Sustainable Practices for Plasticulture Strawberry Production in the South

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Introduction

Strawberry producers in the Southern United States produce an estimated 46 million pounds of fresh berries per year (estimate based on Samtani et al., 2019). The market for strawberries produced in states in the South Atlantic and Mid-South, which in this publication we will collectively refer to simply as the South, has grown substantially in recent years for an estimated total number of acres of 3,342 (Samtani et al., 2019). Nationally, production has increased about 17 percent since 1990. The majority of production uses annual plasticulture systems planted with June bearing (short day) cultivars. In most of the region, production is focused on marketing toward U-Pick customers and local markets, although there are several large grower-shippers in parts of the Carolinas. While there continues to be a demand for locally produced berries, there are particular challenges related to growing strawberries in this region.

Many farms now producing strawberries throughout the South were converted from intensive tobacco production to the intensive production of strawberries and other fruit and vegetable crops. This is typically the case in U-Pick operations, where the same farm land is used to grow strawberries every year. This long-term use of single plots of land for annual production can lead to a decrease in land productivity due to exhaustion of nutrients and soil organic matter.

Soil health losses can be exacerbated by the tendency to re-plant each year in the same location due to limited land availability or marketing strategy. Additionally, strawberry fields allowed to remain fallow during the summer months can lead to an increase of soil erosion, loss of organic matter and the buildup of weed seed banks. Some farms plant a summer crop after strawberries (e.g. watermelon) to reuse the plastic mulch. However, using the same farmland without proper crop rotation leads to insect and pathogen build-up, often resulting in an increased need for chemical inputs. While annual fumigation practices may reduce the risk associated with soilborne pests, this practice also removes helpful biological life that contributes to soil health. The goal of sustainable management practices is to maintain the long-term viability of strawberry production by incorporating practices that contribute to longstanding land stewardship into the production cycle.

This publication will outline sustainable management practices that are appropriate for strawberry growers in the South, the benefits of these practices and how they can be incorporated into plasticulture production systems. We will not give an in-depth overview of the basics of strawberry production here. Rather, this publication is targeted towards growers, managers, and extension personnel interested in incorporating practices that promote farm stewardship and long-term soil health into their strawberry production systems. The practices and recommendations put forth in this publication are based on strawberry research conducted in the southern region of the United States. However, many of these practices have also been demonstrated to be widely applicable in other regions and to other horticultural and agronomic crops.

What are Sustainable Practices?

The 1990 Farm Bill established the Sustainable Agriculture Research and Education (SARE) program, and the definition of sustainable agriculture was outlined by the U.S. Congress as:

> **"… an integrated system of plant and animal production practices having a site-specific application that will, over the long-term –**
>
> **(1) satisfy human food and fiber needs;**
>
> **(2) enhance environmental quality and the natural resource base upon which the agriculture economy depends;**
>
> **(3) make the most efficient use of nonrenewable resources and on-farm resources and integrate, where appropriate, natural biological cycles and controls;**
>
> **(4) sustain the economic viability of farm operations; and**
>
> **(5) enhance the quality of life for farmers and society as a whole."**
>
> **(U.S. Code Title 7, Section 3103)**

More generally, sustainable agricultural practices promote the long-term viability of on-farm natural resources and limit negative environmental impacts that can occur as a result of agricultural production systems. Additionally, sustainable agricultural practices must also recognize the social well-being of the farmer, consumers and the need for economic viability of the farm enterprise. When production practices are carefully chosen for a particular site and situation, on-farm resources can be both used and conserved, the reliance on off-farm resources can be limited, naturally occurring biological controls can be maximized and the potential for contamination that harms the health of humans and the environment can be reduced.

> **"A sustainable agriculture does not deplete soils or people."**
>
> **— WENDELL BERRY**

Examples of sustainable practices include the use of composts, cover crops, crop rotation, protection of beneficial insect habitats and the use of cultural controls to prevent pests. In this publication, we will focus most heavily on the land stewardship part of sustainable agricultural production. However, many of these practices can also support the other two pillars of sustainable agriculture: long-term profitability and quality of life for growers and their communities.

WHAT IS THE DIFFERENCE BETWEEN "SUSTAINABLE" AND "ORGANIC"?

Organically produced products are not the same as sustainably produced products. Organic, in the United States, refers to rules and production standards that are set by the U.S. Department of Agriculture (USDA) National Organic Program. Organic production practices include a prohibition on using synthetic fertilizers, synthetic pesticides, genetically modified organisms, and sewage sludge. The phrase "sustainable practices" does refer to and include many practices that are used by and required of certified organic producers. However, unlike the "organic" label, the "sustainably produced" designation does not require any verification or certification on the part of the producer. The term "sustainable" can therefore be used indiscriminately, and a producer should be ready to explain their use of this term when it is incorporated into marketing language. However, growers who are able to promote their use of sustainable production practices may find it a boon to their marketing strategy, as consumers are becoming increasingly interested in how food is produced.

For more information on organic strawberry production, see the "Other Resources" section.

Why Incorporate Sustainable Practices into Plasticulture Strawberry Production?

Economics

While long-term land stewardship is a concern for all growers, the more immediate concern of maintaining high yields is often the primary driver for choosing which practices to incorporate into a production system. For many of the sustainable practices discussed in this publication, research has shown direct links between incorporation of a given practice and increases in strawberry yields. For other practices, the value lies not in immediate increases in yield but rather in improvements to soil health, services provided by beneficial insects or in reductions in pest or pathogen populations, all of which can result in increased yield over time. While the economic side of implementing any production practice is of utmost importance, the cost-benefit analysis of incorporating sustainable practices into a production system will vary for each grower based on labor costs, availability of materials, access to equipment and local conditions. An analysis of the economics surrounding the implementation of sustainable soil production practices was published in 2015 by Rysin, et al. (see the resources section for a link to this publication).

