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# Estimating Strawberry Yield and Sting Nematode Impacts Using Counts of Plant Sizes and Fruit Stems

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**The objectives of these studies were to: 1) evaluate plant size distributions (canopy diameter) in the field as potential indicators of strawberry yield; and 2) to evaluate temporal relationships between strawberry plant size and average fruit weight and numbers of fruit stems (peduncles) per plant for plants exhibiting different levels of plant stunting due to the sting nematode, *Belonolaimus longicaudatus*. The intent was to establish a chronological record of total fruit picked from the plant during the season for assessing differences in fruit yield among three size classes of nematode stunted plants, small (≤20 cm), medium (>20 cm and ≤30 cm) and large (>30 cm) plant sizes. The relationships between fruit weight and numbers of fruit stems per plant with average canopy diameter were always well described by quadratic, polynomial functions for all years and farm locations. In general, 70% to 75% of the variability in fruit stem counts per plant was explained by changes in canopy diameter. However, even when the same strawberry variety was used, different functional relationships between canopy diameter and counts of fruit stems were observed between years and farm locations. Overall, field scale changes in strawberry crop productivity due to sting nematode can be accurately determined, on a farm-by-farm basis, from end of season assessments of plant sizes and counts of fruit stems per plant.**

The sting nematode, *Belonolaimus longicaudatus*, is a major yield limiting pest of Florida strawberry (Noling, 2009). Soil applied broad spectrum fumigants like methyl bromide have been extensively used in commercial strawberry fields for control of soilborne pests and diseases and to maintain crop production (Gilreath et al., 2008; Noling, 2008). Even with fumigant treatment, however, significant yield losses frequently occur due to suboptimal environmental conditions at the time of treatment that degrade fumigant movement, persistence, and pest control efficacy. With sting nematode, any loss of nematode control typically results in a higher incidence of plant stunting. For most plant parasitic nematode species, plant stunting and yield losses are generally very well correlated with the initial soil population density of the nematode (Potter and Noling, 1998). In practice, however, damage relations for sting nematode have been very difficult to quantify because of the patchy spatial distribution of the nematode in the field and to the deeper soil horizons to which they can reside prior to planting. A significant amount of field research is currently focusing on characterizing field distribution of the nematode with incidence maps of differential plant stunting caused by the nematode using counts of different strawberry plant sizes in the field (Noling, 2008). The objectives of these studies were to evaluate the combined use of end of season plant size assessments (canopy diameter) and of fruit stem (peduncle) counts per plant to provide a chronological record of total fruit picked from the plant during the season and for estimating relative differences in fruit production between size classes of nematode-stunted plants.

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## Materials and Methods

### End of season plant size assessments

In 2004, 2005, and 2006, end of season plant size assessments were carried out in the same 8.1-ha (20 acre) commercial strawberry production field in Dover, FL. The strawberry variety 'Festival' was planted each year. In each year, a long T-handled measuring stick (a 45-cm ruler bolted to the end of a 2.5-cm PVC pipe) was used, as needed, to measure plant canopy diameter in both within and between row directions. Based upon average canopy diameter, plants were classed into one of three plant size canopy diameter categories: small (≤20 cm), medium (>20 cm and ≤30 cm) or large (>30 cm) plant sizes. In this field, plant densities of the three plant size categories were counted annually and expressed as plants per irrigation sprinkler section. Sprinkler sections are the unit lengths of row between elevated, overhead irrigation sprinklers, systematically spaced as a staggered grid at 15.2-m (50 ft) intervals within the field. In a staggered arrangement, sprinklers align at 7.6-m (25 ft) intervals across the field. At 7.6 m, each sprinkler section of row contained a maximum of 41 strawberry plants per 5.8 $m^2$ (75 $ft^2$).

