Assessing Crop impact and Soil Fumigant Performance Using Hyperspectral Reflectance in Florida Strawberry 2013-14

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In Florida, the Sting nematode (Belonolaimus longicaudatus) infests an estimated 40% of strawberry acreage. Any loss of nematode control typically results in a higher incidence of plant stunting in the field. In most years, plant stunting is expressed relatively early in the season, with ultimate size and yield functionally determined by nematode concentration x time products over the season. Because of their microscopic size and irregular field distribution, soil and root tissue samples are usually required to determine whether sting nematodes are causing poor crop growth or to determine the need for nematode management. Once presence is confirmed from soil samples, new technologies based on GPS coordinates are available to characterize damage and spatial distribution of the nematode within the field. Given this inability to monitor nematode population density and distribution in real time, yield loss maps have been developed based on indirect measures of plant yield, such as plant canopy size or using hyperspectral reflectance technologies to characterize canopy cover on a field basis. Since 2005, over 100 commercial strawberry fields have been studied to characterize field distribution and nematode impact using any of these technologies. For purposes of justifying necessity of fumigant treatment, some record of strawberry yield in combination with an end of season assessment of plant size distribution within the field and of relative strawberry yield would be required, or of an analysis of hyperspectral reflectance data from strawberry canopy providing estimate of strawberry yield loss and distribution of nematode stunted plants.

Strawberry field research to support the use of these technologies for nematode crop loss assessment within Florida strawberry industry has been well documented within the annual conference and Proceedings Annual International Research Conference on Methyl Bromide Alternatives and Emissions Reductions for many years. Reports within these proceedings repeatedly indicate that plant stunting and yield losses by the Sting nematode 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 hyperspectral reflectance information using GreenSeeker® (Trimble Navigation Limited, 935 Stewart Drive, Sunnyvale, California 94085). In these previous studies, strawberry yields from commercially hand harvested large plots were well correlated with relative yield values determined from plants of different sizes within the plots. In a chronological summary and overlay of field results 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. These results clearly illustrate how NDVI can be used as a numerical indicator of strawberry plant size (large medium, small, dead plants) derived from measurements utilizing the GreenSeeker®, a plant reflectance optical sensor measuring canopy cover.

Differences in plant size distribution and of relative yield have been effectively used to characterize differences between various alternative to methyl bromide chemical treatments. Since 2005, multi-farm comparisons of a variety of different preplant soil fumigant treatments have documented the utility of using estimates of canopy cover using NDVI or relative strawberry yield (lb/a) determined from enumeration of differences in plant sizes to estimate and compare fumigant treatments. Overall, field scale changes in strawberry crop productivity due to sting nematode and chemical treatment have been 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 currently being used for crop loss assessment and also used to provide growers guidance and quantitative performance data on alternatives to methyl bromide soil fumigation for nematode management. The technology is also now being used as a tool in which to qualify candidate strawberry fields for methyl bromide crop rescue treatment. For studies reported herein the experimental objective were to 1) compare relative strawberry yields determined from ground truth survey of plant size categories with NDVI (Normalized Difference Vegetation Index) using GreenSeeker®, a plant reflectance optical sensor measuring canopy cover; and 2) to relate differences in plant sizing and NDVI to differential fumigant treatment.

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 (67%) chloropicrin (33%) (350 lb/ta), methyl bromide (50%) chloropicrin (50%) (350 lb/ta), Telone C35 (35 gpta), Pic Clor 60 (300 lb/ta), Paladin (DMDS 79%) plus Chloropicrin (21%) (60 gpta), TE3 (44% DMDS, 33% Chloropicrin, 23% 1,3-d)(400 lb/ta), TE3 (44% DMDS, 33% Chloropicrin, 23% 1,3-d)(300 lb/ta) in addition to five drip applied fumigants including, metam sodium (as Vapam, 75 gpta), metam potassium (as KPam, 60 gpta), Dazitol (6.25 gpa); Paladin EC (DMDS 79%) plus Chloropicrin EC (21%) (60 gpta); Paladin EC (50 gpta) + Vapam (75 gpta); at the Florida Strawberry Growers Association (FSGA) Research and Education farm in Dover, FL (**Table 1**). At all field locations, the highly gas retentive Pliant VIF Blockade or Raven Industries Vaporsafe® TIF was installed immediately after TE3 and methyl bromide chloropicrin application. All fumigants were applied with commercial grower equipment. Calibration procedures were followed at each experimental location. Certified applicators and pesticide label requirements for buffers, posting, rates of use, and personal protective equipment requirements were closely followed.

