**EVALUATION OF CROP ROTATION FOR HIGH VALUE COOL SEASON HORTICULTURAL CROP PRODUCTION IN ORGANIC AND SUSTAINABLE SYSTEMS**

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**Cool Season Crop Rotation Final Report**

**Summary**

This three-year study evaluated two vegetable rotations of cool season crops and warm season cover crops for their productivity, economic viability, disease management, and soil building potential. Crop yield and economic profitability were closely linked in that the crops that had good yields also were most profitable. The most profitable crops were onions and lettuce. To a lesser extend broccoli and potatoes were also profitable. Strawberries did well the first year, but yields and profits declined in years 2 and 3. Carrots, bush beans, and southernpeas all had little or no profits. There was little effect of either rotation on soil organic matter. Cover crops did not result in notable increases in organic matter and there was a net loss of labile nitrogen. Longer term work needs to be done to assess soil management strategies. As expected from what is observed in cool season organic vegetable production in Georgia, disease pressure was low.

**Introduction**

The purpose of this project was to evaluate crop rotation systems for high value cool-season vegetables in terms of effects on soil health and diseases as well as to develop an economic model to determine the rotation with the highest return at the lowest risk in the southeastern United States.

There are two important trends with food in the United States. One is the increased demand for organic produce and the other is the interest in local food. The intersection of these trends has increased the demand for organic produce grown in the Southeast. Institutions such as Emory University have made a commitment that 75% of their food will be sustainably grown or locally sourced by 2015. Large grocery chains are looking for suppliers of local organic produce. This increased demand has sparked an interest among conventional vegetable growers about organic production techniques and put increasing demand on existing organic growers. Discussions with organic growers, particularly in Northeast Georgia indicate demand exceeds supply. The challenge is to increase organic production in the Southeast in the face of the higher disease, insect, and weed pressure typically experienced due to long growing seasons under hot, humid conditions. Crop rotations are needed to help growers increase profits and reduce risk, but there is relatively little research based information available on optimal production systems for the Southeast. Growers themselves have identified the need for better production information and the need for research-based information on crop rotations.

Organic farms in the Piedmont area tend to be smaller in size and have developed niche markets around larger population centers; however, there are opportunities for mid-scale organic production to meet wholesale demand in this area. Coastal Plain farms are medium to large in size and have more traditional markets. South Georgia is one of the largest fresh vegetable production regions in the country because of the mild climate, loamy sand soils, and abundance of irrigation water yet there is very little organic production. Barriers to production in this region include soils, the mild climate, and a well-developed extant market for conventional fresh vegetables. The soils have many advantages for vegetable production. These soils drain quickly and warm early in the spring, which is conducive to early production. The soils, however, have little or no organic matter and little intrinsic fertility requiring large amounts of fertilizer to be productive. The mild climates mean that diseases, insects, and weeds can be problematic year round.

An example of an emerging organic market in South Georgia is Vidalia onion production. The economic model for these growers has been based on a single crop. They have relied on this single crop for the bulk of their revenue. In addition, because of fixed irrigation systems these growers have limited opportunities to rotate crops. Because of these issues, they have been reluctant or unable to engage in a more systematic approach to production. It is estimated that 300-400 acres of Vidalia onions were produced organically, which represents close to 15% of total organic acres in Georgia. These growers have not fully realized the opportunity they see in organic production. Developing an integrated system of high value crops that could be grown in rotation would help these growers overcome these limitations by allowing them to grow high value crops in every rotation cycle. Vidalia onions may represent a unique opportunity to develop production practices that medium-size conventional growers can adopt to develop organic markets. Showing conventional growers systems of production that they can adopt is a key to expanding sustainable production.

There is also significant production in the Southeast of strawberries (i.e. Plant City/Dover, FL area), carrots in south central Georgia, brassicas throughout the region particularly in the Tifton, GA area, northeastern GA and NC, potatoes in the Hastings, FL area, and onions are produced in other regions such as NC (salad onions) and north FL (St Augustine Sweets). These regions could benefit economically by adopting a system of production that included all of these crops. Growers in these regions already have expertise in at least one of the crops, which should increase their willingness to adopt organic production practices.

Based on previous research on component crops in the proposed systems, information is also needed to improve integrated management of plant pests. An important economic aspect of an effective integrated management system for organic production is adequate disease suppression. Studies on factors related to the use of crop rotations and cover crops have shown beneficial effects on diminishing disease severity (% host tissue infected) and incidence (number of plants infected) (Koike et. al., 2000; van Bruggen and Temorshuizen, 2003). Alternating non-host crops after a host crop can lessen the season to season survival of host-specific pathogens. Increasing soil organic matter not only improves plant health, but the increase in soil microbial diversity reduces the ability of soil-borne pathogens to survive and infect.