At the end of the Florida strawberry harvest season in March and April, plant size distributions were determined by a walk survey, counting the number of small, medium, and large plants per sprinkler section within every row of the 8.1-ha field. Three to 4 d were always required to complete the annual survey. Hand-held tally counters were used to tally plant counts of small and medium sized plants per 7.6 m of row. The number of dead or missing plants was also recorded within each sprinkler section. The number of large plants per sprinkler section was not counted directly but determined by subtracting number of small, medium, dead, and missing plants from the maximum number of plants possible per sprinkler section in the field. All data were first organized two dimensionally by consecutive plant row number [X distance coordinate assumes 1.2-m (4 ft) row centers] and the midpoint distance location of each consecutive sprinkler section (Y coordinate) within and along each plant row. The contour function of Surfer (Version 8.05; Golden Software Inc., Golden, CO) was used to provide three-dimensional representations of number of and proportions of small, medium, and large plants per 7.6 m of row. Relative yields were also determined and plotted for each sprinkler section assuming proportional reductions in yield of small and medium sized plants relative to large plants.

#### Determination of average fruit weight and numbers per plant size category

At each of three commercial strawberry farms, a single field study was conducted to relate plant size (average canopy diameter) to plant foliage weight, fruit number, and other indirect measures of strawberry yield. Immediately after final commercial harvest, 54 individual strawberry plants were harvested from each of the three nematode infested fields. At each of the three field locations, plant canopy diameters were measured both along the row and across the bed before the plants were cut along the plastic mulch and soil interface. This was done to insure equal representation of 18 plants within each of a small (≤20 cm), medium (>20 cm and ≤30 cm), and large (>30 cm) size category. After harvesting, plants were bagged, tagged, and returned to the laboratory where total plant fresh weight was determined, and the plant was then further subdivided to assess foliage weight, both harvestable and developing fruit number and weight, number of flowers, and the number of harvested fruit stems (peduncles). The relationship between canopy diameter and foliage weight, fruit number, stems of harvested fruit, and average fruit weight was analyzed using the dynamic fit and regression procedures of SigmaPlot10 (Systat Software, Chicago, IL). All category means and standard errors were calculated using the Describe procedure of Minitab (Minitab Inc., State College, PA).

A field survey was also conducted four times over a 3-month harvest period in a sting nematode infested commercial field in Dover, FL. Each sampling date was scheduled to occur the day prior to commercial harvest in the field. For each sampling date, individual strawberry fruit weights were determined from harvest of all mature fruit from 25 individual plants within each of the three plant size categories. For the fruit weight survey, individual fruit were weighed and average weight and standard error for each size category and sampling date was determined using the Describe procedure of Minitab (Minitab Inc.). In this same field but on different dates, the number of harvested fruit stems was counted from 25 individual plants within each of the three plant size categories and sampling dates. Average fruit stem number and standard error for each plant size category and sample date was again determined as above.

Using the plant size data, strawberry plant yield was described for each plant size category as a multiplicative function of total fruit stem number times average fruit weight per plant (data not shown). Relative strawberry yield per plant was then computed using the estimated strawberry plant yield for a given size category, divided by and relative to the plant yields of large plants, summarized over the three farm locations. Using the canopy size field distribution data, relative strawberry crop yield per sprinkler section of row was described as a multiplicative function of total plant number times relative plant yield for that size category summed over the three plant size categories. Dead or missing plants were accounted for in the analysis. Plots of relative strawberry crop yield with individual row and midpoint of each sprinkler section coordinate were then plotted to construct contour maps of sting nematode yield impacts in a commercial strawberry field over a 3-year period.

## Results

#### End of harvest season average fruit weight and numbers of fruit stems

Highly significant correlations were observed between total plant weight, foliage weight, both harvestable and developing fruit number and weight, and number of flowers with average plant canopy diameter (data not shown). Figure 1a–c shows the functional relationship between the number of strawberry fruit stems per plant and average plant canopy diameter measured at the end of the strawberry production season in the stratified, random survey of 54 plants in each of three commercial fields. For each field, best-fit mathematical functions explain as much as 69% to 77% of the variability between fruit stems and strawberry canopy diameter. Even though the strawberry cultivar 'Festival' was planted in each field, over 2.5-fold differences in the number of harvested fruit stems per plant were observed between the commercial field sites. These are likely due to between field differences in microclimate and crop management practices during plant development and fruit set.