Soil Health

Maintaining healthy soil is critical to the sustainable production of strawberries. Often what lies beneath our feet in the field is a source of worry, whether it is low fertility or possible disease presence. Growers also know, however, that a healthy soil can contribute to successful crop production. Factors that contribute to a healthy soil include a diverse microbial community, maintenance or improvement of soil organic matter, good soil aggregation (the ability of a soil to hold itself together), and balanced soil nutrients. Many of these factors can be measured and are used as indicators of soil health, which is a measure of the soils ability to support plant growth and other ecological functions. Selecting production practices that maximize and maintain soil health can ensure long-term crop productivity.

The addition or conservation of soil organic matter is the basis for implementing most sustainable soil management practices. Increasing soil organic matter can improve soil structure or aggregation, increase the nutrient-holding capacity, and support a more diverse soil microbial community. The resulting soil structure improvements can lead to reduced erosion, better root growth, greater infiltration and drainage in clay soils, and an increased water holding capacity in well-drained soils. For the many sandy soils found in many parts of the Southern United States, increasing organic matter levels can greatly increase water holding capacity and the retention of soil nutrients.

WHAT IS SOIL HEALTH?

Soil health is a measure of the ability of the soil to provide services, such as supporting plant and animal growth and maintaining water and air quality.

HOW DO YOU MEASURE IT?

Soil health is complex, and changes to it are measured by monitoring soil microbial populations, soil chemical prop erties, the speed of water infiltration into the soil, and the ability of the soil to resist erosion and maintain soil aggre gates. These qualities of the soil will change based on how the soil is managed and are good indicators of the soil's ability to function to support plant growth.

While there are soil microorganisms that are well known for causing plant disease, there are also soil microorganisms that promote plant growth. Beneficial soil microorganisms contribute to plant growth by producing plant growth-promoting hormones, providing protection from or inhibiting plant pathogens, fixing nitrogen (e.g., rhizobia bacteria), enhancing plant drought tolerance, increasing soil aggregation, or converting nutrients in the soil into forms that plants can use. Just as a city has many different types of jobs that must be filled by people who have diverse skills, the soil benefits from diverse soil microorganisms that are capable of performing different jobs in the soil community. However, strawberry systems with histories of annual fumigation or low levels of soil organic matter often lack healthy and active populations of beneficial microorganisms in the soil. By implementing practices that increase soil organic matter and conserve soil microbe diversity, growers can take advantage of beneficial soil microorganism's natural ability to suppress disease-causing microorganisms and promote nutrient cycling.

Finally, certain sustainable soil management practices, like the use of compost and cover cropping can contribute nitrogen, phosphorous, potassium, and micronutrients to the soil.

Pest Management

Pests are organisms, including insects, mites, microorganisms (e.g., fungi, bacteria and nematodes) or weeds that negatively affect crop health. One key to reducing pest pressure on a farm is to select cultural management practices that break up the pest lifecycle. Soil management practices such as crop rotation, cover cropping, or additions of compost can interrupt pest life cycles and contribute to reductions in pest population growth in addition to increasing soil organic matter.

Many of management strategies work based on selecting crops that are non-hosts to the pest organism, which disrupts the pest lifecycle and can reduce the population of the pest over time. Rotating to crops that are non-hosts to the pest organism can be an effective strategy if used for a long enough time. Generally 3-5 years cycles of crop rotation are recommended.

Another way to naturally suppress pest populations is to maintain populations of beneficial insects or microorganisms on the farm. Beneficial insects or microbes are those that feed on or otherwise kill pest organisms that damage the crop. Important considerations for promoting populations of beneficial organisms include providing appropriate habitats for them and planning any pesticide applications so that non-target effects are minimized.

Environmental Impacts

Pesticide drift, fertilizer runoff, erosion from alleyways or bare ground, and air pollution from fumigation are some potential negative environmental impacts of strawberry production. Sandy soils that are low in organic matter are particularly prone to fertilizer losses through leaching. Some of these negative impacts can be reduced by using appropriate pesticide and fumigation practices and by planting cover crops in fallow fields or in alleyways to reduce the amount of time the soil is bare. Using compost and cover crops as nutrient sources also generally reduces the potential of nutrient loss due to leaching and run-off as compared to chemical fertilizer sources.

Sustainable Practices for Strawberry Production: Description and Use

Site Preparation and Soil Testing

As with any type of crop production, site preparation is key to success and profitability. For strawberry production in the Southern US, water drainage, soil pH and light exposure are key. Most importantly, choose a site that has well-drained soil, a soil pH that can be adjusted, that receives full sun, has fertile soil and is accessible to irrigation and transportation of harvested fruits. To grow strawberries, the soil pH needs to be between 6.0 and 6.5. Usually, soils with pH above 5.0 are adjustable by applying lime. Further, strawberries grow best on well drained, sandy soils. For U-Pick operations, visibility of the field is key. For long-term sustainability, several plots with these characteristics should be identified for annual rotation of the strawberry crop when possible.

For both new growers and seasoned producers, annual soil nutrient testing should be used to determine which soil nutrients are required for the next cropping cycle and whether the soil pH needs to be adjusted. Soil samples should be taken in a randomized design, and approximately six months before the estimated planting date, to allow enough time to adjust the soil pH. Understanding these basic chemical properties of your soil and any changes over time is key to preventing costly crop losses and ensuring healthy crop establishment.

Consult the list of testing agencies at the end of this publication or check with your local extension personnel to identify a soil testing service in your area. In order to receive appropriate soil nutrient recommendations when submitting a sample, remember to indicate that strawberries are your next crop. Most testing agencies provide an easy guide for interpreting soil test results and make recommendations for adjusting soil fertility.

Nematode sampling can be insightful for growers who are starting out and using land that does not have a history of fumigation or for growers who notice localized declines in crop growth within a field. Nematode sampling should take place in late summer to determine the types of nematodes and the size of their populations in a given field. Annual or semi-annual sampling allows a grower to monitor nematode populations over time. Samples should be taken over an area and mixed together in a plastic bag to be submitted as one sample.

Soil testing for plant pathogen presence is currently not available in the southern region of the United States. In order to assess long-term changes in soil health, additional specialized testing is required. A few of these specialized tests might include earthworm populations, aggregate stability, organic matter content, and microbial activity. Some of these tests are basic and can be performed on-farm by the grower, while others require submission of soil samples to a specialized testing facility. The Cornell University Soil Health Laboratory has a free training manual that provides details of how to perform some of these types of analysis. For more information on testing services in the Southern states or Cornell's testing services, review the section "Other Resources."