At FSGA, as in previous years, the numbers of plants in four plant size categories were systematically enumerated and recorded at 40-50 ft intervals within the field. Plant size categories, measured as average canopy diameter, were dead (0), small (<20 cm), medium (>20 and < 30 cm) and large (>30 cm). Based on previous research, relative yield values of 0, 0.17, 0.48, and 1.0 were assigned to dead, small, medium and large size plants. In addition to relative yield based on counts of different plant sizes, hyperspectral reflectance field imaging technology was also 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 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 and commercial strawberry fruit harvests conducted on a 2-3 day schedule over a December to April harvesting season.

In two commercial field demonstration sites, chisel applied soil treatments Paladin (DMDS 79%) plus Chloropicrin (21%) (60 gpta), TE3 (44% DMDS, 33% Chloropicrin, 23% 1,3-d)(400 lb/ta), TE3 (44% DMDS, 33% Chloropicrin, 23% 1,3-d)(300 lb/ta) in addition to five drip applied fumigants including, metam sodium (as Vapam, 75 gpta), metam potassium (as KPam, 60 gpta), Dazitol (6.25 gpa); Paladin EC (DMDS 79%) plus Chloropicrin EC (21%) (60 gpta); Paladin EC (50 gpta) + Vapam (75 gpta); at the Florida Strawberry Growers Association (FSGA) Research and Education farm in Dover, FL

Results: Accurate maps of fumigant treatment performance, GPS location, and sting nematode stunting severity of strawberry plants was visually and statistically well described by NDVI field mapping at FSGA (**Figure 1**). In general, severe stunting of strawberry plants were linearly expressed usually along the entire length of most 2 row plots within either the Dazitol and untreated control treatments. Strawberry yields (**Figure 2**) from commercially hand harvested large plots (lb /220 linear feet of row) were well correlated (r^2 = 0.91) with NDVI field assessment for each different fumigant treated plot (**Figures 3**). Strawberry yields from commercially hand harvested large plots (lb /220 linear feet of row) were also very well correlated with relative yield values computed from end of season assessments of yield contributions from small, medium, large and dead plant sizes within each of the different 2 row fumigant treated plots (**Figure 4**). Ground truth surveying of plant size distribution 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. These results again illustrate how NDVI can be quantitatively 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. No meaningful differences (P=0.05) in strawberry yield, NDVI, or relative yield were observed between the different drip and shank applied fumigants including different formulations, application rates, and types of plastic mulch films used with methyl bromide chloropicrin, Telone C35, Pic Clor 60, or of DMDS (**Figure 2, 3, 4**). Significant differences (P=0.05) in strawberry yield, canopy cover expressed by NDVI or relative strawberry yield (lb/a) determined from enumeration of differences in plant sizes were observed between these fumigant treatments and the untreated control and Dazitol treatments in Dover, FL during 2013-14.