Nematodes are a major constraint to crop production in the Southeast with some species, such as the root knot nematode (*Meloidogyne* spp.) and the sting nematode (*Belanolaimus longicaudarus*), having wide host ranges. However, rotational crops have been found to reduce nematode populations. Sunn hemp and Southernpeas used as a summer rotation in Florida tomato plots were found to suppress plant pathogenic nematodes while enhancing beneficial nematodes (Wang et al., 2002).

Organic production systems must also build and maintain soil quality and fertility. Cover crops are an important component of this, but they need to be chosen carefully to fit into overall management objectives. Constructing rotations that meet multiple objectives of profitability, building soil and suppressing pests can be a challenge and growers must be shown the economic benefit of these rotations. Current organic vegetable budgets tend to focus only on one crop. The purpose of this project is to take a systems approach to evaluate different crop rotations to produce high value certified organic vegetables that conventional as well as traditional organic growers can adopt.

**Objectives/Performance Targets**

The overarching objective of the study is to evaluate the profitability and production characteristics of two cool-season vegetable crop rotations in the Piedmont and Coastal Plain physiographic regions. The research will be conducted at University Research and Education Centers that have certified organic land in each region.

Objective 1 - Develop an econometric model to evaluate the profitability of the two rotations.

Objective 2 - Evaluate changes in plant nutrient status, crop yield and quality in the two crop rotations. Data on harvest date, yield, and graded yield will be collected for all treatments. Tissue samples will be collected to evaluate plant nutrient status at critical growth stages.

Objective 3 - Evaluate changes in soil quality in the two crop rotations. Changes in soil quality will be measured using total carbon and nitrogen, potentially mineralizable nitrogen, active carbon, pH, and Mehlich extractable P, K, Ca, Mg, and Zn.

Objective 4 - Determine disease incidence in the two rotations and on the specific crops grown.

Objective 5 - Evaluate the research and potential impact, and disseminate results.

**Materials and Methods**

The rotation research was conducted on certified organic land at the UGA Horticulture Farm in Watkinsville, GA (Piedmont).

In the first rotation strawberries were planted in the fall (September) and grown through the winter for harvest in the spring. Following strawberry harvest, which is finished in May, soybeans were planted as a summer crop. This was followed in late summer/early fall with oats/Austrian winter pea, which was followed in late winter with potatoes, which was harvested in May. This was followed by a summer crop of sunhemp, which was followed by onions planted in September for Harvest in April and May.

The second rotation began with a broccoli. This was transplanted in September for harvest in November/December was followed by sugar snap peas in January with a sudax/iron clay pea mix planted in April to grow over summer. This was followed by carrots sown in September/October for harvest in January/February, which was originally followed by sugar snap peas. Sunhemp was planted in May to grow over summer at which time onions will be planted in December for harvest the following April/May. This was followed by millet over the summer.

The experiment consisted of 6 treatments, 3 entry points for each rotation. For example in the first year in the fall with rotation 1, experimental units of strawberries, oats/Austrian winter peas, and onions were established in a randomized complete block design of 3 replications at the Horticulture Farm and 4 replications at the Vidalia Farm.

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| Table 1. The two rotations with the different entry points to be evaluated in this study.\* |
| Rotation A |
| STR | SOY | OAP | POT | SUN | ONO | SOP |
| OAP | POT | SUN | ONO | SOP | STR | SOY |
| ONO | SOP | STR | SOY | OAP | POT | SUN |
|  |  |  |  |  |  |  |
| Rotation B |
| BRA | SUG | SUX | CAR | SUG | SUN | ONO | MIL |
| CAR | SUG | SUN | ONO | MIL | BRA | SUG | SUX |
| ONO | MIL | BRA | SUG | SUX | CAR | SUG | SUN |

\*STR – strawberries, SOY – soybeans, OAP – oats/Austrian winter peas, POT – potatoes, SUN – sunhemp, ONO – onions, BRA – brassicas, SUG – Sugar snap peas, SUX – sudax, CAR – carrots, MIL - millet

These rotations were discussed and modified based on experience and input from the grower advisory team. For example, sugar snaps were dropped from Rotation B based on our experience in year 1 and grower input that the time frame for getting carrots harvested and then sugar snaps in was too tight.

Objective 1 – Economic analysis was accomplished by collecting and compiling all the case study data from the study. The case study data was first used to develop a traditional risk-rated enterprise budget for each rotation technique. The field trials were a source of information on yields, variable planting and overhead costs which were integrated into a risk-rated enterprise budget model. The enterprise budget attempts to control for incomplete knowledge concerning input and output factors of production by systematically organizing data into a framework conducive to more accurate decision making (Fonsah and Hudgins, 2007; Fonsah and Torrance, 2008).

Objective 2 - Data on harvest date, yield, and graded yield were collected for each vegetable crop. Tissue samples were collected to evaluate plant nutrient status at critical growth stages.

