This USDA ARS Areawide project was funded for 2011-12 ($62,000) to demonstrate and improve the performance and consistency of next-best chemical alternatives to methyl bromide in at a large scale trail at FSGA and at two other grower field demonstration trials. Alternative chemicals evaluated within these trials include individual and or combined uses of chloropicrin, and 1,3-dichloropropene with use of appropriate herbicide(s). A diversity of drip fumigants were also evaluated for pest control efficacy, strawberry yield enhancement, and as a potential risk mitigation tactic to reduce buffer zone distances and overall personal protective equipment requirements which were being proposed by EPA. Secondary objectives were to evaluate the feasibility of using two drip tapes per bed rather than one to enhance efficacy and yield of methyl bromide chloropicrin and of other different drip applied fumigants; and use of a high barrier, semi-impermeable mulch film (Pliant Blockade) to reduce emissions and soil fumigant field application rates and to compare crop yield and pest control efficacy of methyl bromide alternatives. A final objective was to evaluate the performance of drip applied fumigants into beds being cropped for the second time to strawberry (double cropping) with as many as 20,000 /acre open planting holes in the plastic mulch from the previous year’s strawberry plants.

Methods: Two grower field studies focused on a co-application approach of different fumigants, herbicides, and other alternative tactics to achieve pest control efficacy and crop growth response similar to that of methyl bromide. Among the sites, chisel applied soil treatments included broadcast equivalent methyl bromide (50%) chloropicrin (50%) (288 – 320 lb/ta), in addition to five drip applied fumigants including, metam sodium (as Vapam, 75 gpta), and Telone Inline (35- 48 gpta) were evaluated with either one or two drip tapes per bed at the Florida Strawberry Growers Association (FSGA) Research and Education farm in Dover, FL ; and at Ferris Farms, Floral City, FL. At all field locations, the highly gas retentive Pliant Blockade was installed immediately after methyl bromide chloropicrin application. All fumigants were applied with commercial grower equipment. Calibration procedures were followed at each experiment location. Certified applicators and pesticide label requirements for buffers, posting, rates of use, and personal protective
equipment requirements were closely followed.

At all farm locations, beds measured 32 inches wide, 10 inches in height, with rows spaced on 4 foot centers. Actual per acre fumigant use rates represent 62.5% of the broadcast or reported per treated acre (ta) rates expressed above. At FSGA and Ferris, bare root 'Festival' transplants from Canadian nurseries were planted between 4 to 5 weeks following fumigant treatment. Water and nutrients were supplied to each plant row with Netafim or TTape (0.22 gpm/100 ft or 0.45 gpm/100 ft row; or 0.40 gpm/100 ft row) on at least a daily/ twice daily basis (unless sufficient rainfall occurs) for much of the season. Fertigation rates were seasonally defined based on crop growth stage. Fertilization rates were generally based on a near field equivalent of 225 lbs NPK per acre per season. Other pest and disease control measures were maintained primarily on both a prophylactic and as needed basis.

Assessments of plant growth were made as appropriate during the course of the season to characterize differences in plant size, health, and vigor. Strawberry fruit were harvested (lb/plot or lb/row) and numbers of individual flats (8 lb/flat and 10,890 ft/a) were determined on a 2 to 3 day basis from early December 2011 through April 2011. Following chemical treatment, weed densities were monitored and recorded on a periodic basis to determine any differences in weed control between fumigant treatments. An untreated control was not included as a replicated treatment for comparison at Ferris Farms, Floral City. All treatments were arranged within their respective experimental areas as a completely randomized block design with 4 replications per treatment. Plot sizes varied from 2 to 12 rows or 0.06 to 0.4 acres among the different grower farm locations.

In addition to the above assessments, the numbers of plants in four plant size categories were also systematically enumerated and recorded at 40 to 50 ft intervals in over 20 monitored fields (all data not included). Plant size categories, measured as average canopy diameter, were dead (0), small (<20 cm), medium (>20 and < 30 cm) and large (>30 cm). Using plant sizes, fumigant treatment evaluations based on relative yield were determined in commercial fields with recurring histories of sting nematode problems. Hyperspectral reflectance field imaging technology was used to characterize and relate differences in relative strawberry crop yield (based on plant sizing) to within row, green vegetative cover. A tractor mounted GreenSeeker optical sensor (NTech Industries; Ukiah, Ca) was used to scan strawberry rows to provide estimates of green canopy cover (NDVI) against a backdrop of black plastic mulch covering the raised bed. Cumulative differences in plant numbers and relative yield contribution within each plant size category were then statistically compared with NDVI, and both values used to
independently compare differences between various soil fumigant treatments.