NDVI field analysis showing distribution of Sting nematode, *Belonolaimus longicaudatus*, stunted plants (red areas) ant the performance of different Paladin (DMDS) ,chloropicrin, and Telone treatments in field and whole farm experimental units at the MH Bethlehem Rd Farm in Dover, FL. March 20, 2014 is illustrated in **Figure 6**. Strawberry canopy cover differences can be observed to the row among the different fumigant treatments evaluated within this large scale-multiple field trial. The Trifecta blend (TE3) of DMDS (44%), chloropicrin (33%) and Telone II (23%) (400 lb/a) generally produced the larger plants which resulted in the overall greater canopy cover (P≤ 0.001) of plants compared to either the 24 or 38 gpa Paladin (DMDS) chloropicrin treatments (**Figure 6**). With each treatment applied in replicated strips across the field (complete random block design), it was clear that none of the treatments evaluated at the MB Favorite Farm completely resolved the sting nematode problem within the field. The lack of effective and acceptable control from each of the treatments were most evident in what appears to be site specific areas within the field where sting nematode distribution and populations are typically most severe.

NDVI field analysis showing distribution of Sting nematode, Belonolaimus longicaudatus, stunted plants (red areas) in two commercial '*Hilltop*' strawberry fields MB Favorite Farm in Dover, FL. March 20, 2014. In the north block, the Trifecta blend (TE3) of DMDS (44%), chloropicrin (33%) and Telone II (23%) (400 lb/a) generally produced the larger plants which resulted in the overall greater canopy cover (P≤ 0.001) of plants compared the 38 gpa Paladin (DMDS) chloropicrin treatment (**Figure 7**). Although an untreated control was not included for comparison, neither treatment evaluated in either the north or south blocks at the MB Favorite Farm did an effective job of nematode control or even adequately resolved sting nematode induced yield losses within these fields.

NDVI field analysis showing distribution of Sting nematode, Belonolaimus longicaudatus, stunted plants (red areas) at the MB Favorite Farm Labor Camp field, Dover, FL. March 5, 2014 is illustrated in **Figure 8**. Strawberry canopy cover differences can be observed to the row among the different fumigant treatments evaluated within the large scale field trial. The Trifecta blend (TE3) of DMDS (44%), chloropicrin (33%) and Telone II (23%) (400 lb/a) generally produced the larger plants which resulted in the overall greater canopy cover (P≤

0.001) of plants compared to either the 24 or 38 gpa Paladin (DMDS) chloropicrin treatments (**Figure 8**). With each treatment applied in replicated strips across the field (complete random block design), it was clear that none of the treatments evaluated at the MB Favorite Farm completely resolved the sting nematode problem within the field. The lack of effective and acceptable control from each of the treatments were most evident in what appears to be site specific areas within the field where sting nematode distribution and populations are typically most severe.

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.

KEY POINTS:

- Strawberry yields ascertained from commercially harvested small plots were again well correlated with relative yield values determined as a cumulative sum of relative yield contributions from plants of different sizes within the small plots.

- Relative strawberry yields determined from ground truth survey of plant size categories was well correlated with NDVI estimates of canopy cover using Greenseeker optical sensors of strawberry plant reflectance.

- Nematode induced crop losses on a field scale could be easily and economically derived from simple end of season plant size assessments (relative yield) and by NDVI.

- These data again suggest that the impacts of various chemical and soil fumigant treatments can be meaningfully determined, on a farm by farm basis, from post harvest assessments of counts of different plant sizes.

- Relative yield and the NDVI methodology is being used to provide growers guidance and quantitative performance data on alternatives to methyl bromide soil fumigation for nematode management.

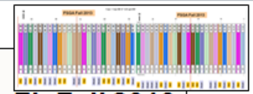


Table 1. Fumigant treatment list for Florida Strawberry Growers Research and Education Foundation Farm, Dover, FL Fall 2013