Objective 3 –Changes in soil quality were measured using total carbon (C) and nitrogen (N), potentially mineralizable nitrogen, 3-day respiration, active C, pH, and Mehlich extractable P, K, Ca, Mg, and Zn. Fertility was based on soil test recommendations.

Soil samples for the analyses listed above were collected in the fall of each year from 0 to 15 cm. Total C and N was measured by combustion. Potentially mineralizable N was measured using a hot and cold KCl extraction (Gianello and Bremner, 1986). Active C was measured using method developed by Weil et al. (2003). This carbon fraction has been shown to more quickly respond to management changes than total C. Soil pH was determined on a 2.5:1 soil:water paste (Thomas, 1996). The Mehlich I extraction is a weak double acid extraction used for fertility recommendations in Georgia. In addition, soil samples (0-15 cm) was collected in the spring and analyzed for potentially mineralizable nitrogen and active carbon. Results from the potentially mineralizable nitrogen and Mehlich I analyses were used to guide the fertility recommendations. Fertilizer sources included legumes in the rotations, and a commercial organic, pelleted animal byproduct fertilizer During year 3, we began testing a new cover crop nitrogen production tool – MinImob. The tool uses soil and cover crop characteristics along with local weather station data to predict the amount of nitrogen released over the growing season. The prediction from the tool was compared to estimates of nitrogen from the literature.

Objective 4 – High value cool-season crops were evaluated for incidence and severity of the major pathogens that constrain organic production in order to assess the beneficial effects of cover crops on disease suppression. The following major diseases were assessed: *Sclerotium rolfsii* and other root pathogens on carrot (Smith, et al. 1988), *Botrytis cinerea* and *Colletotrichum acutatum* on strawberry (Chandler, et al. 2006), *Botrytis spp.* and *Burkholderia spp.* on onions (Adam, 2006; Boyhan et al., 2006), and *Pectobacterium* *carotovorum* and other soilborne diseases on potatoes (Stevenson, et al., 2001). Any additional diseases causing significant damage were assessed and identified, with particular attention paid to the incidence of important soilborne pathogens that have the ability to infect multiple crop families, such as *Rhizoctonia*, *Sclerotium*, and *Pectobacterium spp*. High value cool-season crops were evaluated during the growing season for disease incidence (number of plants with symptoms) and severity (% of plant tissue damaged) and samples were collected as needed for pathogen identification. At harvest, the entire crop was evaluated for incidence and severity of disease .Confirmation of pathogen identity was based on visual, cultural, serological, and or DNA-based techniques as appropriate for the different pathogen groups.

Strawberry fruit was evaluated for fruit rot caused by *C. acutatum* and B*. cinerea* by determining the percentage of fruit from each treatment exhibiting disease symptoms. Onion foliage was evaluated for incidence (number of plants infected) and severity (visual assessment of % leaf area infected) from Botrytis leaf blight. A preliminary diagnosis of the fungal pathogens associated with leaf and fruit diseases was made by visual examination for characteristic symptoms and pathogen structures. Pathogen identity was confirmed from a subset of infected fruit and leaves after isolation onto media using standard methods (Dhingra and Sinclair, 1985). Harvested potatoes tubers and carrots roots were examined for the incidence and severity of disease lesions. Strawberry roots of individual plants within each treatment were rated for incidence of root rot by examining a random sampling of root segments for symptoms (Copes and Stevenson, 2008). The identity of soilborne fungal pathogens was confirmed using standard methods. Roots crops were assessed for the incidence of bacterial soft rots caused by *Pectobacterium carotovorum* and *Burkholderia* *gladioli pv. alliicola* and the identity was confirmed by using standard methods for plant pathogenic bacteria (Schaad et al., 2001). Pathogenic nematode populations were enumerated in soil samples at harvest of each high value cool-season vegetable and cover crop to evaluate the suppressive effects of cover crops and rotation. Soil samples were collected based on the recommendations of the CAES Plant Nematode Laboratory (www.ciids.org/nars/NemaGuide.pdf). One bulked soil sample from each experimental unit consisting of three subplot soil cores, was submitted for evaluation of root knot nematode (*Meloidogyne* spp.) and sting nematode (*Belanolaimus longicaudarus*) populations.

Objective 5 –Results were presented at regional and national horticultural conferences, and growers’ meetings. The study was integrated into the training for the Organic Production Team through field days. Results will be posted on the Sustainable Agriculture webpage ([**www.SustainAgGa.org)**](http://www.SustainAgGa.org)), The Watkinsville, GA site was used as part of the UGA Organic Agriculture Certificate Program, and graduate student support will enhance sustainable agriculture learning opportunities. We expect several peer-reviewed publications to be developed and presented at regional conferences. Details of this approach are in the Information Dissemination and Outreach Plan.

**Results and discussion/Milestones**

Initial soil tests indicated that the ph was near neutral, soil test P levels were high and soil test K levels were low. Consequently we used a Nature Safe 10-2-8 for the primary fertility source to avoid over applying P. Potassium levels were supplemented with KSO4 as needed. A nitrogen credit was given for cover crops based on values in the literature (Table 2).

