually limited to washing, grinding, sifting, sizing, and/or drying.

FREQUENTLY-ASKED QUESTION:
“Isn’t nutrient solubility low in natural rock minerals?”

Yes, nutrient solubility of ground rock materials is low. Organic farmers prefer that the minerals in ground rock become available through biological processes in a measured and natural way. This is how soils and soil fertility are created in natural systems. Fine grinding, however, does speed the process; soil organisms have more surface area on which to work.
Looking Down the Road: Integrating Perennials and Permanent Beds

**Coming to terms...**

**Bio-intensive** farming and gardening are organic systems that focus on achieving maximum yields from a minimum area of land, while simultaneously increasing biodiversity and sustaining the fertility of the soil. Annual plants perform their entire life cycle from seed to flower to seed within a single growing season. All roots, stems and leaves of the plant die each year. **Perennial plants** persist for many growing seasons. Generally, with herbaceous plants, the top portion dies back each winter and regrows the following spring from the same root system or underground stems.

**Rotavators** are large PTO-driven rototillers designed to be mounted on standard four-wheel tractors. **Multivators** are PTO-driven cultivation tools that feature small rototiller units mounted on a toolbar. The units are spaced to cultivate between the rows of crops. A **plow pan** is a layer of hard subsurface soil or clay. Also called **hardpan**, it can form naturally in some soils, or can result from tillage practices. **Subsoiling** involves shattering a plow pan using mechanical means. On a large or intermediate scale, tractors pull a large chisel plow or curved shank **subsoiler**, set deep, through the field. Small growers may break up plow pans by using a **broadfork**, which is also called a **u-bar**. This is a large two-handled digging fork, used for deep hand tillage.

**Moving to Permanent Bed Culture.** Permanent beds are a great way to grow vegetable crops. The tools used can be very low-tech, yet the output can be very high, while making efficient use of water and nutrients. To this point, we have discouraged using permanent beds because they don’t work well where bermudagrass is a problem. Still, we believe it may be possible to transition fields to permanent beds by clearing bermudagrass through bio-extensive management.

We began exploring the possibilities for permanent bed transition in 2012. At that time, we committed a strip of land within one of the bio-extensive plots to permanent bio-intensive growing beds. It was a test to see whether bermudagrass would re-emerge once the land was no longer in a rotation with green fallow. The bio-extensive rotation we have been practicing continued on the remaining ground on the field. Only the permanent beds were excluded.

Perhaps three seasons is a somewhat brief time, but throughout that period, we have found no evidence of bermudagrass on the permanent beds. It was blocked from re-infestation from outside by ongoing bio-extensive management, and was basically eradicated from the permanent bed “island.” (See Figure 30.)

This bodes well for permanent bed systems within fields already cleared of bermudagrass, as long as a buffer is maintained. It seems most commonsensical to maintain a “no creep” buffer...
on all four sides of each field, to shield the permanent beds from bermudagrass. We have considered two approaches: regular tillage and smother crop buffers. Figure 31 is an example of how a field with a tilled buffer might look.

However, because of our desire to keep all of our soil covered as much as possible, we would favor a smother crop buffer, such as that illustrated in Figure 32. Smother crops, remember, might also do double duty as beneficial habitat, and we could choose species for that purpose.

If a grower chose to transition a field or fields to permanent beds in this way, it would remain important that he or she remain vigilant against bermudagrass and other perennial weeds. Wherever and whenever they might emerge in a perennial planting, pounce on them immediately! The longer they are allowed to grow, the more difficult they will be to dig out, smother, or control by any means.

From Bermudagrass to Perennials, Organically.
Through bio-extensive management and without chemical herbicides, we have succeeded in converting a 50% stand of bermudagrass to annual vegetable production. This is a significant accomplishment, of course, but it is not a stopping place. If we truly want to pursue sustainability, it is important that we pursue a means for integrating perennial

**The Permanent Bed Trial at the Cannon Horticulture Plots**

**FIGURE 30.** This drawing illustrates how a permanent bed “island” was buffered from bermudagrass re-infestation from the bordering conservation strips through ongoing bio-extensive management on all four sides of the beds.