1.	MBr + PIC 67/33 (218 lb/ta)	SHANK	+ Blockade	1 tape	4 reps
2.	MBr + PIC 50/50 (320 lb/ta)	SHANK	+ Blockade	1 tape	4 reps
3.	Telone C35 (35 gpta)	SHANK	+ LDPE	1 tape	4 reps
4.	Pic-Clor 60 (300 lb/ta)	SHANK	+ LDPE	1 tape	4 reps
5.	DMDS + PIC (60 gpta)	SHANK	+ Blockade	1 tape	4 reps
6.	DMDS EC(50gpta)+Vapam(75gpta)	DRIP	+ Blockade	1 tape	4 reps
7.	DMDS+PIC+Telone II (TE3)(400 lb/ta)	DRIP	+ Blockade	1 tape	4 reps
8.	DMDS EC+PIC (60gpta)	DRIP	+ Blockade	1 tape	4 reps
9.	Kpam (60 gpta)	DRIP	+ LDPE	1 tape	4 reps
10.	Vapam (75 gpta)	DRIP	+ LDPE	1 tape	4 reps
11.	Untreated		+ LDPE	1 tape	4 reps
12.	Dazitol(6.3 gpa)+ Integrate 20(2 gpa)	DRIP	+ LDPE	1 tape	4 reps
13.	TE3 (19 gpta;12 gpa)	SHANK	+ VaporSafe	1 tape	4 reps
14.	TE3 (29 gpta;18 gpa)	SHANK	+ Blockade	1 tape	4 reps
15.	Kpam (62 gpta) + Integrate 20	DRIP	+ LDPE	1 tape	4 reps
16.	MBr + PIC 67/33 (350 lb/ta)	SHANK	+ Blockade	1 tape	4 reps

16 treatments x 4 reps x 2 row plots = 128 rows; 240 ft / row

Figure 1. NDVI field analysis showing distribution of Sting nematode, *Belonolaimus longicaudatus*, stunted plants (red areas) at the Florida Strawberry Growers Association Research and Education Foundation Farm, Dover, FL. March 20, 2014. Strawberry canopy cover differences can be observed to the row among the different fumigant treatments evaluated within the large scale field trial.