There were no significant changes in the overall characteristics of soil in the study due to the different rotations. Soil pH ranged from 6.7-6.8 over the study. There were no differences in soil test phosphorus, which ranged from 138-181 mg/kg and remained in the very high range (>75 mg/kg) throughout the study.. Phosphorus was added at a rate of 10-35 lbs P2O5/ac each year.

There were no differences in potassium levels between the different rotations. Overall K levels decreased during the study from a medium level to a low level (<120 mg/kg). Potassium was over applied on the strawberries, broccoli, lettuce, while under applied on the potatoes based on soil test recommendations (Table 2).

In both rotations A and B, there was a net loss of potentially mineralizable nitrogen of about 7-8 mg/kg (Figure 1). . There was little change in total soil carbon over the three year period and no difference between rotations (Figure 2). This is not surprising because total C in the soil is known to change very slowly in response to management. There was an increase of 100-120 mg/kg in active carbon over the duration of the study; however, there was no difference between the two rotations.(Figure 3). Active C is known to respond quickly to management changes.

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| Table 2. Soil test based fertilizer recommendations and actual nutrient application rates for vegetable crops and cover crops. |
|  | Planting | Nitrogen | Phosphorus | Potassium | Cover Crop N Credit |
| Crop | Date | Applied | Recs | Applied | Recs | Applied | Recs |  |
| Rotation A |   | lbs/ac |
| Strawberries | Sept. | 100 |  90 |  20 |  0 |  80 |  70 | 10 – S. peas |
| Bush Beans | June |  90 |  80 |  18 |  0 |  70 |  70 |   |
| Oats/AWP | Oct |  0 |   |  0 |   |  0 |   |   |
| Potatoes | March |  90 | 120 |  18 | 70 | 127 | 150 | 30 – Oats/AWP |
| Sunnhemp | June |  0 |   |  0 |   |  0 |   |   |
| Onions | Dec |  30 | 120 |  6 | 45 |  91 |  90 | 90 - Sunnhemp |
| Southern Peas | June |  40 |  40 |  8 |  0 |  31 |  40 |   |
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| Rotation B |  |  |  |  |  |  |  |  |
| Broccoli | Sept | 174 | 150 |  35 | 75 | 206 | 150 |   |
| Lettuce | Feb |  68 |  75 |  14 |  0 | 136 |  90 |   |
| Sudax/Iron clay peas | June |  0 |   |  0 |   |  0 |   |   |
| Carrots | Sept |  54 |  90 |  11 | 30 | 121 | 120 | 45 – Sudax/ Southernpeas |
| Sunnhemp | June |  0 |   |  0 |   |  0 |   |   |
| Onions | Sept |  30 | 120 |  6 | 45 |  91 |  90 | 90 - Sunnhemp |
| Millet | June |  0 |   |  0 |   |  0 |   |   |
| Rotation A: Total N credit - 130 lbs/ac.Rotation B: Total N credit – 135 lbs/ac. |

Figure 1. Average changes in mineralizable nitrogen over three growing seasons in two cool-season vegetable rotations at Watkinsville, Georgia. The error bars represent one standard deviation.

Figure 2. Average changes in total carbon over three growing seasons within two cool-season vegetable rotations at Watkinsville, Georgia. The error bars represent one standard deviation.

Figure 3. Average changes in active soil carbon over three growing seasons between two cool-season vegetable rotations at Watkinsville, Georgia. The error bars represent one standard deviation.

Generally there was low disease pressure in the study across all crops grown. There was a minor infection of Botrytis on onion foliage that did not affect yield. There are several species of Botrytis with *B. squamosa* causing Botrytis leaf blight in onions. Late in the season, approximately one month previous to harvest, purple blotch (*Alternaria porri*) occurred on the onions in both 2012 and 2013. This pathogen occurs during the warm wet weather of late spring. No significant differences were seen between rotations (figure 4).

In 2012, lettuce drop caused by *Sclerotinia sclerotiorum* resulted in a disease incidence of 5 to 7% (Table 3). This disease has a wide host range and form sclerotia in the soil that can persist for relatively long periods of time. In 2012, the mild wet spring weather favored development of the disease on lettuce. Crop rotation to non-hosts and maintaining soil moisture during periods of high soil temperature can reduce the sclerotia found in the soil thus reducing the potential for future infections. This pathogen was also found on the bean crop later in the 2012 season although losses were not significant.

In 2013, but not in the other two years, beans were found to be infected with southern blight (*Sclerotium rolfsii*). In 2013 there was abundant rainfall during the summer months, making for ideal disease conditions. This can be a difficult pathogen to control because of long lived sclerotia in the soil and the wide host range. Crop rotation to non preferred hosts and cover crops, combined with adequate soil organic matter and moisture management to keep the crowns of plants dry, are the best methods for organic management. Interestingly, the affected beans were only in one of the subplots on the edge of the rotation study while the other subplots which were surrounded by other crops were not affected. This demonstrates the microclimate effects that can have an effect on disease suppression.