**An Example:**
A Tilled Buffer on All Sides of Field. Preventive Tillage Done Regularly Throughout Summer

**FIGURE 31.** This drawing illustrates a theoretical example of how a grower might convert and maintain a bio-extensive field (cleared of bermudagrass), to permanent beds. He or she might establish and keep a buffer zone that is tilled several times throughout the growing season to prevent re-infestation by bermudagrass. It is our educated guess that such buffers should be at least six feet wide, where bermudagrass or a similar aggressive weed occupies the adjacent ground. Keep in mind that, once the summer season is over, this tilled buffer could be planted to a winter cover crop, rather than left bare. Cultivation would resume again in mid-spring as bermudagrass breaks dormancy.
crops. We plan to take the first steps in spring 2015, with a small planting of elderberries. We are pleased to share our tentative plans and some of the ideas that emerged in the planning process.

No matter what we choose to plant on the Cannon Plots, ongoing management of bermudagrass remains a critical concern. Should it infest a perennial crop, it would be agonizing, and maybe even impossible, to bring it under control without Round-up® or similar herbicides. (Since using these would terminate our organic certification, they are not even up for consideration.) For us, the key to keeping bermudagrass suppressed is the bio-extensive system we have been using and describing all along. We have illustrated how it suppresses and controls bermudagrass and other weeds within our field plots. We have also described how a permanent bed island can be maintained within a cleared field, buffered from bermudagrass by ongoing bio-extensive management – especially the use of green fallow. It does not require a great leap of imagination to see that the same approach might work as well with perennial crops!

As with the theoretical conversions to permanent beds illustrated in Figures 31 and 32, we have two obvious options for buffering perennial fields against bermudagrass encroachment: annual tillage or annual smother crops. We illustrate these in Figures 33 and 34.

Figures 33 and 34 do demonstrate how a field cleared of bermudagrass might be maintained in perennial crops. However, for the Cannon Project, we are less interested in converting solely to perennials than we are in mixed culture that would combine both annual and perennial crops. We are also interested in preserving the bio-extensive rotation for annual crop production, since it provides so many benefits.

Figure 35 illustrates one possibility in which all four of the Cannon field plots might be redesigned to accommodate three “islands” of diverse perennial crops. Our well-established

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**FIGURE 32.** This drawing illustrates another theoretical example for transitioning a bio-extensive field to permanent beds. In this instance, the buffer zone is established in a smother crop each year. The best smother crop species would likely be sorghum-sudangrass, pearl millet, long-season cowpeas, and/or crotalaria.
bio-extensive rotation would continue as before on the field perimeter and in zones between the perennial islands. The selection of perennial crops shown – blackberries, elderberries, and asparagus – are all relatively short crops. Tree fruits and nuts grow too tall and shade out annual vegetable crops in this arrangement; shrubs, cane fruits, and perennial vegetables are much better suited. Tree crops, however, would be much better adapted to the earlier designs shown in Figures 33 and 34.

Figure 36 is an alternative option that we will implement should we choose to reduce the size of our demonstration. Here, the full four-year bio-extensive system rotates among the four zones in between and bordering the perennial islands.40

In Figure 37 we present one final theoretical design. In this instance we are trying to accommodate both perennials and permanent raised beds – something that begins to approach permaculture. Again, we are presuming that the field would be cleared of bermudagrass.

It makes no difference whether you are considering converting to permanent beds or to perennial crops, you need to remain vigilant against bermudagrass and other perennial weeds. If they appear, act as soon as possible to save yourself from the pain and frustration of fighting them ever after.
An Alternative Proposed Perennial Plan
Year 1: Single Field Demonstration

**FIGURE 36.** An alternative plan. Note that green fallow always occupies the extreme ends of each bed. We believe this will be the easiest way to maintain the ends of perennial plantings free from encroaching bermudagrass.