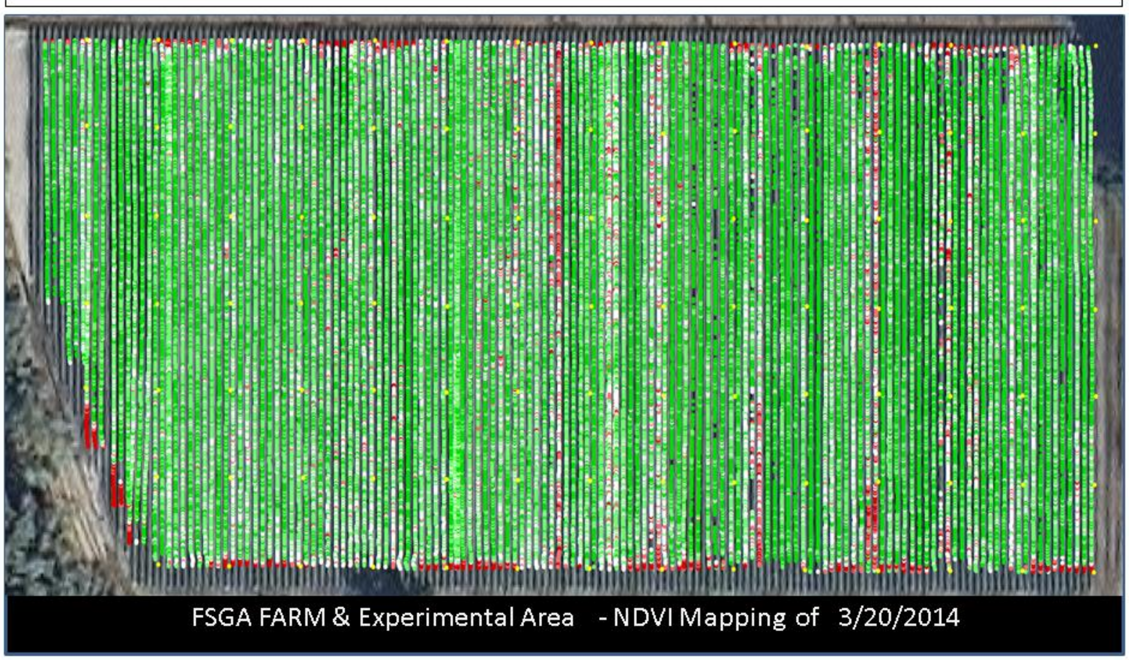


Figure 2. Strawberry fruit yields (lb/plot) for 16 different fumigants, rates of application, types of plastic mulch applied via shank or drip tape delivery at the Florida Strawberry Growers Association Farm in Dover, FL during Fall 2013-Spring 2014. Treatments that are not followed by the same letter differ significantly (P≤ 0.05) from one another.

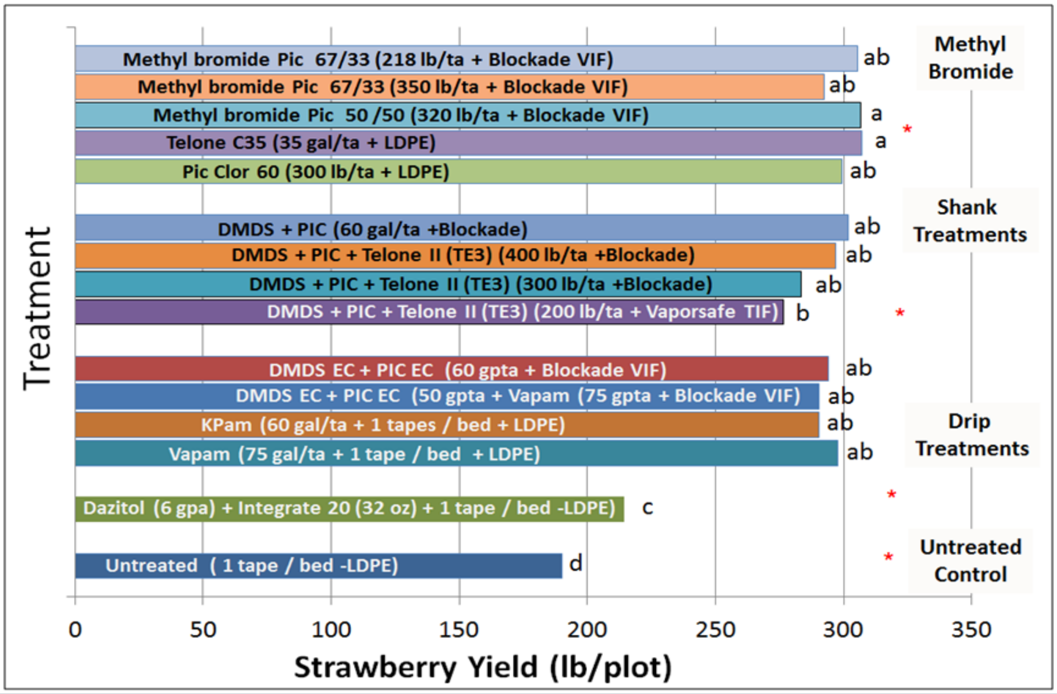


Figure 3. Comparison of mean strawberry yields (lb/plot) and NDVI assessments for 16 different fumigants, rates of application, types of plastic mulch applied via shank or drip fumigation delivery at the Florida Strawberry Growers Association Research and Education Foundation Farm in Dover, FL. NDVI assessment made March 20,2014.