HOW AND WHEN DO I SOIL TEST?

Soil samples should be collected from each management area within a field. A management area is an area that receives the same management practices and fertilization schedule. Collect 10 to 15 soil cores randomly through out the area from a depth of 0-6 inches. The 10 to 15 soil cores should be gathered and mixed together in a bucket. The mixed sample can then be sent to the preferred soil testing agency. Areas of different soil texture, drainage patterns or areas that are otherwise abnormal should be avoided or sampled separately if a diagnosis of the problem area is desired.

Soil tests should be performed at the end of the cropping cycle in early June so that there is time to add any amendments recommended by the soil test results prior to the next strawberry crop.

Soil Management Practices

Once you know the chemical, physical and biological characteristics of your soil, you can begin to make decisions about how you will manage its production potential and long-term soil health.

Crop Rotation

Crop rotation involves planting in succession crops that are not closely related or that are from different plant families. The ability of crop rotation to positively impact crop production should not be underestimated but does require long-term planning and knowing what crop pests the grower may be trying to suppress. Crop rotation plans can involve rotating away from a certain group or family of plants for as short as a season or as long as five to 10 years. Crop rotation provides a break in pest-cycles, diversifies the depths at which plants are rooting at which can break up hardpans and make use of nutrients stored in different parts of the soil profile, and provides an opportunity for the soil to rebuild nutrients and organic matter after an intensive crop cycles like strawberries. Just as a diversity of soil microbes is good for the soil, so is having a diversity of crops in a crop rotation.

For strawberries grown in an annual plasticulture system, crop rotation should take place annually if sufficient land is available. Growers should avoid planting strawberries on the same ground year after year. The greatest benefit from crop rotation is seen in rotations in which the cash crop (e.g., strawberries) is planted on the same piece of land only once every three to five years.

However, if growers are unable to rotate where they plant their strawberry fields each year, other management practices can help to provide relief to intensively managed soils.

Compost

Composted materials incorporated into the soil can increase organic matter, improve aggregate stability, decrease soil erosion and promote soil microbial activity. In clayey soils prone to ponding, water infiltration can be increased by adding organic matter. In sandy soils that do not hold water well, adding compost increases soil organic matter and enhance microbial populations which can increase water-holding capacity. Organic matter in the soil acts like a sponge that holds water while allowing the excess to drain. In addition, compost can be a slowly available nutrient source for plants, providing nitrogen and micronutrients. Compost has also been investigated as an alternative to fumigation with some positive results, but thus far has not been found to be as effective in controlling soilborne diseases as chemical fumigation (Grabowski, 2001; Louws et al., 2000; Leandro et al, 2007). The use of locally produced compost or the production of compost on-farm, when feasible, will increase on-farm nutrient cycling and makes applying compost more economical.

To avoid plant injury, any applications of compost should be tested for their nutrient and salt content or applied well in advance of strawberry crop establishment.

It is important to test compost for excessive nutrient and salt levels. Some testing services not only provide information about the total amounts of nutrients in the compost but also provide estimates of the amounts of nutrients that will be available to the next crop. Growers should use these estimates of nutrient inputs to adjust their applications of chemical fertilizer accordingly. In addition, growers who apply compost annually should also soil test every year to monitor nutrient changes and avoid nutrient or salt build-up in the soil.

Composted manure is preferable to use of raw manure due to USDA and Food Safety Modernization Act (FSMA) restrictions on the application of un-composted manure. These restrictions are in place due to risks for food-borne illness in raw manure and the potential to over-apply some nutrients (particularly Phosphorus) with repeated manure applications. However, it is important to be aware that even some manure-based composts can have high phosphorus or salt concentrations, and excessive use of these products may lead to nutrient toxicities in the crop. Having the material tested prior to application can prevent these potential issues.

Timing

In the Southern United States, compost can be applied in early summer, following the end of the strawberry season and removal of plastic, or just prior to raising beds in the fall. High quality compost applied just prior to plastic laying can improve fall plant establishment. If the compost has a high salt content, applying compost in the early summer prior to fall planting reduces the risk of salt burn to strawberries, which are salt sensitive. Applying compost prior to seeding summer cover crops in early summer can have dual benefits. The cover crop will benefit from the nutrients provided by the compost, the cover crop will provide soil cover and much of these nutrients will be returned to the soil when the cover crop is incorporated into the soil. Compost may also help support strong cover crop growth and biomass production during the short summer window.

Rates

Compost application rates should vary based on the nutrient content and cost of the material you are using. Generally, rates of six to ten tons of compost per acre are adequate. Multiplying the rate of application (pounds/acre) by the estimated nutrient content of the material will give an estimate of the pounds of nitrogen, phosphorus, potassium, and other nutrients that the material supplies per acre. Once the amount of nutrients supplied by the material is determined, pre-plant fertilizer applications should be scaled back appropriately.

Incorporation

Compost should be applied evenly over the field and incorporated to a depth of several inches, ideally within several hours after application. Incorporation of the material results in the retention of a greater percent of nutrients for the subsequent crop.

Summer Cover Crops

There is a dual benefit to applying compost in early summer followed closely by cover crop establishment. Cowpea established with pre-plant applied compost (left-side) and without compost (right-side).

A cover crop is a crop that is planted for the benefits it provides to the soil or the subsequent crop, and is a crop that is generally not harvested or sold. The benefits of planting a cover crop can include adding nitrogen to the soil, increasing soil organic matter, preventing erosion by covering the soil when the field would otherwise sit fallow, reducing soil compaction and suppressing weeds. After the cover crop has grown and accumulated substantial biomass, it is mowed and tilled into the soil. Incorporation of the summer cover crop biomass into the soil is preferable for plasticulture systems so that the biomass does not interfere with the bedding equipment or plastic laying. Summer cover crops can fit into a strawberry production system with advanced planning. Your farm specific goals and reasons for including summer cover crops will determine what type of cover crop is most appropriate.

