# Assessing Crop impact and Soil Fumigant Performance against Sting Nematode Using Hyperspectral Reflectance

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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. A gradient of plant stunting is typically observed to radiate outward from field areas where soil densities are highest and recolonization of the plant bed is earliest and most rapid. Plant stunting and yield losses are very well correlated with initial soil population density of the nematode. The patchiness and spatial variability in plant sizing (and thus yield) does not appear suddenly before harvest, but reflects a slowing or a failure to continue growth during the time continuum from planting in October to final harvest in March / April. 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**: Chisel applied soil fumigant treatments included broadcast equivalent methyl bromide (67%) chloropicrin (33%) (350 lb/ta), methyl bromide (50%) chloropicrin (50%) (320 lb/ta), Telone C35 (35 gpta), Pic Clor 60 (300 lb/ta), a variety of Dimethyl disulfide treatments coformulated with either chloropicrin or Telone (1,3-d), in addition to five drip applied fumigants including, metam sodium (as Vapam, 75 gpta), Kpam (60 gpta) and dimethyl disulfide EC + Chloropicrin EC (79:21; 60 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. The numbers of plants in four plant size categories were systematically enumerated and recorded at 40-50 ft intervals in monitored fields. 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. 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 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.

**Results**: Accurate maps of fumigant treatment performance, GPS location, and sting nematode stunting severity of strawberry plants was well described by NDVI field mapping (Figure 1). In general, severe stunting of strawberry plants were linearly expressed along the entire length of most 2 row plots within Vapam, KPam, and untreated control treatments. Strawberry yields 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 (Figure 2.) 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 3A). Ground truth surveying of plant size distribution demonstrated the accuracy of in-field, remotely sensed GreenSeeker® information (Figure 3B). 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. Differences in plant size distribution and of relative yield also occurred between various alternative to methyl bromide chemical treatments. 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 2010. 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**:

- Relative yield determination is a simple process conducting within a few days of seasons end in which field distributions of plant sizes within the field are characterized.

- 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.

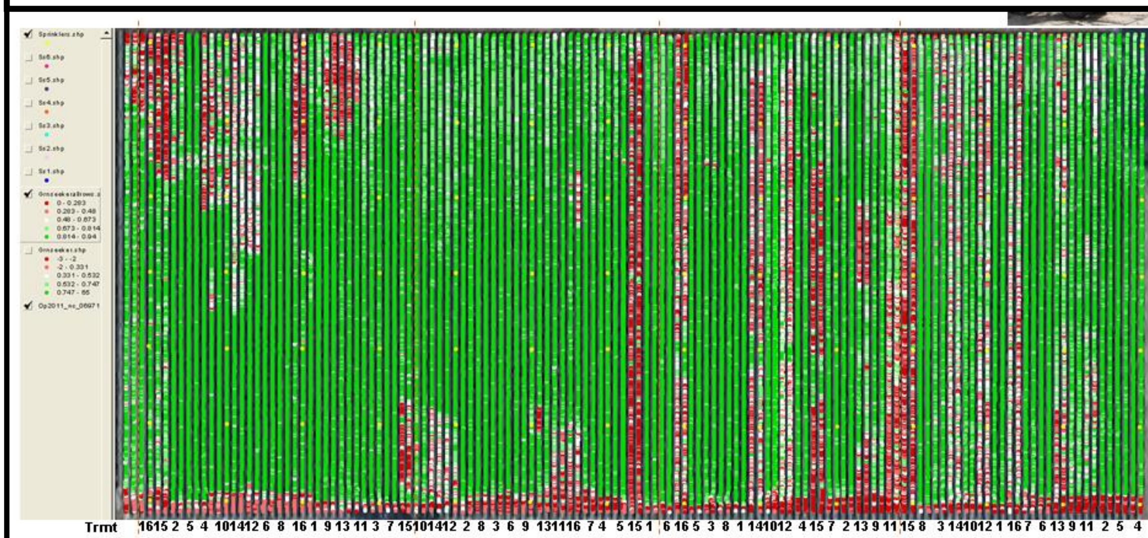
- These data again suggest that the impacts of various chemical and soil fumigant treatments can be meaningfully determined, on a farm by farm basis, from post harvest assessments of counts of different plant sizes.