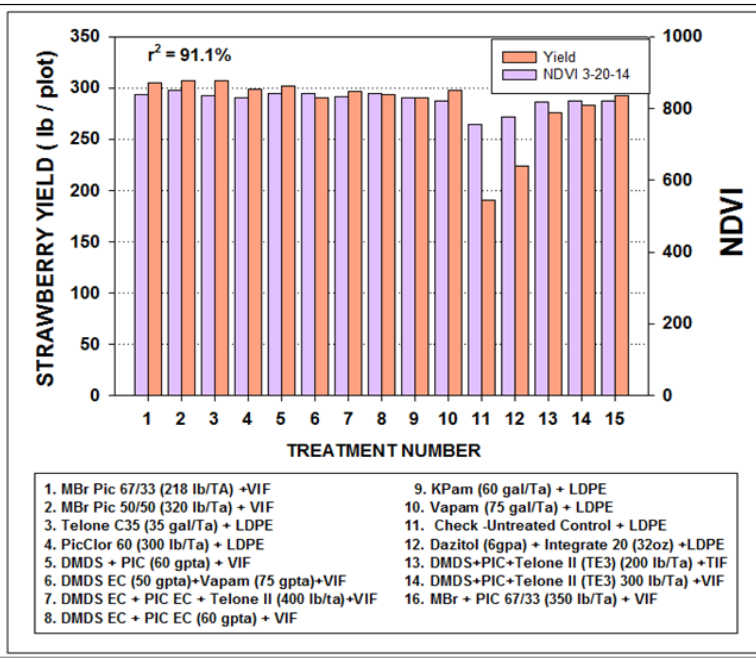


Figure 4 . Relationship between mean strawberry yields (lb/plot) and relative strawberry yield for 15 different fumigants, rates of application, types of plastic mulch applied via shank or drip fumigation delivery at the Florida Strawberry Growers Association Research and Education Foundation Farm in Dover, FL. Relative strawberry yield based on the sum of yield contribution from small, medium, large, and dead plant size categories enumerated within treatment plots.

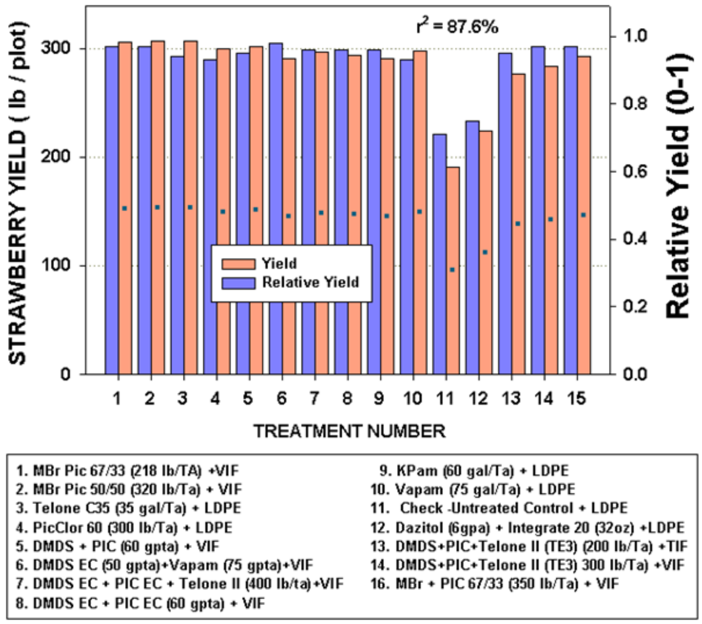
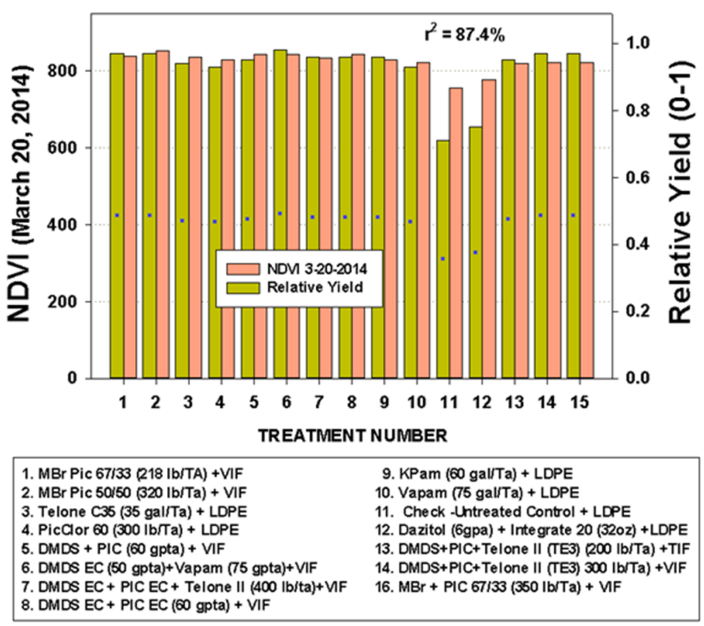