There are three broad classes of summer cover crops: legumes, grasses and others. Leguminous cover crops allow farmers to "grow" their own nitrogen fertilizer via the fixing of nitrogen in the plant's roots by bacteria. Grass cover crops generally produce large amounts of biomass, are better at suppressing weeds, and will ultimately contribute larger amounts of organic matter to the soil. A mix of a legume and grass provides the benefits of both crop types, and the grass can help support the vines of the legume crop. There are few other types of summer cover crops that can used including plants from the mustard family (Brassicaceae) or Buckwheat. Plants from the Brassicaceae family are often planted for their pest suppression capabilities and their bio-fumigant effects. This is an evolving area of research for strawberry production in the Southern US. Research has shown that bio-fumigant mustard and brassica cover crops can suppress diseases and nematodes in subsequent crops. The effect is dependent on having an effective cover crop stand, ample biomass and mowing and immediately tilling the biomass into the soil.

For more information on the specific characteristics of some common summer cover crops that are appropriate for the South, see Table 1.

SUMMER COVER CROPS FOR WEED AND PEST MANAGEMENT

While summer cover crops have been shown to substantially suppress summer weeds, they may be less effective at suppressing cool season weeds. Certain cover crops, however, have been shown to have a suppressive effect on soil pathogens well into the following strawberry cropping season.

It is important to be aware that some cover crops can serve as a host to the same pests that occur on strawberries. However, this can be avoided by using cover crop varieties that are resistant to strawberry pests, such as 'Iron Clay' cowpeas, which are resistant to root-knot nematodes.

In contrast, cover crops can sometimes be non-host to certain beneficial soil microbes. An example is brassicas are non-hosts to arbuscular mycorrhizal fungi. These covers should be avoided if you wish to promote these soil microbes.

The most important consideration for incorporating summer cover crops into plasticulture strawberry production is the issue of time of planting and terminating. In order to get the most benefit from the short window between strawberry production seasons, it is important to establish the cover crop as early as possible in the late spring or early summer.

In order to get the maximum benefit from planting the cover crop it should be allowed to reach maturity and maximize its biomass or nitrogen production. Summer cover crops need anywhere from 45-90 days to reach maturity and be ready for termination. Cover crop residues can make it difficult to raise a bed and lay plastic. It is important that cover crops are terminated 20-30 days before raising beds. In a year or region where the strawberry season extends well into June, a grower will have less time to establish the cover crop before it will need to be mowed and tilled into the soil prior to fall strawberry field preparations. Thus, in some years, a short-season cover crop might be more useful than a more slowly maturing one.

Local Conditions

Your land and specific conditions will also influence what cover crop or combination of cover crops is most appropriate. Temperature ranges, expected rainfall, soil texture (sandy vs. clayey), and soil moisture should all be taken into consideration. For instance, some cover crops may require supplemental irrigation to become established or may perform poorly in wet soils.

COVER CROPS AND EXTRAFLORAL NECTARIES

Some cover crops, such as cowpea and buckwheat, are known to have "extrafloral nectaries" that act as a food source for some beneficial insects. Planting these crops may help sustain and promote populations of these good insects between cropping seasons.

Reminder: When planting a leguminous cover crop, use an appropriate soil inoculant to ensure Rhizobia bacteria are present in the soil. This is especially important if there is a history of soil fumigation or if there hasn't been a history of other leguminous crops being planted on the land.

Seeding Rates

Cover crop seeding rates will be determined by multiple factors, including the cover crop or combination of cover crops chosen, the seeding method and the amount of time available to establish and grow the cover crop between cash crops. For instance, when a mixture of a grass and legume is used, the legume is generally planted at 70-80 percent of its full rate while the seeding rate of the grass is planted at only 20-30 percent of its full rate to give the slower growing legume an advantage. On the other hand, greatly increasing the seeding rate of a grass when it is planted individually will result in greater competition between plants and thinner stalked plants that break down more quickly in the soil. Drilling the seed at establishment requires lower seeding rates than what will be required by broadcasting to get similar stands. If there is only a short window for the growth of a cover crop, increasing the seeding rate can lead to increased biomass production as compared to a using a lower seeding rate.

Machinery

Using machinery that places the seed at the correct depth and spacing will greatly increase the success of cover crop establishment. A grain drill can be used but it is easy to broadcast seeds with handheld seeders for smaller areas. It may be necessary to make a few test runs to calculate and correctly calibrate your seeder to the cover crop's planting requirements. Extra time spent calibrating equipment to achieve the correct seeding rate will pay off over the course of the season in good crop establishment, crop growth, and in weed suppression.

Machinery that can mow and incorporate the cover crop must be available in late summer and is an important consideration because some cover crops may grow more than 6 feet tall. Flail mowers or bush hogs are generally preferred for cover crops that produce large amounts of biomass because flail mowing will reduce the tissue to pieces small enough to be easily incorporated into the soil. Several passes with a mower may be required to sufficiently reduce the crop to small enough pieces that can be easily tilled in.

Cover Crop Termination Date and Incorporation

It is important to choose the appropriate date to mow or otherwise "terminate" the cover crop in order to allow enough time to grow and reach its full potential, while also providing ample time after mowing and tilling for the plant tissue to break down prior to laying plastic. If the cover crop is cut and incorporated into the soil too late in the season, it will not decompose sufficiently and may get hung up in bed-laying equipment. Thick grass stalks that are not decomposed may also puncture the plastic in newly laid beds.

Most cover crops should be terminated around the time of flowering and before seed set. Visually this means at the beginning of flower with no more than 20 percent of the field setting flowers. The speed at which cover crop tissues will decompose is dependent on method of incorporation, crop type, crop age, soil moisture, and temperature. Cover crops tilled into the soil will break down more quickly than if the biomass is left on the soil surface. Legumes will generally decompose more rapidly than grasses. Some soil moisture is required for microbes to break down tissues; however, excessive moisture can delay decomposition. Additionally, warm soil temperatures generally lead to quicker decomposition than cool temperatures.

Flail mowing a summer cover crop.