Root knot nematode (RKN) populations did increase from undetectable levels in one section of the field over the course of the study, although they did not consistently reach damaging levels in any one plot. Nematode sampling was conducted before crop harvest in January, June, and September. Detection of significant populations occurred in late summer 2012 after strawberries/bush bean crops and in late summer 2013 after the lettuce/sudax crops. Sunnhemp appeared to suppress these populations although a longer study would be needed to see if the increase in nematodes was a long term trend. RKN can be a major problem in organic vegetable production in the southeast. Adequate incorporation of high-quality soil organic matter combined with proper selection of rotations and cover crops can suppress RKN populations and other soil borne diseases, and this should be a consideration when scaling up organic production. Further investigations are needed to develop effective methods for suppressing RKN in organic vegetable production under southeastern conditions.

The strawberry leaves were infected with leaf spot (*Mycosphaerella fragariae*) during the fall and winter, but the disease was confined to older leaves and was not severe enough to cause any significant losses. There was an occasional low incidence of fruit rot from Botrytis after periods of rain but no evidence of root rot. The strawberries were remarkably free of disease.

Potatoes had some wireworm damage the first year, but no significant disease problems. Finally there were no significant diseases on the carrots.



Figure 4. Purple blotch disease on onion in 2012 (Rating: 1-5, 1-few lesions, 5-severe infection).

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| Table 3. Incidence of Sclerotinia Disease on Lettuce, 4/17/2012. |
| Rep # | # of infected plants | % infected plants |
| 1 | 20 | 5 |
| 2 | 28 | 7 |
| 3 | 23 | 6 |

In both rotations, A and B, onions did as well or better than the average county yields for onions (Figures 5 & 6). Onions were grown on plastic with all the fertilizer preplant incorporated prior to bedding and then applying the plastic mulch. The plastic mulch offers several advantages including weed control, conservation of nutrients (less prone to leaching). Of course plastic mulch is a non-biodegradable product that is manufactured from non-renewable petroleum. There was also a significant reliance on the previous cover crop residue for nitrogen (Table 2). The sunnhemp cover crop appeared to supply about 90 lbs N/ac. Our modelling of N release in the 3rd year indicated both the soil and the cover crop were significant sources of N. Finally the relatively high onion yields may be partially due to the fact they were grown outside the traditional onion belt of southeast Georgia.

Although onions did well in comparison to average farm gate yields, the onion sizes were generally smaller than what is traditionally produced in conventional production. Most of the onions were in the medium size class (2-3 inches), while in conventional onions most are in the jumbo size (≥3 inches) (Figure 6). Conventional onion production will have approximately 80% of the onions in the jumbo size class. It should be noted that there is a consumer preference for the medium size onion, apparently because this is the right size for cooking without leftover onion pieces.

Strawberries on the other hand did not do very well with yields going down over the course of the three years. In all years yields were significantly lower than the farm gate estimates (Figure 5). The relatively high yields the first year may have been due to previous soil management.

Bush bean yields were modest at best with the first year’s yields a complete loss. In the first year, the variety used was ‘Yellow Wax Bean’, which did poorly and was eventually abandoned. In subsequent years, the grower recommended green bean variety ‘Provider’ was used.

The potato variety used in this study was ‘Yukon Gold’ a yellow fleshed variety. Yields improved from one year to the next, but never reached the level of reported farm gate yields.

Southernpeas were included in rotation A because they offered the benefits of a summer legume cover crop and the potential as a fresh market vegetable crop. The variety chosen was ‘Pink Eye Purple Hull’, a popular and widely available southernpea variety. Unfortunately, there were no yields to report in years 1 or 3 and the year 2 yields were modest. Part of the difficulty with yields in this crop was the short time period between when the onions were harvested and the followed strawberry crop needed to be planted.

In year 1, broccoli was grown on plastic mulch to minimize weed problems. In years 2 and 3 the crop was grown on bareground since the winter weed pressure was minimal. Yields improved over the course of the study with the third year yields equivalent to the reported average farm gate yields.

Lettuce production overall was successful in all three years of the study with yields better than double the average farm gate yields. There is not much conventional lettuce production in Georgia; however, it is a popular crop among organic growers. In the first year, the lettuce was grown on plastic mulch behind the broccoli. This practice was abandoned in subsequent years because the plastic ended up with too many holes (punched for the broccoli and then for the lettuce). The lettuce variety that was used was ‘Winter Density’, which was pelleted with a clay coating. The pelleting made the seed easier to handle for transplant production.