Figure 5 . Relationship between mean strawberry yields (lb/plot) and relative strawberry yield for 15 different fumigants, rates of application, types of plastic mulch applied via shank or drip fumigation delivery at the Florida Strawberry Growers Association Research and Education Foundation Farm in Dover, FL. Relative strawberry yield based on the sum of yield contribution from small, medium, large, and dead plant size categories enumerated within treatment plots.



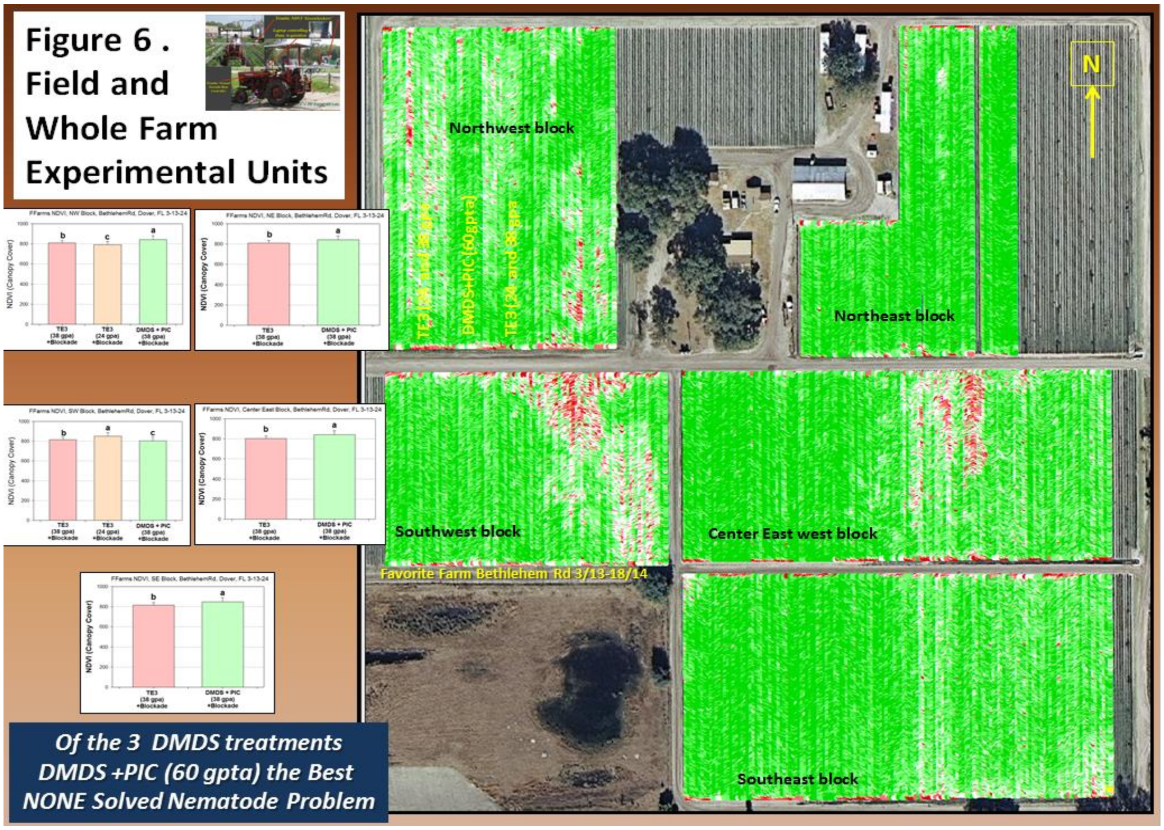


Figure 7. NDVI field analysis showing distribution of Sting nematode, *Belonolaimus longicaudatus*, stunted plants (red areas) in two commercial strawberry fields in Dover, FL. March 20, 2014. NDVI assessments of fumigant treatments compared in these fields that are not followed by the same letter differ significantly (P≤ 0.05) from one another.