**FIGURE 37.** In this option we are getting closer to what some proponents might call a permaculture design, where the only tillage being done is in the maintenance of a smother-crop buffer.
FREQUENTLY-ASKED QUESTION:
“*What are the economic implications of bio-extensive management?”*

This is a critical question! We have not done a full economic analysis of this system. Now that we have a functioning model, it becomes a task to be addressed within the next few years. What we can say at this time is that economic feasibility will depend on a number of specific variables such as the costs of land and of labor. Obviously, the system makes better economic sense where land is relatively abundant and low-cost and where labor cost is high. The latter is due to the expected decrease in hand-weeding and cultivation, such as we are seeing on our plots. Another consideration is the cost of cover crop seed and the cost of time to manage green fallow, versus the availability and costs of importing organic matter and nitrogenous organic fertilizers such as poultry litter.

Another factor worthy of comment is future policy. NRCS grant programs, EPA restrictions, and NOP regulations combine to influence the way we choose to farm. Where policies limit the use of certain inputs – poultry litter, for example – and favor conservation practices such as cover crops and rotations, the economics of what, today, seems marginal, might begin to look feasible, if not darn good!

FREQUENTLY-ASKED QUESTION:
“*Are rodents a problem in a bio-extensive system?”*

It seems that, the more ground a grower keeps covered with mulch and cover crops, and the less he or she tills, the better rodents thrive. To date, our mice and rat problems have been minor, but we would not be surprised if problems emerged in the future.

FREQUENTLY-ASKED QUESTION:
“*I’ve redesigned my system to use a bio-extensive rotation, but I’m still new to market farming and am not ready to try killed or living mulches. I’ll be introducing some transferred mulches, but plan to use mostly conventional tillage to control weeds for a few more years, at least. Do you have any recommended practices or tools to reduce the harm I’ll be doing to the soil food web?”*

Your measured approach to implementing no-till practices is wise, and starting with a bio-extensive rotation will make them work easier and better. On the Cannon Plots, we continue to use some conventional tillage and cultivation as well. Here are some suggestions based on our experience:

- When planting large-seeded crops or cover crops, you rarely need to prepare as fine a seedbed as you would for carrots, lettuce, or other greens. Perhaps you can reduce preparation by one or two passes.
- When preparing a seedbed, use rototillers and rotavators sparingly. Rotary tillage pounds the soil, damaging soil structure and the soil food web. Use it where and when you must, but no more than necessary.
• Be equally cautious about plows and heavy disks. Repeated use tends to build a plow pan several inches under the surface of the soil. This restricts the crop root zone and slows water drainage. Tap-rooted cover crops like tillage radish or sweetclover counteract plow pan development. Otherwise, use mechanical subsoiling to shatter it.

• If you can, avoid using a rototiller or multivator for crop cultivation. As mentioned earlier, they are hard on the soil. If you must use a tiller, set it as shallow as you can, while still doing the job. Some tillers have special features that help maintain a shallow setting. BCS has a specialized depth wheel option for this purpose.

• Shallow cultivation is possible once perennial weeds are controlled. It requires less energy, prunes fewer crop roots, is less harmful to soil organisms, and brings fewer weed seeds to the surface where they can germinate. For shallow crop cultivating, we favor the use of toolbar-mounted tines or sweep when using our BCS tractor; when not, we like wheel hoes with mounted stirrup cultivators.

• Successful shallow cultivation is easiest and most successful when weeds are small! The larger they become, the deeper you may need to cultivate and the more likely the weed will survive the experience and keep growing.

FREQUENTLY-ASKED QUESTION:
“You have not mentioned plasticulture. Could plastic mulch have a place within a bio-extensive system?”