Carrots yields were disappointing overall. They are a difficult crop to grow organically because they have small seed, are direct seeded, and are slow growing. Weed control is particularly difficult because of the close spacing and slow growth. Weeds must be controlled very close to the plants particularly during early growth, which is very time consuming and expensive. Yields were less than half the average farm gate values for Georgia. Carrots yields may have been adversely affected by the previous Egyptian wheat/cowpea cover crop. Eyptian wheat is in the sorghum family and is a locally produced seed. The cover crop was chosen because it has good weed suppression properties and both cowpeas and sorghums may also help reduce nematode pressure, which would be important before a root crop like carrots. However, the Egyptian wheat consistently dominated the cover crop mixture and decomposed slowly. These could have created two negative effects on the carrots. First, the sorghum family can have allelopathic properties, which may have affected seed germination. Second, our modelling of N release in the 3rd year indicated there was N immobilization following the Egyptian wheat/cowpea incorporation. Consequently, we may have had too little N for good carrot production.

Figure 5. Revenue generating crop yields from rotation A at Watksinsville , Georgia, including annual yields (2011-13) and average yields from the 2012 Georgia Farm Gate Value Report.

Figure 6. Revenue generating crop yields from rotation B at Watksinsville, Georgia, including annual yields (2011-13) and average yields from the 2012 Georgia Farm Gate Value Report.

Figure 7. Distribution of onion yield at Watkinsville, Georgia by size class (smalls <2 inches, mediums ≥2 inches & <3 inches, jumbos ≥3 inches, and Colossal >4 inches).

In conclusion, yield results were mixed in this study. Onions definitely did well in all years consistently producing good yields. This was also true for lettuce. Broccoli and potatoes did reasonably well and would be good choices for organic production. Strawberries were inconsistent with good yields in the first year, but subsequent years were disappointing. Beans, southernpeas, and carrots, based on this study, did not perform well in these rotations.

**Impacts and Results/Outcomes**

This research certainly has shown the potential for several crops including onions, lettuce, broccoli, and potatoes. Surprisingly the study was less successful with several crops including strawberries, carrots, beans, and southernpeas. It should be emphasized that this work was with small plots in a research setting. There probably are greater efficiencies with increased size that were not realized in this research.

These rotations can be a good choice for mid-scale organic growers. Although more land is used, there are several alternative crops that can be profitable and used in a successful cool season rotation. Rotation costs do go down on average as the scale of the operation increases. Cover crops costs, however, are not inconsequential. Cover crops in rotation are important because of their contribution to soil fertility, managing soil diseases and controlling weeds. Table 4 lists the costs of various cover crops used in these rotations. These amounted to $6,339/acre over the course of the experiment for rotation A and $6,283/acre for rotation B.

Cover crops in some cases were very successful at providing the necessary nutrients for the subsequent crop. For example sunnhemp supplied 75% of the onion nitrogen requirement with very good results.

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| Table 4. Cost per acre for various cover crops or cover crop combinations used in these two rotations. |
| Cover crop | Rotation A | Rotation B |
| Oats/Aust. Winter Peas | $2,147 |  |
| Southernpeas | $1,996 |  |
| Sunnhemp | $2,196 | $2,196 |
| Sudan-sorghum/southernpeas |  | $2,306 |
| Millet |  | $1,781 |

**Economic Analysis**

Table 5 depicts a summarized breakdown of key economic parameters extracted from the various enterprise budgets developed from the following organic rotation crops: broccoli, carrot, lettuce, onion, potato, strawberry, bush beans, and southern peas, using field data collected by UGA Scientists at the Durham Horticulture Farm, Watkinsville, Georgia. The economic parameters include pre-harvest variable cost (P-HVC), total harvesting and marketing cost (THMC), total variable cost (TVC), total fixed cost (TFC), total revenue (TR) and net returns and/or profit*(𝜋*). Amongst the crops in the 2011 (year 1) rotation, broccoli, carrot, bush beans and southern peas were the least favored in terms of net returns. On the other hand, onions were the most favored with a net return of $11,237 in rotation A and 11,156 in rotation B. Strawberry and lettuce were the 2nd and 3rd favorites with net returns of $10,995 and $4,567, respectively.