Finally, consider that, for some legumes, it is ideal to kill the cover crop before seed-set so that more nitrogen will be retained in the plant tissue instead of being transferred into the seed. The nitrogen in the plant tissue will be more readily available to subsequent crops than nitrogen stored in the seeds, and there is less chance that "volunteer" plants will emerge later. **A general approach might be to mow the cover crop at least 20 days before laying plastic, and incorporate the cover crop either immediately or soon after mowing.**

More information on cover crop seeding, management and termination can be found in the Resources section at the end of this publication.

Table 1: Common Summer Cover Crops for Strawberry Production in the South

COVER CROP	USES/QUALITIES	DRILLED SEEDING RATE LBS./ACRE [RATE IF PLANTED WITH COMPANION]	POSSIBLE COMPANION CROPS
Legumes			
Cowpea 'Iron clay'	Moderate to good weed control, drought and heat tolerant legume (may produce 100-150 lbs. N/acre), good for beneficial insects (extrafloral nectaries)	100-130 [100]	Various, Pearl Millet
Sunn Hemp	Tropical legume, nematode resistant and may produce large amounts of biomass and over 150 lbs. of N/ acre. Research and used in organic strawberry production in Florida†	10-40	
Grasses			
Buckwheat	Matures rapidly in 6-7 weeks, not heat tolerant, low-moderate biomass, not good for poor soil, scavenges nutrients, not a host for arbuscular mycorrhizal fungi (AMF)	60-70	Cowpea
Pearl Millet	Excellent weed control, drought tolerant, does not get as tall as Sudan or Sorghum-Sudan, adapted to poor soils	30 [10]	
Sudan	Excellent weed control, some drought tolerance, high biomass, adapted to poor soils	20-90	
Sorghum-Sudan	Bio-fumigant properties, smothers weeds, tremendous biomass producer in hot/dry weather; if lower seeding rate is used, likely will require two mowings and extra time to decompose thick stalks	20-90	Cowpea
Others			
Bio fumigant Mustards	Several commercial varieties exist, types with high glucosinolate content should be chosen (ex. Mighty Mustard, Kodiak, etc.). Can be planted in late summer with enough irrigation. Must be mowed and tilled into the soil for maximum biofumigant effect. Not a host for AMF	5-10	

*The specific varieties mentioned after each cover crop name are varieties that are specifically adapted to the Southeast. **This list is not meant to be exhaustive of all cover crops or companion crops that are appropriate for the Southeast. Consult your local extension personnel for specific information on species, seeding rate, and other considerations for your specific region. †Sunn hemp (Crotalaria juncea L) is restricted from being sold or planted in some southern states, check with your local extension service and state department of agriculture.

Beneficial Soil Inoculants

Beneficial soil inoculants are materials that are added to the soil with the goal of introducing or re-establishing populations of "good" soil microbes that will promote plant growth. There are many different materials available that can be used for this purpose, and it is important to note that the application of compost can also introduce and support diverse soil microbial populations.

Two types of materials that have been investigated are vermicompost (compost made by earthworms), which has high microbial activity, and arbuscular mycorrhizal fungi (AMF), which are fungi that form beneficial relationships with plant roots and help plants scavenge the soil for nutrients. The use of these types of materials in fumigated systems has been investigated in the South as a way to re-introduce "good" microbes back into the soil following fumigation practices — however, results showed that the live AMF in plug plant roots did not survive once planted into fumigated beds even when the appropriate plant back period was observed.

BENEFICIAL SOIL INOCULANTS AND THE STRAWBERRY PLUG:

Previous research has shown that adding vermicompost and arbuscular mycorrhizal fungi (AMF) to the planting hole or plant plug increased yields in some years compared to non-inoculated plants (McWhirt, 2016). For more information on the use of these two inoculants and methods for their incorporation into strawberry plug production, see the following demonstration video: https://www.youtube.com/watch?v=-dET8r3bhdQ.

Calculating Nitrogen Additions

Cover cropping and applying compost add large quantities of plant nutrients, particularly nitrogen, to the soil. It is important, however, to remember that not all of the applied nitrogen from compost and cover crops will be available to the next crop. This nitrogen becomes available as microbes break down the organic matter and it is released over time. Estimates of nitrogen inputs from these sources should be used to reduce pre-plant fertilizer rates to avoid burning plants and wasting money. The following describes how to estimate the amount of nitrogen from compost or cover crops that will become available during the subsequent cropping cycle.

To figure out how much nitrogen is provided to your strawberry crop by a leguminous cover crop or compost application, you will need the following three pieces of information:

1. **The amount (lbs. per acre) of dry plant tissue or material applied to the soil.**
2. **Percentage or concentration of nitrogen present in the plant tissue or compost material (from lab analyses).**
3. **Percentage of the nitrogen present in the material that will be available to the next crop.**

With the three pieces of information mentioned above, you can use the following calculation to determine how much nitrogen (N) will be available to your strawberry crop:

LBS of material applied per acre	X	% (Percent) or concentration of total N in the material	X	% (Percent) of the total N in the material that will become available during the following crop season	=	Amount of available N applied per acre

Figure 1, on page 11, shows an example calculation to estimate nitrogen inputs from compost and cover crops. In the example, compost that is 2 percent N is applied at rate of 6 tons/acre and a cover crop that is 3 percent N and produced 3,126 lbs. of dry biomass/acre. This results in a combined estimated total of 94.89 lbs. of nitrogen applied. (Remember to convert tons to lbs./acre).

This example calculation estimates that 48 lbs. of N per acre from the compost and 47 lbs. (rounded up from 46.89) of N per acre from the cover crop will be available in the upcoming season. If the compost and cover crop were applied in the same field, this is a total of 95 lbs. of N that will be available to the subsequent crop. Using this estimate, a grower could decide to eliminate all pre-plant nitrogen fertilizer additions and reduce subsequent spring fertigation applications.

Plant tissue and petiole analysis in the spring should always be relied on to monitor the nitrogen status of the crop, as factors like weather, soil type, and temperatures will influence the rate at which soil nitrogen becomes available. Plant tissue analysis protocols will be covered in the following section. Remember that soil-incorporated materials will supply a greater percentage of the total nitrogen content to the subsequent crop than materials left on the surface.