As we see it, plastic mulch is one of the several tools you can choose among to back up your system. It might be especially valuable if you face heavy annual summer weed pressure. While the bio-extensive rotation and green fallow crops will help reduce the weed seedbank, this will take quite a few seasons, and you might prefer plastic mulch to cultivation and hand-weeding in the meantime.

Another advantage plastic mulch (black plastic mulch, specifically) has is early warming of the soil. Some of the other colored mulches may also contribute to insect pest management. Such factors are worth considering case by case.
A Few Resources

ORGANIC AGRICULTURE:

First, we recommend two of our own publications. First: A Brief Overview of the History and Philosophy of Organic Agriculture is self-explanatory. It can be found at: http://kerrcenter.com/publication/brief-overview-history-philosophy-organic-agriculture/


For a step-by-step guide to organic certification, see the MOSES’ (Midwest Organic and Sustainable Education Services) publication Guidebook for Organic Certification at: http://mosesorganic.org/publications/guidebook-for-certification/ or call MOSES at 888.551.4769 to request a print copy.

CROP ROTATION:

There are a number of good books and articles on organic crop rotation. Unfortunately, few of them present good examples for the southern states. However, they do a good job of explaining principles. Some of these include:


Crop Rotations on Organic Farms by Keith Baldwin. A publication of North Carolina State University’s Center for Environmental Farming Systems. It can be downloaded free of charge at: http://www.cefs.ncsu.edu/resources/organicproductionguide/croprotationsfinaljan09.pdf

BIO-EXTENSIVE MANAGEMENT:

The true pioneers of bio-extensive management in the U.S. are Anne and Eric Nordell. The Nordells work with horses to raise a six-acre organic market garden in north-central Pennsylvania, growing dried flowers, herbs, lettuce, potatoes, onions, and other vegetables. They use a combination of cover crops, fallowing, tillage, and hand weeding for weed control.

They have produced a 72-minute DVD that focuses on rotational cover cropping and reduced tillage as a means of effectively managing weeds and fertility with limited off-farm inputs. It includes an introduction on putting together a holistic weed management plan.

The DVD was produced in 2007, and it is designed to complement their 42-page booklet of articles which
details how they developed each aspect of their bio-extensive cropping system over the past 24 years. The DVD costs $15 plus $3 shipping and handling; the booklet costs $10 plus $3 shipping and handling. Please make checks to ‘Anne and Eric Nordell’ and send to: Anne and Eric Nordell, 3410 Route 184, Trout Run, PA 17771.41

Anne and Eric also publish a regular column in Small Farmers Journal under the heading “Cultivating Questions.” For subscription information visit: http://smallfarmersjournal.com/ or call 800.876.2893.

**COVER CROPS:**

The most comprehensive guide we are familiar with is: Managing Cover Crops Profitably, edited by Andy Clark, as Book 9 in the SARE Handbook Series. It can be downloaded for free from: http://www.sare.org/Learning-Center/Books/Managing-Cover-Crops-Profitably-3rd-Edition Print copies are available from SARE for $19.00. Call 301.779.1007 to order.

**Also worth noting:**


*Feed the Soil* by Edwin McLeod. This 1982 book is rich in specifics about cover crop species. It is currently out of print but can be found occasionally in the used book markets.

*Overview of Cover Crops and Green Manures* by Preston Sullivan. An ATTRA publication, it is available at: https://attra.ncat.org/attra-pub/summaries/summary.php?pub=288

*Midwest Cover Crops Field Guide, 2nd ed. 2014.* Produced cooperatively by the Midwest Cover Crops Council and the Purdue Crop Diagnostic Training and Research Center. Copies are available for $5 plus shipping. See: https://ag.purdue.edu/agry/dtc/Pages/CCFG.aspx

**WALK-BEHIND TRACTORS AND EQUIPMENT:**

A wealth of information is available at several commercial websites:

Earth Tools http://earthtoolsbcs.com/
Ferrari Tractors C.I.E. http://www.ferrari-tractors.com/default.htm and
Cedar Farm/BCS http://www.cedarfarmok.com/