Based on end-of-season assessments of sting nematode stunted plants, strawberry fruit size and weight (g) significantly increased from the smallest to largest plant canopy size categories at each commercial farm location (Table 1). Overall, average strawberry fruit weight increased 59% from the small to medium size plant canopy size category, and increased another 27% from the medium to large plant canopy size category. For small plants, an average fruit weight of 9.26 g (0.3 oz) was observed, which is slightly less than the minimum USDA market threshold standard of 10 g (0.32 oz) per fruit. The number of harvested fruit stems per plant significantly increased from one plant size category to the next for each farm location (Table 1). On average, fruit stem number increased 83% from the small to medium size plant canopy size category, and increased another 66% from the medium to large plant size category. Although inadequate to accurately formulate an overall impact to strawberry yield, the comparison of fruit stem counts between plant size categories provides an estimate of relative impact by sting nematode on strawberry yield via a reduction in actual number of fruit seasonally produced.

#### Differences in average fruit weight and stem numbers among plant size category

In general, average strawberry fruit weight (g) progressively increased from the smallest to largest plant size canopy diameter category during each of the four survey harvest dates (Fig. 2b). Thus as expected, larger plants produced the largest berries. Average fruit weight were not observed to change dramatically from one sample date to the next within each plant size category. Fruit from plants within the medium and small size categories were on average 20% and 40% less, respectively, than fruit within the large size category. For small plants, the average weight of fruit harvested at each of four sampling dates over a 3-month period were always close to USDA market threshold standard of 10 g per fruit. Average number of strawberry fruit stems also progressively increased from the smallest to largest plant size canopy diameter category during each of the five sample dates (Fig. 2a). Differences in average fruit stem number between plant canopy size diameter