To estimate the amount of cover crop biomass, cut down all the plants within one square foot, dry them, weigh them, and multiply the weight by 43,560 to get the dry weight biomass per acre. Many testing agencies can analyze samples of either plant tissue or compost to provide information about the amount of nitrogen present and estimate the amount of nitrogen that will likely be available to the next crop. You can use this information to determine how much compost is needed to supply a desired amount of nitrogen per acre, or alternatively, how much nitrogen has been applied by a cover crop or by previously applied compost.

Figure 1: Calculating how much nitrogen (N) is applied.

COMPOST:

0.02 x 12,000 lbs = 240 lbs of N (X) 0.2 = **48 lbs N Added**

(2% N) (6 tons compost) (total N) (20% available to 1st crop) per acre

COVER CROP:

0.03 x 3,126 lbs = 93.78 lbs of N (X) 0.5 = **46.89 lbs N Added**

(3% N) (lbs dry biomass) (total N) (50% available to 1st crop) per acre

**The values used for estimates of nutrient availability in this example are not applicable to all composts or cover crops.

A FEW NOTES ON NUTRIENT CALCULATIONS:

Wet vs. Dry Weight

Wet weight refers to the amount of nitrogen in fresh tissue. Dry weight refers to the tissue after it has been dried in an oven to remove the water weight. The units of your calculation must be in dry weights. If you use the wet percent nitrogen concentration with the dry weight application rate you will over-apply nitrogen.

Nutrient Availability

Consider that while nitrogen availability rates may vary from 20-80 percent over the subsequent cropping cycle; 70-80 percent of the phosphorus (P) and 80-90 percent of the potassium (K) applied will be available in that first year. It is important to be aware of compost's phosphorus and nitrogen contents as you can over apply these nutrients to the point that they are toxic to the plant or that they cause environmental harm.

Plant Tissue Testing

Plant tissue testing is a great tool for monitoring nutrient availability in the plant that can be calibrated with soil nutrient additions and for detecting nutrient problems before visual symptoms appear. This is important for determining nitrogen fertigation strategies in the spring, especially if rates are reduced following cover crop incorporation or compost application. Plant tissue testing should begin before the first fertigation application. Testing should continue bi-weekly if no problems are detected or weekly if a deficiency is found during bloom or through the early fruiting part of the season.

To sample plant tissues, collect 25-30 mid-tier leaves across a field. If fields are managed differently, collect separate samples from each zone or area with a different soil type, variety, or fertilizer schedule. Mid-tier leaves are fully expanded leaves that are three to five leaves back from the growing point. Detach the leaves near the crown, and separate the petioles from the leaflets immediately. Place the leaflets and petioles in separate paper bags, and submit everything as one sample. Timely submission of the sample will improve the accuracy of your results.

Integrated Pest Management (IPM)

Integrated pest management is the strategy of utilizing preventive, biological, physical, and cultural management practices to reduce populations of identified pests or disease-causing organisms before turning to the use of chemical controls. Some examples of IPM practices include planting pest or disease-resistant varieties (preventive), removing infected plants (physical), and releasing predatory mites (biological). The type of management method that should or can be used will vary based on the conditions and the pest organism that is being targeted, but some of the most important tips you can remember to implement IPM strategies and reduce the need for a chemical control are:

1. Maintain a Healthy Crop

Starting with clean plants and then maintaining a healthy crop is one of the easiest ways to prevent pest problems from the beginning. For example, excessive nitrogen applications can lead to spikes in aphid populations, while droughty or excessively wet soil conditions can be favorable to two-spotted spider mites. Planting the right variety for your site, history of pest pressures or conditions can go a long way toward avoiding pest issues. Removal of infected or infested plants or fruit will also reduce further spread of the pest organism.*

*However, when anthracnose is present, hand removal of infected plants is not recommended.

2. Perform Weekly Scouting

Regular scouting and monitoring of pests during times when they may become economically damaging is critical to identifying specific pests and developing a specific management plan for emerging populations. A pest population that is detected early might be more easily controlled with a small, targeted pesticide application than that same population a week later. A good scouting plan is to walk through the field in a zigzag pattern and look randomly at the tops and undersides of leaves. Keep notes of when an issue is found, flag the spot, and continue to monitor those areas. The most important part of scouting and monitoring is being able to accurately identify what insects or pathogens are in your field.

Adult Strawberry Clipper

Photo courtesy of Hannah Burrack

Aphid

Photo courtesy of Paul Adams

Immature Ladybeetle

Photo courtesy of Amanda McWhirt

Greenlace Wing

Photo courtesy of Amanda McWhirt

Remember not all insects are bad for your crop and some, like ladybeetle and green lacewings, are beneficial because they eat damaging pests. Some practices, such as planting habitat for beneficial organisms, may help support populations of these "good" insects. For help in identifying common insects, see the "Guide to Strawberry Insect Pests" in the "Other Resources" section. Also, there are various offices and labs that can help you identify pests or disease issues in your field. Consult the list of testing agencies at the end of this publication to identify an office near you.

3. Know When to Treat

Once you know what pests or pathogens are present, you also need to know at what point their populations become economically damaging or the point at which action should be taken to prevent economic damage from occurring (i.e., economic threshold). For example, the treatment threshold for two-spotted spider mites is an average of 5 mites per leaflet sampled off of at least 10 leaflets per acre. Treating prior to reaching the economic threshold may cost more in chemical application costs than the value of any saved yield that is lost due to the insect's feeding. For example, spider mite populations in the late part of the harvest season are not likely to impact yield.

Also, preemptive sprays may eliminate populations of good insects that would otherwise help to reduce the pest organism's populations. For instance, if you have a population of aphids in one part of your field but also a large population of ladybeetle, which eat aphids, you may wish to wait several days before deciding to treat and allow the ladybeetle to act as biological controls of the pests. It is also important to be aware of non-target effects during flowering, as certain pesticides are toxic to bees.

Please consult the "Other Resources" section for other guides and information on IPM practices, including threshold levels for some pests and more recommendations about when to treat.

This section does not provide an exhaustive list of all the cultural, physical, biological, or preventive methods that can be used to manage all strawberry pests. However, prevention, early detection, and appropriate management strategies are vital to minimizing the damage caused by pest populations.