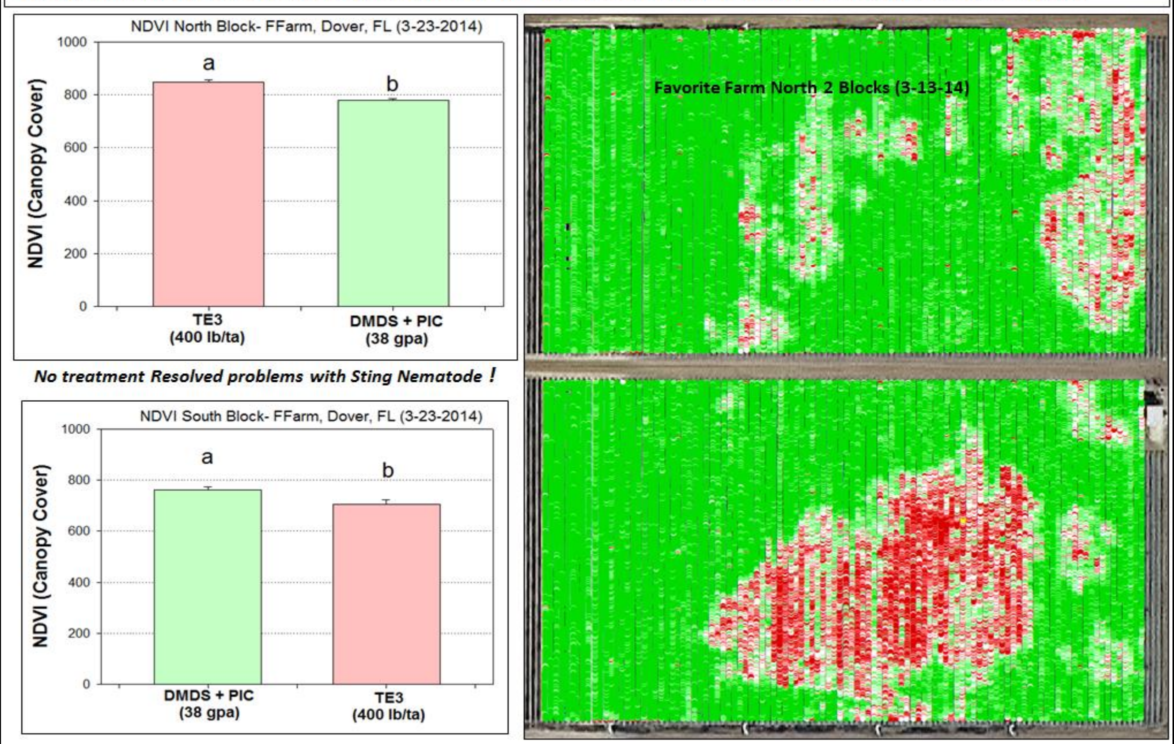


Figure 8. NDVI field analysis showing distribution of Sting nematode, *Belonolaimus longicaudatus*, stunted plants (red areas) at the MB Favorite Farm, Dover, FL. March 5, 2014. Strawberry canopy cover differences can be observed to the row among the different fumigant treatments evaluated within the large scale field trial. NDVI assessments of fumigant treatments compared in these fields that are not followed by the same letter differ significantly (P≤ 0.05) from one another. No treatment completely resolved problems and crop impacts with Sting nematode.