Also see Walk-behind Tractors: Miracle Multitaskers by Dan Nagengast, on the Mother Earth News website at: http://www.motherearthnews.com/homesteading-and-livestock/walk-behind-tractors-zmaz06djzraw.aspx#axzz3PjQ2n6l

**BENEFICIAL INSECT HABITAT:**

We strongly recommend the 2014 Xerces Society book *Farming with Native Beneficial Insects* by Eric Lee-Mäder et al. Visit Storey publishing at www.storey.com/ or call 800.441.5700.
Also see:

*Manage Insects On Your Farm,* by Miguel Altieri et al. Book 7 in the SARE Handbook Series. It can be downloaded for free from: [http://www.sare.org/Learning-Center/Books/Manage-Insects-on-Your-Farm](http://www.sare.org/Learning-Center/Books/Manage-Insects-on-Your-Farm)

Print copies are available from SARE for $15.95. Call 301.779.1007 to order.


**ORGANIC WEED CONTROL PRACTICES:**

Some suggested resources include:


Ten Steps Toward Organic Weed Control by Vern Grubinger. This University of Vermont Publication is available free of charge at: [http://www.uvm.edu/vtvegandberry/factsheets/orgweedcontrol.html](http://www.uvm.edu/vtvegandberry/factsheets/orgweedcontrol.html)

**ORGANIC NO-TILL:**


Jan-Hendrik Cropp offered an excellent webinar on the eOrganic website, in January 2015, titled *Rotational No-Till, Mulching, and Conservation Tillage for Organic Vegetable Farms.* It is available in the eOrganic Webinar archives at: eorganic.info


In the text of this publication, we mentioned several small-scale no-till production systems. Here are some resources for further information on them.

**Emilia Hazelip’s Synergistic Gardening**

We are not aware of any books or detailed publications on the Synergistic method, but the following websites provide enough information for one to build a good picture.
http://www.thefrenchgardener.net/edu/synergistic.php

http://web.archive.org/web/20060316085845/

http://www.seedballs.com/hazelip.html

http://en.wikipedia.org/wiki/Synergistic_gardening

http://overgrowthesystem.com/permaculture-emilia-hazelip-synergistic-garden/

http://patchworkspermaculture.net/tag/emilia-hazelip/

http://www.selfsufficiencyhq.com/synergistic-agriculture-emilia-hazelip/

http://schumacherapprenticeadventures.wordpress.com/2014/04/10/emiliahazelipsynergisticgarden/

*Ruth Stout’s Mulch Gardening*

We are familiar with two books on Ruth Stout’s philosophy and methodology: *How to Have a Green Thumb Without an Aching Back* by Ruth Stout, and *The Ruth Stout No-Work Garden Book* by Ruth Stout and Richard Clemence.

*Patrice Gros’ Machine-Free Vegetable Farming*

Patrice has written a series of three booklets on this subject. His first, *Machine-Free Vegetable Farming, Book 1: Peace and Yields*, was published in 2013. In it he describes his no-till system and methods. To learn how and where to get copies, email Patrice at: mamakapa@yahoo.com or call 479.253.7461

Some additional resources on specialized mulch gardening:


**NATURAL ROCK POWDERS:**

*Bread from Stones* by Julius Hensel. Available from Acres U.S.A. for $16.00 plus postage. See www.acresusa.com or call 800.355.5313

**BIO-INTENSIVE FARMING AND GARDENING:**

Bio-intensive farming or gardening is a raised bed approach that, if practiced as promoted by Jeavons, is a largely self-sufficient system in which cover crops are grown to be composted before they are returned to growing beds.

SOIL FOOD WEB:

NRCS’ Soil Biology Primer by Elaine Ingham, Andrew Moldenke, and Clive Edwards. A free online version of this document is available at: http://www.nrcs.usda.gov/wps/portal/nrcs/detailfull/soils/health/biology/. For print copies, contact: pubs@swcs.org


Notes


2 National Organic Standard §205.2


4 We did not invent the terms bio-extensive or green fallow. We credit them to Anne and Eric Nordell who, if they did not coin the terms, are responsible for their growing use.