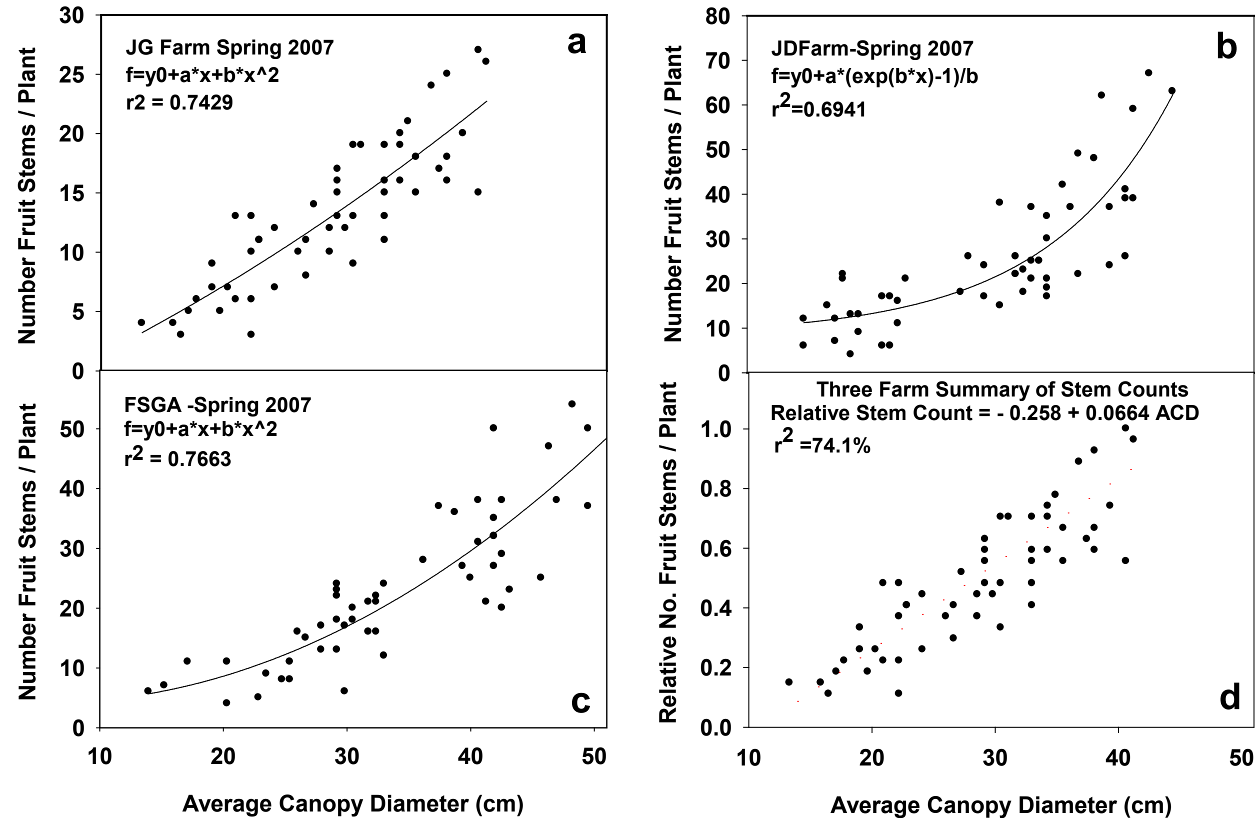


Fig. 1a–d. Relationship between numbers of strawberry fruit stems per plant and average plant canopy diameter (cm) measured at the end of the strawberry production season in each of three commercial, sting nematode infested fields in Dover, FL during March 2007. Best-fit mathematical functions describing the functional relationship and variation explained is provided for each commercial farm. Fig. 1d illustrates a three-farm summary of relative stem counts per plant and average canopy diameter.

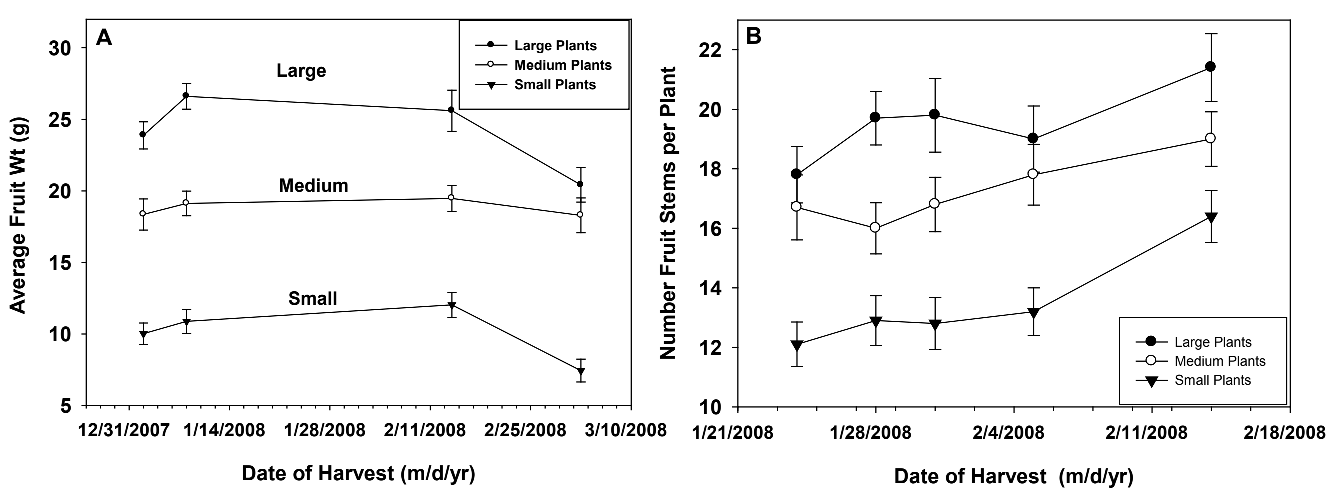


Fig. 2A–B. Average number of fruit stems per plant and average weight (g) of individual strawberry fruit harvested from 25 randomly selected plants within each of three plant size canopy diameter (cm) categories, including large > 30 cm, 20 cm < medium < 30 cm, and small < 20 cm sized plants during four general field survey harvest dates in a sting nematode infested commercial strawberry field, Dover, FL, 2007–2008.

categories were not observed to change dramatically from one sample date to the next. The number of harvested fruit (stems) generally increased linearly with each successive sampling date and with plant size category. At each sampling date, fruit stems counts from the small plants were on average 12% less than that of the intermediately sized plants, and 31% less than that of large plants. Differences between plant size categories clearly show a strong correction between fruit stem counts and plant size.