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| Table 5: Economic summary analysis of the crop rotation based on year 1 data, Durham Horticulture Farm, Watkinsville, GA, 2011. |
| Crop | *Pre-harvest variable costs**(P-HVC)* | *Total Harvest and marketing (THMC)* | *Total Variable costs (TVC)* | *Total Fixed costs (TFC)* | Tptal costs(TC) | Total Return (TR) | Net Profit ( |
| *Brocolli* | $2,807.95 | $1,286.16 | $4,094  | $664.91 | $4,759  | 2,762 | ($1,997) |
| *Carrot* | $2,430.70 | $1,920.60 | $4,351  | $605.92 | $4,957  | 4,756 | ($201) |
| *Lettuce* | $2,761.75 | $4,075.40 | $6,837  | $659.61 | $7,497  | 12,064 | $4,567  |
| *Onion Rot A* | $4,771.60 | $3,035.64 | $7,807  | $715.74 | $8,523  | $19,760  | $11,237  |
| *Onion Rot B* | $4,771.60 | $3,020.88 | $7,792  | $715.74 | $8,508  | 19,664 | $11,156  |
| *Potato* | $3,643.19 | $1,583.75 | $5,227  | $788  | $6,015  | 6,655 | $640  |
| *Strawberry* | $6,478.09 | $2,334.00 | $8,812  | $1,216.16 | $10,028  | 21,023 | $10,995  |
| *Bush Beans*  | $1,680.05 | $0  | $1,680  | $493.32 | $2,173  | $0  | ($2,173) |
| *Southernpeas* | $1,443.40 | $0  | $1,443  | $523  | $1,966  | $0  | ($1,966) |
| *\**The number in parenthesis represents a negative net return per acre. |

Further, a summarized breakdown of the same key economic parameters is presented in Table 6. Amongst the crops in the 2012 (year 2) rotation, only bush beans exhibited a negative net return of -$101 per acre. On the other hand, onions still maintained its lead position with a net return of $18,406 in rotation A and 18,887 in rotation B. The net return for lettuce increased to $11,790 per acre, i.e. 2.5 times higher than year 1 whereas the net return for strawberry decreased to $3,541

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| Table 6: Economic summary analysis of the crop rotation based on year 2 data, Durham Horticulture Farm, Watkinsville, GA, 2012. |
| Crop | *Pre-harvest variable costs**(P-HVC)* | *Total Harvest and marketing (THMC)* | *Total Variable costs (TVC)* | *Total Fixed costs (TFC)* | Total costs(TC) | Total Return (TR) | Net Profit ( |
| *Brocolli* | $2,807.95 | $1,869.92 | $4,678  | $664.91 | $5,343  | 6,205 | $862  |
| *Carrot* | $2,430.70 | $2,260.10 | $4,691  | $605.92 | $5,297  | 5,596 | $300  |
| *Lettuce* | $2,761.75 | $7,760.30 | $10,522  | $659.61 | $11,182  | 22,971 | $11,790  |
| *Onion Rot A* | $4,980.60 | $4,380.52 | $9,361  | $747.09 | $10,108  | 28,514 | $18,406  |
| *Onion Rot B* | $4,354.20 | $4,354.20 | $8,708  | $747.09 | $9,455  | 28,343 | $18,887  |
| *Potato* | $3,643.19 | $1,605.31 | $5,248  | $788  | $6,036  | 7,844 | $1,807  |
| *Strawberry* | $6,478.09 | $1,735.20 | $8,213  | $1,216.16 | $9,429  | 12,970 | $3,541  |
| *Bush Beans*  | $2,256.05 | $1,504.03 | $3,760  | $579.72 | $4,340  | 4,238 | ($101) |
| Southernpeas | $1,831.24 | $1,032.00 | $2,863  | $516.00 | $3,379  | 4,323 | $944  |

 A summarized breakdown of the same key economic parameters is presented in Table 7. Amongst the crops in the 2013 (year 3) rotation, only strawberry exhibited a negative net return of -$152 per acre. Though the net returns for onions have decreased from year 2 to year 3, onions still maintained its lead position with a net return of $12,646 in rotation A and $13,240 in rotation B. Lettuce maintained its second position with a net return of $11,967 followed by potatoes and broccoli with net returns of $3,508 and $ 3,236 respectively.

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| Table 7. Economic summary analysis of the crop rotation based on year 3 data, Durham Horticulture Farm, Watkinsville, GA, 2013 |
| Crop | *Pre-harvest variable costs* *(P-HVC)* | *Total Harvest and marketing (THMC)* | *Total Variable costs (TVC)* | *Total Fixed costs (TFC)* | Total costs(TC) | Total Return (TR) | Net Profit ( |
| *Broccoli* | $3,423.05 | $2,790.40 | $6,213  | $800.73 | $7,014  | 10,248 | $3,234  |
| *Carrot* | $2,869.97 | $1,984.50 | $4,854  | $671.81 | $5,526  | 6,130 | $604  |
| *Lettuce* | $2,982.89 | $6,775.91 | $9,759  | $692.79 | $10,452  | 22,418 | $11,967  |
| *Onion Rot A* | $5,373.11 | $4,276.80 | $9,650  | $1,050.42 | $10,700  | 23,347 | $12,646  |
| *Onion Rot B* | $5,164.11 | $4,356.00 | $9,520  | $1,019.07 | $10,539  | 23,779 | $13,240  |
| *Potato* | $4,023.39 | $1,740.34 | $5,764  | $844.82 | $6,609  | 10,116 | $3,508  |
| *Strawberry* | $8,402.16 | $1,510.18 | $9,912  | $1,504.77 | $11,417  | 11,265 | ($152) |
| *Bush Beans*  | $2,571.05 | $2,254.84 | $4,826  | $626.97 | $5,453  | 7,111 | $1,658  |

 The net returns by crop and by year are summarized in Table 8. The net return has increased from year 1 to 3 for almost all the crops except for onions and strawberries. The net return for strawberries exhibits a negative trend over the three years. In contrast to other crops, year 1 was the best year for strawberries and year 3 was the worst. Furthermore, the net return for onions was higher in year 2 than in the others two years.