Results and Discussion:
At FSGA, weed densities were generally quite low, but highest densities were always observed in the untreated and drip fumigant treatments (Vapam, Kpam, Telone Inline). A similar relationship was observed with the number of end of season dead plants, highest densities occurring with the untreated and Telone Inline drip treatments. Strawberry plant growth assessments and of strawberry yield demonstrated significantly improved (P=0.05) strawberry plant growth between adjacent rows within the bed when shank applications of Telone C35 or DMDS+Pic were applied and compared with either the drip applied fumigants or untreated control (Figure 1). Unlike previous years and pretty much in the absence of damaging populations of sting nematode in the field, there was consistent benefit associated with delivery of the fumigants through 2 (twin) drip tapes per bed compared to one for and of the drip fumigants (Figure 1). With regard to end of season nematode population densities at FSGA, improved fumigant efficiency was not observed with two tapes per plant bed. The horticultural benefits of a second drip tape per bed were not demonstrated this year when damaging populations of sting nematode were not observed. Lowest nematode densities were associated with shank applications of methyl bromide chloropicrin (333 lb/ta), Telone C35 (40 g/ta), or DMDS+Pic (60 g/ta). Significant difference in strawberry yield was observed between shank and drip fumigant treatments. Strawberry yields were greatest (P=0.05) with methyl bromide chloropicrin (333 lb/ta), Telone C35 (40 g/ta), DMDS+Pic (60 g/ta) intermediate with Telone Inline (42 g/ta) and the Vapam (75 g/ta) and KPam (60 g/ta) drip fumigation treatments, all of which being significantly lower than that of the untreated control. Similar results were observed with estimates of relative yield derived from analysis of the numbers of small, medium, large, and dead plants per 40 linear feet of row.

At Ferris Farms, no significant differences in strawberry yield were observed between fumigant treatments, methods of Spring Crop termination, or with the timings delays for plastic mulch removal into the summer season (data not shown). A significant (P=0.05) early season enhancement of strawberry plant growth and degree of canopy closure between adjacent strawberry rows within the same bed were observed with the Telone EC (12gpa) spring crop termination treatment and late season removal of the plastic mulch. In general no significant (P=0.05) differences in numbers of dead or decline strawberry plants were observed among treatments season long. In a separate experiment, shank applications of Telone C35 (35 gpta) produced higher (P=0.05) higher strawberry yields than that of Pic Clor 60 (250 lbta), Pic Clor 60 (300 lbta) or that of methyl bromide chloropicrin 50/50 (320 lbta).
In a final but separate experiment evaluating the horticultural and fumigation benefits of 1 or 2 drip tapes per bed at Ferris Farms, methyl bromide chloropicrin 50/50 (320 lb/ta) produced significantly (P=0.05) higher strawberry fruit yields under new plastic than either of the double crop Telone Inline treatments using 1 or 2 drip tapes per bed. No significant (P=0.821) drip tape effect was observed with regard to strawberry yield.

GreenSeeker Results: Plant stunting and yield losses were well correlated with final harvest soil population density of the nematode. Ground truth surveying of plant size distribution repeatedly demonstrated the accuracy of in-field, remotely sensed GreenSeeker information (Figure 5). Strawberry yields from commercially hand harvested large plots were well correlated with relative yield values determined from plants of different sizes within the plots (data not shown). An overlay of the results of six field studies during spring 2012 Dover, FL illustrates the well defined nonlinear, logarithmic relationship between relative strawberry yield (0-1) and NDVI (Normalized Difference Vegetation Index) within fields displaying varying degrees of Sting nematode stunting severity (Figure 5). These results clearly illustrate how NDVI can be used as a numerical indicator of strawberry plant size (L,M,S) derived from measurements utilizing the GreenSeeker®, a plant reflectance optical sensor measuring canopy cover. Differences in plant size distribution and of relative yield also occurred between various alternative to methyl bromide chemical treatments. A comparison of 5 farm locations and five preplant soil fumigant treatments is presented in Figure 5. No significant differences (P=0.05) in canopy cover express by NDVI or relative strawberry yield (lb/a) determined from enumeration of differences in plant sizes were observed between fumigant treatments including methyl bromide chloropicrin 50/50 (225 lb/a) with VIF or in combination with LDPE plastic mulch film, drip applied chloropicrin EC (150 lb/a) + LDPE, and prebed disk hiller applied Telone C35® (22 gpa) alone or combined with minicoulter application of Vapam® (46 gpa) to the bed top on in Dover, FL during Spring 2012. Overall, field scale changes in strawberry crop productivity due to sting nematode and chemical treatment were again effectively determined, on a farm by farm or industry-wide basis, from post harvest assessments of counts of different plant sizes and NDVI measurement. The methodology is being used to provide growers guidance and quantitative performance data on alternatives to methyl bromide soil fumigation for nematode management.