- 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 2012 | | | | |
|---|---|---|---|---|
| 1. Methyl bromide + PIC 67/33 (350 lb/ta) | | + Blockade | 1 tape | 4 reps |
| 2. Methyl bromide + PIC 50/50 (320 lb/ta) | | + Blockade | 1 tape | 4 reps |
| 3. Telone C35 (35 gpta) | Shank | + LDPE | 1 tape | 4 reps |
| 4. Telone C35 (30 gpta) | Shank | + Blockade | 1 tape | 4 reps |
| 5. DMDS + PIC (45 gpta) | Shank | + Blockade | 1 tape | 4 reps |
| 6. DMDS + PIC (60 gpta) | Shank | + Blockade | 1 tape | 4 reps |
| 7. DMDS + PIC + Telone II (TE3)(400 lb/ta) | | + Blockade | 1 tape | 4 reps |
| 8. DMDS EC + PIC EC + (60 gpta) | DRIP | + Blockade | 1 tape | 4 reps |
| 9. Pic-Clor 60 (300 lb/ta) | Shank | + LDPE | 1 tape | 4 reps |
| 10. Pic-Clor 60 (250 lb/ta) | SHANK | + Blockade | 1 tape | 4 reps |
| 11. Kpam (60 gpta) | Drip | + LDPE | 1 tape | 4 reps |
| 12. Kpam (60 gpta) | Drip | + LDPE | 2 tapes | 4 reps |
| 13. Vapam (75 gpta) | Drip | + LDPE | 1 tape | 4 reps |
| 14. Vapam (75 gpta) | Drip | + LDPE | 2 tapes | 4 reps |
| 15. Untreated | - | + LDPE | 1 tape | 4 reps |
| 16. Untreated | - | + LDPE | 2 tapes | 4 reps |

*LDPE (Low density polyethylene mulch film; Berry Plastics Corporation Blockade ® VIF, 1.25 mil*
*1 or 2 drip tapes per plant bed; 16 treatments x 4 reps x 2 row plots = 128 rows x 240 ft /row*

**Figure 1. NDVI field analysis showing distribution of Sting nematode stunted plants (red areas) at the Florida Strawberry Growers Research Foundation Farm, Dover, FL. April 3, 2013**




| Treatment | NDVI | SE | obs | Treatment | NDVI | SE | obs |
|---|---|---|---|---|---|---|---|
| 1-Methyl Bromide 67/33 (350 lb/ta) | 851 | 1.08 | 4165 | 9-Pic-Clor60 (300 lb/ta)+LDPE | 797 | 2.14 | 4497 |
| 2-Methyl Bromide 50/50 (320 lb/ta) | 822 | 1.71 | 3685 | 10-Pic-Clor60 (250 lb/ta)+Blockade | 799 | 1.86 | 4144 |
| 3-Telone C35 (35gpta)+LDPE | 816 | 1.77 | 3346 | 11-Kpam (60gpta)+LDPE-1 tape | 688 | 3.14 | 4162 |
| 4-Telone C35 (30gpta)+Blockade | 800 | 2.63 | 3334 | 12-Kpam (60gpta)+LDPE-2 tapes | 628 | 3.06 | 4099 |
| 5-DMDS + PIC (45gpta) | 853 | 1.21 | 3745 | 13-Vapam (75gpta)+LDPE-1 tape | 713 | 3.59 | 3386 |
| 5-DMDS + PIC (60gpta) | 846 | 1.31 | 3299 | 14-Vapam (75gpta)+LDPE-2 tapes | 631 | 3.54 | 3316 |
| 7-DMDS+PIC+TeloneII(Te3)(400 lb/ta) | 835 | 1.52 | 3326 | 15-Untreated-1 tape | 450 | 4.64 | 3746 |
| 8-DMDS + PIC EC(60gpta) | 861 | 1.02 | 3710 | 16-Untreated-2 tapes | 606 | 4.08 | 3313 |

Figure 4. NDVI assessments for 16 different fumigants, rates of application, types of plastic mulch, and numbers of drip tapes per bed applied via shankor drip tape delivery at the Florida Strawberry Growers Research and Education Foundation Farm in Dover, FL. NDVA assessment made April 3, 2013.