Planning Your Production Schedule

Before setting out to incorporate new sustainable practices, it is important to consider how they will fit into your current production system in terms of availability of equipment, resources, and time. The calendar on the following page outlines a general production schedule for incorporating the soil management practices of compost and cover crops into the typical systems of plasticulture strawberry production in the Southern US. This calendar

is most specific to the piedmont of North Carolina or the central part of Arkansas in a typical climatic year; dates should be shifted two weeks later in the fall and two weeks earlier in the spring for more southern or coastal areas, or two weeks earlier in fall and two weeks later in spring, for mountainous or more Northern areas. Growers outside of these areas will need to alter the calendar dates according to their local conditions.

In addition to outlining when various field activities should take place, under "In the Field," there is a list of activities related to ordering supplies for later in the season, under "Planning."

Plasticulture production calendar for sustainable practices in strawberries.

MONTH	IN THE FIELD	PLANNING
January		
February	Begin weekly spider mite and clipper scouting.	Plan integrated pest management scouting schedule for the season; monitor updates on pest emergencies and trends.
		Arrange bee boxes or hives for start of flowering.
March	+ March 1: Monitor nightly low temperatures and apply frost protection as needed; as flowering begins, start fertigation program.	
Harvest (early April - late May)		
April	+ Continually monitor for SWD, botrytis, Phytopthora, etc.	Schedule compost delivery for early June (if applying prior to cover crop seeding).
May	+ End of harvest; remove plastic and till; take soil samples.	
June	Incorporate compost (Option 1).	Order tips for mid-August delivery.
	Plant cover crops.	
July	Monitor cover crop growth.	Order plastic and drip tape.
		Order vermicompost and AMF inoculant (if inoculating tips).
		Schedule compost delivery for late-August (if applying prior to bed raising).
August	Mow cover crop; send tissue analysis.	Order ryegrass seed for alleyways.
	+ Stick tips for plug establishment/ (inoculate media).	
	Incorporate cover crop residue.	
	Incorporate compost (Option 2).	
September	+ Shape beds, lay plastic, and install irrigation lines.	
	+ Plant ryegrass in alleyways prior to punching holes; install deer fence.	
October	+ Transplant strawberry plants to the field; irrigate well after transplanting for two to three days.	
November	Scout for spider mites.	Ensure that you have row covers, repair as needed.
	+ Remove runners, and dead leaves.	
December		

++This calendar is specific to the piedmont of North Carolina or central Arkansas in a typical climatic year. Scheduling should be adapted to your local conditions++

Long-term Production Practices

For sustainable practices to have a real impact on the long-term sustainability of the farm enterprise — in terms of improving soil physical properties, reducing soil erosion, reducing insect and disease pressure, promoting beneficial insect populations and contributing to the bank of nutrients within the soil – they must be adopted and implemented over the long-term.

Drastic changes in soil health or pest reduction cannot be expected within the first or even second year after a new practice is implemented. However, as strawberry producers continue to increase their production, find new ways to market their farms, and grow their businesses in order to preserve the farm for the next generation, the importance of sustainable production practices that maintain land for the future cannot be forgotten.

Resources

North Carolina Cooperative Extension Strawberry Growers Portal
http://strawberries.ces.ncsu.edu/

Evaluating Nutrient, Soil Health, and Economic Benefits of Compost Additions to Summer Cover Crops for Strawberries in North Carolina (SARE Factsheet)
https://www.southernsare.org/SARE-in-YourState/North-Carolina/State-News/Cover-Crops-Research-Across-the-Southern-Region/Evaluating-Nutrient-Soil-Health-and-Economic-Benefits-of-Compost-Additions-to-Summer-Cover-Crops-for-Strawberries-in-North-Carolina

Economic Viability and Environmental Impact Assessment of Three Different Strawberry Production Systems in the Southeastern United States, (Rysin et al., 2015)
https://pdfs.semanticscholar.org/986d/2b2a062101b6accaeca528dbe24f3d61cb83.pdf

Southeast Regional Strawberry Integrated Pest Management Guide
http://www.smallfruits.org/SmallFruitsRegGuide/index.htm

Guide to Strawberry Insect Pests
http://entomology.ces.ncsu.edu/strawberry-insects/

Southeast Regional Strawberry Plasticulture Production Guide
https://smallfruits.org/files/2019/06/2005culturalguidepart1bs1.pdf

Video: The Use of Beneficial Soil Inoculants for Strawberry Tip Production
https://www.youtube.com/watch?v=-dET8r3bhdQ

Southern Region Small Fruit Consortium
https://smallfruits.org/crops-strawberries/

Crop Rotation On Organic Farms- A Planning Manual (SARE)
https://www.sare.org/Learning-Center/Books/Crop-Rotation-on-Organic-Farms

National Organic Program
http://www.ams.usda.gov/AMSv1.0/nop

Cornell Soil Health Assessment Training Manual, 2nd Edition (2009)
http://www.css.cornell.edu/extension/soil-health/manual.pdf

Cover Crops Basics - Training for Arkansas Producers, Funded by Southern SARE
https://www.uaex.uada.edu/sarecovercrop

Managing Cover Crops Profitably, 3rd Edition SARE Publication Available for free download:
http://www.sare.org/Learning-Center/Books/Managing-Cover-Crops-Profitably-3rd-Edition

Soil, Nematode, Compost, and Plant Tissue Testing Agencies in the South

National Directory of Laboratories. National Plant Diagnostic Network
http://www.npdn.org/

Laboratories Listed By State

ARKANSAS

University of Arkansas Soil Testing and Research Laboratory
P.O. Drawer 767
Marianna, AR 72360
Phone: 870-295-2851 Fax: 870-295-2432 / Email: soiltest@uark.edu
https://aaes.uark.edu/technical-services/soil-testing-and-research-laboratory/

Arkansas Nematode Diagnostic Laboratory
362 Highway 174 North
Hope, AR 71801
Phone: (870) 777-9702, Ext. 128 or 119 / Email: agreer@uaex.edu
https://aaes.uark.edu/technical-services/nematode-diagnostic-laboratory/