GENERAL SUMMARY:

The focus of this USDA ARS South Atlantic Areawide funded project for 2011-2012 was to characterized performance differences between shank applied methyl bromide chloropicrin, Telone C35, Pic Clor 60, DMDS+PIC fumigant treatments with that of the drip fumigants metam sodium, metam
potassium, Telone EC, and Telone Inline applied as combinations of crop termination treatments in the spring after the initial crop of strawberry, followed by a stale bed treatment during the summer, and concluding in fall with another preplant drip fumigant treatments. Early season stunting from sting nematode was not observed at either double cropping demonstration locations. Temperature probes installed stale-beds into east and west bed shoulders and bed center locations demonstrated that soil temperature at 30 cm depth could attain temperatures of 100 to 110 F on a daily basis. These results suggested that crop termination treatments with either metam sodium or Telone Inline did not necessarily have to be 100% effective to provide nematode control within strawberry plant beds. It is possible that all of our treatments (except the untreated control) were successful in reducing sting nematode populations to low levels. The FSGA data also strongly supports the need for specific fumigants to provide season long protection from a newly emerging fungal disease problem, Charcoal rot caused by *Macrophomina phaseolina* (Figure 4).
Figure 1. Comparison of shank applied DMDS+PIC (60 gpta) and Telone C35 (40 gpta), with or without a spring crop termination treatment with Telone EC (12 gpa), and compared with an untreated control and Methyl bromide Chloropicrin 50/50 (333 lb/ta) under LDPE or VIF mulch on strawberry yield (cv. Festival) at the Florida Strawberry Growers Association Farm, Dover, FL. 2011-12. Some plastic mulch removed in April, August, or left to be reused for 2nd strawberry crop. 1 or 2 drip tapes per bed.
Figure 1. Comparison of shank applied DMDS + PIC (60 gpta), Telone C35 (40 gpta) and drip applied Telone Inline (40 gpta), Vapam (75 gpta), or KPam (60 gpta) with or without spring drip fumigation / crop termination treatment with Vapam (75 gpta), KPam (60 gpta) or Telone EC (12 gpa), and compared with an untreated control and Methyl bromide Chloropicrin 50/50 (320 lb/ta) under VIF Plast Blockade on strawberry yield (cv. Festival) at the Florida Strawberry Growers Association Farm, Dover, FL. 2011-12.

Figure 2. Results from USDA ARS Areawide Project study (2011-2012) at Ferris Farm, Floral City, Fl evaluating the strawberry yield (cv. Festival) responses to shank applied Telone C35 (35 gpta) or Pic Clor 60 (250 and 300 lb/ta) compared with methyl bromide chloropicrin 50/50 (320 gpta).
Figure 3. Comparison of shank and drip applied fumigant treatments on strawberry yields at the Ferris Farms, Floral City, FL 2011-2012. Fumigant treatments are shank applied methyl bromide chloropicrin 50/50 (lb/ta) and Telone Inline (35 g/ta) drip applied into double cropped strawberry beds with one (0.45 g/min/100 ft) or two (each 0.225 g/min/100 ft) drip tapes per bed. Methyl bromide chloropicrin was also similarly irrigated with 1 or 2 drip tapes per bed to characterize horticultural benefit.

Shank Injection

<table>
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<tr>
<th>Treatment</th>
<th>Strawberry Yield (lb/25 ft)</th>
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<tr>
<td>1 tape/ bed New Plastic</td>
<td>MBr 50/50 (320 lb/ta)</td>
</tr>
<tr>
<td>2 tapes/ bed New Plastic</td>
<td>MBr 50/50 (320 lb/ta)</td>
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Drip Application

<table>
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<tr>
<th>Treatment</th>
<th>Strawberry Yield (lb/25 ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 tape/ bed Double Crop</td>
<td>Inline (35 gal/ta)</td>
</tr>
<tr>
<td>2 tapes/ bed Double Crop</td>
<td>Inline (35 gal/ta)</td>
</tr>
</tbody>
</table>

Fumigant P ≤ 0.001
Drip Tape P ≤ 0.821

Treatment does not factor possible double crop effect independent of fumigant.
USDA ARS Areawide Strawberry Project - FSGA 2011-12
Charcoal Root Rot Plant Mortality

-Macrophomina phaseolina-

**Figure 4.** Comparison of shank applied DMDS + PIC (60 gpta), Telone C35 (40 gpta) and drip applied Telone Inline (40 gpta), Vapam (75 gpta), or KPam (60 gpta) with or without spring drip fumigation / crop termination treatment with Vapam (75 gpta), KPam (60 gpta) or Telone EC (12 gpa), and compared with an untreated control and Methyl bromide Chloropicrin 50/50 (320 lb/ta) on Charcoal Root rot induced plant mortality (cv. Festival) at the FSGA Farm, Dover, FL. 2011-12.

**Figure 5.** Comparison of six field research site locations plotting relative strawberry yield computed from end of season assessments of yield contributions from small, medium, large, and dead plant sizes and of NDVI (Normalized Difference Vegetation Index) within fields displaying varying degrees of Sting nematode stunting severity. Data derive from the USDA ARS South Atlantic Areawide funded project during 2011-2012.