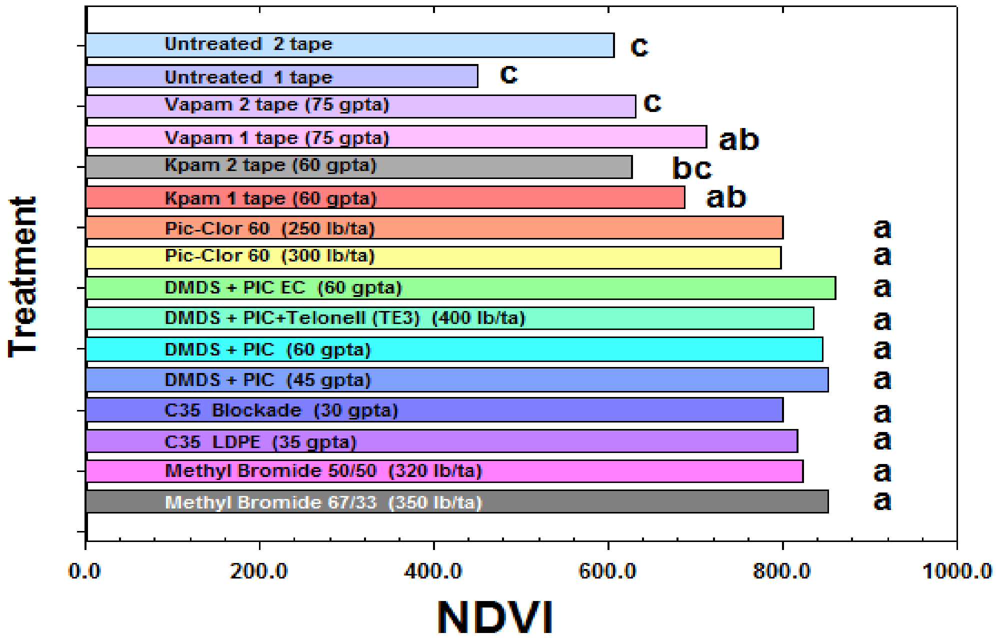



Figure 2. Close Agreement between strawberry yield and NDVI field assessment (April 3, 2013) at the Florida Strawberry Growers Association Research & Education Foundation Farm, Dover, FL.

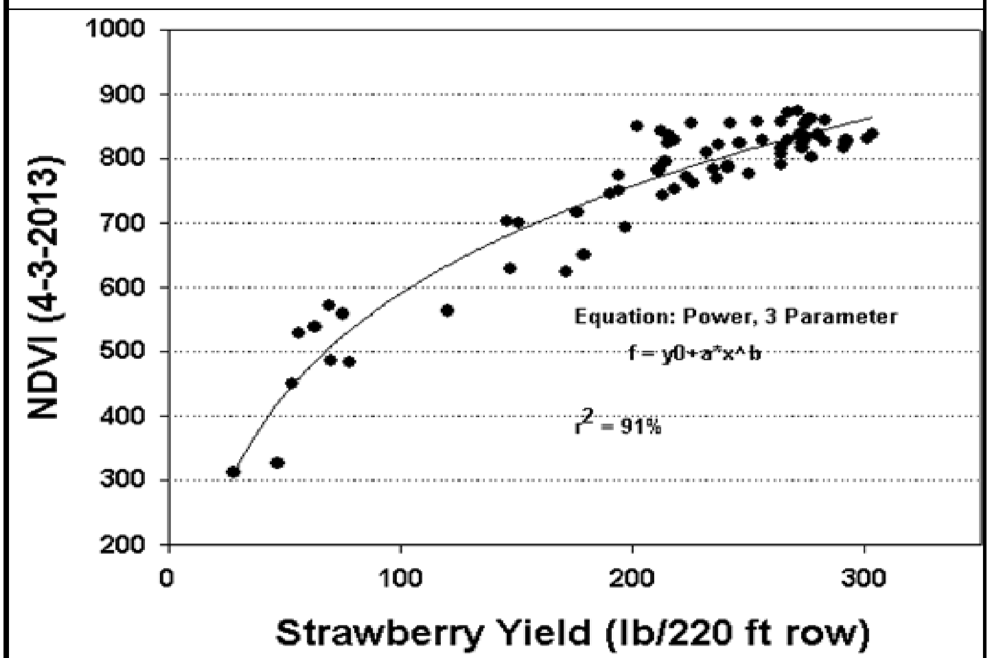


**Figure 3. Comparison of strawberry yield (lb/ 220 ft row) and relative strawberry yield (panel A) computed from end of season assessments of yield contributions from small, medium, large, and dead plant sizes and of relative strawberry yield and NDVI (Normalized Difference Vegetation Index) (Panel B) within a field displaying varying degrees of Sting nematode stunting severity. Data derive from the Florida Strawberry Growers research and Education Foundation Farm 2013.**