6 This is not true in all cases, of course. Southern blight (Sclerotium rolfsii) is known to attack a wide range of vegetable crops. The bio-extensive rotation detailed in this publication incorporates the use of summer annual sorghums and millets, which are not susceptible, and help break the life cycle of this disease.

7 Note that this does not mean extremely long rotations (e.g. 20 years for allium white rot) are advised. Rather, it shows the length of time that might be required to abandon a crop if a disease problem builds up. Four- to eight-year rotations should be adequate to prevent that from happening.

8 While it is better to plan a rotation based on the family groupings outlined in Figure 5, this simplified rotation scheme, which is borrowed from the well-known horticultural consultant, Shepherd Ogden, will work just as well in most circumstances.

9 The chemical name for the active ingredient in herbicides like Roundup®.
10 National Organic Standard §205.105(a)

11 National Organic Standard §205.202(b)


15 Not all oat varieties winter-kill in our climate, as we learned by experience. “Cayuse White Oats” survives Eastern Oklahoma winters with only a bit of tip burn on the leaves, and grows as vigorously as rye in spring.


18 Ibid.


20 According to the Conservation Technology Information Center in West Lafayette, Indiana, as cited on the UN’s FAO Web site at: http://www.fao.org/docrep/t1696e/t1696e09.htm

21 National Organic Standard §205.206(c)(6)

22 Sicklebar mowers are primarily used for making hay or similar applications where leaves and stems should be left intact. They are slowly being supplanted by cone mowers, which have multiple spinning blades. We have no experience with cone mowers but understand they present the same benefits and detriments as sicklebars when mow-killing cover crops. There are additional hazards from the fast spinning blades, which can throw dangerous stones and other debris, so tractors with shields are recommended.

23 We would plant hardier, non-heirloom varieties up to two weeks earlier, as soil temperatures approach 65° F.

24 In some instances, where we have stubble foot paths and plenty of soil moisture, we’ve elected to use shallow tillage to prepare a seedbed for buckwheat. As with weeds, most of the buckwheat becomes trampled, but it does supplant weeds.


Confirmed in discussions with Jacob Wilson, Lincoln University Cooperative Extension, Jefferson City, Missouri. June, 2014.

For information on the Green Seeder, see: http://smallfarmtoolbox.com/

www.lehmans.com

www.johnnyseeds.com


Note that not all allowed herbicides have unrestricted use in organic production. At this time, soap-based herbicides – which are “synthetic” – can be used only on ornamental crops and for farmstead maintenance, not for organic food crop production, per §205.601(b)(1) of the National Organic Standard. They may not be used for killing mulch for crop production as described.


National Organic Standard §205.203(a)

We apply compost tea and extract sprays only to cover crops and on ground to be seeded to cover crops. We do the same with compost. This is consistent with the traditional organic strategy of feeding and building the soil so it can feed crops for the long term. In addition, we need not be too concerned about National Organic Program regulations regarding manure, compost and compost tea (see National Organic Standard §205.203(c)(1) and §205.203(c)(2)).

At the time of this writing, sodium nitrate (also known as Chilean nitrate) is still allowed for use in organic farming (see the National Organic Standard §205.602(g). The rule, however, may change. Be certain before purchasing or using it.

http://en.wikipedia.org/wiki/Biointensive_agriculture

http://aggie-horticulture.tamu.edu/wildseed/growing/annual.html

This option may well be implemented at the Cannon Site. It is a means for reducing the size of the bio-extensive demonstration to one more manageable by our small staff, and freeing the remaining horticulture plots for other demonstrations.

Details copied verbatim from: http://www.uvm.edu/vtvegandberry/Videos/nordellinfo.html. The DVD and the booklet are marketed under the title Weed the Soil, Not the Crop.