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| Table 8. Summary of net returns for the three years, 2011-2013 |
|  | Net Returns |
| Crop | Year 1 | Year 2 | Year 3 |
| *Broccoli* | ($1,997) | $862 | $3,234 |
| *Carrot* | ($201) | $300 | $604 |
| *Lettuce* | $4,567 | $11,790 | $11,967 |
| *Onion Rot A* | $11,237 | $18,406 | $12,646 |
| *Onion Rot B* | $11,156 | $18,887 | $13,240 |
| *Potato* | $640 | $1,807 | $3,508 |
| *Strawberry* | $10,995 | $3,541 | ($152) |
| *Bush Beans*  | ($2,173) | ($101) | $1,658 |
| *Southernpeas* | ($1,966) | $944 |  |

Table 9 gives the summary of net returns by rotation. The SARE project consists of two rotations (rotation A and B) with three starting points each. The sub rotation 1 had the highest net return for the rotation A. However, the starting point or sub-rotation 2 had the highest net return for the rotation B.

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| Table 9. Net returns by Rotation over the 3 years |
|  | Rotation A | Rotation B |
| 1 | 2 | 3 | 1 | 2 | 3 |
| *Strawberry* | *Oats/Aust.W Peas* | *Onion* | *Broccoli* | *Carrot* | Onion |
| Bush Beans | *Potatoes* | *Southernpeas* | *Lettuce* | *Sun Hemp* | Milet |
| Oats/ Aust.W peas | *Sun Hemp* | *Strawberry* | *Su/C.peas* | *Onion* | Brocolli |
| Potatoes | *Onion* | *Bush Beans* | *Carrot* | *Millet* | Lettuce |
| Sun hemp | *Southernpeas* | *Aots/Aust.Wpeas* | *Sunhemp* | *Broccoli* | Su/C.peas |
| Onion | *Strawberry* | *Potatoes* | *Onion* | *Lettuce* | Carrot |
|  | Bush beans |  |  |  |  |
| Net return | $21,063 | $17,339 | $14,317 | $11,765 | $30,957 | $20,168 |

**Publications/Outreach**

Results from this study have been shared at several venues including the Southeastern Fruit and Vegetable Grower Conference, Southern Sustainable Agriculture Working Group, American Society for Horticultural Crops Annual Conference, American Society of Agronomy International Annual Meeting and Georgia Organics Annual Conference. We are still in discussion and planning on publishing these results.

**Farmer Adoption**

Both onions and lettuce are popular organic crops in Georgia, which were important crops in this study. A recent study by the Center for Agribusiness and Economic Development – ***The Local Food Impact:What If Georgian’s Ate Georgia Produce*** – indicated that Georgian’s consume much more lettuce than is grown in the state (utilization gap of 284,947,724 lbs). This study has spurred interest in lettuce production and our study indicates that lettuce can be grown profitably. Consequently, we expect to see increased lettuce production in the state. Further work needs to be done with many of these crops to validate their profitability, but our study indicates that several of these crops can be grown profitably for wholesale market. This is important because many smaller grower believe they can only be profitable through direct sales. Finally, in our presentations at farmers meetings, there was great interest in rotation based on cool season crops rather than the traditional summer crops. Conversations with farmers indicate that the mid-scale, cool-season wholesale production model or parts of this model, may be a way for them to profitably expand their operations. The average net returns over the three years of $17,573 for Rotation A and $20,963 for Rotation B are promising.

**Areas Needing Additional Study**

The rotations could be improved. Timing is critical in organic production and rotations have to be flexible to accommodate different growing conditions in different years. We did not see organic matter increase in the soil during this study, which may be partially a function of the short duration of the study (3 years) and the location here in the South with mild winters and continuous oxidation. These conditions require high biomass cover crops to maintain and replenish soil C. Replacing the millet with a higher biomass legume or legume grain mixture might be a better option.More work needs to be done on tools for nitrogen management with cover crops, so that farmers can better predict N replacement. Longer term experiments and bigger plots would be helpful in these areas and to better evaluate profitability in a more realistic setting. In addition, winter production does have a higher risk with very cold winters. We saw this when we tried to extend the study to year four and had a near total crop loss for most of the cash crops. This may or may not be problematic long term. Further work is needed to examine the long term effects of intensive organic vegetable production on root knot nematode populations and development of cultural methods to suppress harmful nematode populations under southeastern growing conditions.

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