FLORIDA

University of Florida Analytical Services Laboratories
Soil Testing Laboratory
Accepts samples from Florida residents only
2390 Mowry Road
Wallace Building #631
P.O. Box 110740
Gainesville, FL 32611-0740
Phone: 352-392-1950 Ext. 221 / Email: soilslab@ifas.ufl.edu
http://soilslab.ifas.ufl.edu/

GEORGIA

Extension Nematology Laboratory
2350 College Station Rd.
Athens, GA 30602
Dr. Ganpati Jagdale, gbjagdal@uga.edu
Phone: 706-542-9144
http://plantpath.caes.uga.edu/extension/clinic.html

NORTH CAROLINA

NC Dept. of Agriculture and Consumer Services Agronomic Division
4300 Reedy Creek Road
Raleigh, NC 27607-6465
Phone: 919-733-2655 Fax: 919-733-2837
http://www.ncagr.gov/agronomi/

NC Plant Disease & Insect Clinic
1227 Gardner Hall
100 Derieux Place
Raleigh, NC 27607
Disease Problems: 919-515-3619 / Insect Related: 919-515- 9530
General Questions: plantclinic@ces.ncsu.edu
http://www.cals.ncsu.edu/plantpath/extension/clinic/index.html

A&L Eastern Laboratories
2850 Daisy Lane
Wilson, North Carolina 27896
Phone: (252) 206-1721 / Email: supportale@aleastern.com
http://www.al-labs-eastern.com/

SOUTH CAROLINA

Clemson University Agricultural Service Laboratory
171 Old Cherry Road, Clemson, SC 29634
Phone: 864-656-2068
https://www.clemson.edu/public/regulatory/ag-srvc-lab/

Clemson University Nematode Assay Laboratory
511 Westinghouse Road
Pendleton, SC 29670
Phone: (864) 646-2133 / Email: nemalab@clemson.edu
http://www.clemson.edu/plantclinic

TENNESSEE

University of Tennessee Soil, Plant & Pest Diagnostic Center
5201 Marchant Drive
Nashville, TN 37211-5112
Phone: (615) 832-5850 / Email: soilplantpestcenter@tennessee.edu
https://ag.tennessee.edu/spp/Pages/default.aspx
Nematode Services / Phone: (615) 832-6802; Email: tstebbin@utk.edu

VIRGINIA

Virginia Tech Soil Testing Laboratory
Phone: 540-231-6893
http://www.soiltest.vt.edu/

Nematode Assay Laboratory
115 Price Hall
170 Drillfield Drive
Virginia Tech
Blacksburg, VA 24061-0331
Phone: (540) 231-4650 Fax: (540) 231-7477
https://www.ppws.vt.edu/extension/nematode-laboratory.html

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NC State University Strawberry Growers Portal.

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USDA, Economic Research Service. U.S. Strawberry Industry (95003). Accessed on 5/4/2014. https://usda.library.cornell.edu/concern/publications/8s45q876k?locale=en.

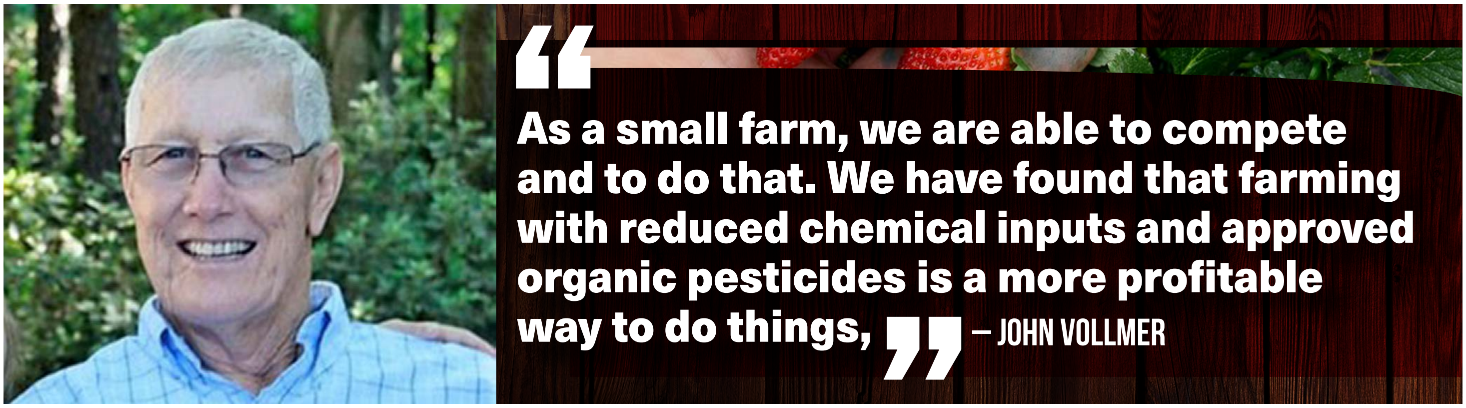
USDA, National Institute of Food and Agriculture. Legal Definition of Sustainable Agriculture. Last updated: March 18, 2009.

Acknowledgements

Dedicated to John Vollmer

1942 - 2014

An innovative strawberry grower and longtime friend of sustainable agriculture.



Thanks to the Vollmer Family for the use of the picture of John Vollmer.

All other photos taken by Amanda McWhirt unless otherwise noted.

Contacts for nematode testing compiled in part by Terrence L. Kirkpatrick.

A very special thanks to Debby Wechsler and Mary Helen Ferguson for contributing their superb editing talents and insightful recommendations to this publication during 2015. Debby has served both the North Carolina Strawberry and North American Raspberry and Blackberry industries for over 20 years. Mary Helen is a former NC State University graduate student and North Carolina Cooperative Extension Agent. She completed her PhD at Louisiana State University and is now an Associate Extension agent at LSU.

This project was originally funded by a grant from the Walmart Foundation and administered by the University of Arkansas System Division of Agriculture Center for Agricultural and Rural Sustainability.

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Published by

North Carolina Cooperative Extension Service
And University of Arkansas Cooperative Extension Service