## Estimates of relative yield from plants of different sizes

Comparisons of strawberry relative yields between plant canopy size categories illustrated a highly significant impact of

Table 1. Differences in average strawberry fruit weight (g) per plant and number of fruit harvested during the season (as estimated by residual fruit stems) and relative strawberry plant yield by canopy size category (small ≤20 cm; 20 cm <medium <30 cm; large ≥30 cm) at each of three experimental locations. Relative strawberry plant yield is computed as a multiplicative function of average weight of fruit per plant and size category times average no. of fruit harvested per plant and size category, divided by and relative to plant yields of large plants for each experimental location. Values within columns of each canopy diameter (cm) category represent calculated averages and mean standard errors (Std Error) for each experimental location. Means of fruit weight and harvested fruit number (stems) represent the means of 18 plants per canopy size category and experimental location.

| Experimental location | Small ≤20 cm | Medium >20 cm and ≤30 cm | Large ≥30 cm |
|---|---|---|---|
| | Avg fruit wt (g) per plant and canopy size category (Mean ± Std Error) | | |
| JD Farm | 8.13 ± 0.81 | 10.63 ± 0.54 | 18.34 ± 1.05 |
| JG Farm | 10.75 ± 1.42 | 20.77 ± 1.26 | 22.90 ± 3.39 |
| FSGA | 8.90 ± 1.94 | 12.73 ± 1.09 | 14.74 ± 1.27 |
| 3-site mean | 9.26 ± 0.78 | 14.71 ± 3.43 | 18.66 ± 2.18 |
| | Avg no. harvested fruit (stems) per plant and canopy size category (Mean ± Std Error) | | |
| JD Farm | 12.67 ± 1.33 | 24.00 ± 1.57 | 39.60 ± 3.2 |
| JG Farm | 7.50 ± 0.72 | 13.61 ± 0.71 | 19.75 ± 0.97 |
| FSGA | 10.88 ± 1.85 | 19.15 ± 1.65 | 34.79 ± 2.29 |
| 3-site mean | 10.35 ± 1.52 | 18.92 ± 3.00 | 31.38 ± 5.98 |
| | Relative yield [(AFW/plant) × ANF/plant]/relative to large size category (Mean ± Std Error) | | |
| JD Farm | 14.18 --- | 35.13 --- | 100 --- |
| JG Farm | 17.83 --- | 62.50 --- | 100 --- |
| FSGA | 18.88 --- | 47.54 --- | 100 --- |
| 3-site mean | 16.98% ± 1.42 | 48.37% ± 7.92 | 100% 0.0 |

sting nematode on plant productivity (Table 1). A high degree of nematode induced stunting within the small category was computed to result in an 83% loss in plant productivity. These losses probably represent a near total loss in plant productivity since USDA food grading standards require market threshold fruit weight of 10 g or higher. A high level of variation was observed in relative yields of medium sized plants compared to large plants between the three commercial farm locations (Table 1). When averaged across experimental site locations, the range in relative yield values for medium sized plants, relative to large plants, illustrates a potential yield loss due to sting nematode of 38% to 65%, and a mean loss of 48%. Utilizing the per plant relative yield estimates for the three plant size categories, field areas impacted by the sting nematode *Belonolaimus longicaudatus* during each of 3 years in an 8.1-ha strawberry field in Dover, FL are illustrated in Fig. 3. White to darkest black scaling indicates an increasing proportional reduction in relative strawberry yield from the nematode-free condition.

## Discussion

Sting nematode has a unique symptomology on strawberry consisting of plant stunting caused by significant, often near complete, root loss (Potter and Noling, 1998). The nematode is unique to Florida, and is not easily confused with any other pest of strawberry, particularly since the nematode does not immediately kill the plant, but with continued feeding, incrementally reduces root abundance and stunts plant size and canopy diameter with time. Other primary pests that affect strawberry are also not as widespread or as devastating in impact. Our original objective was to map the field distribution and severity of sting nematode damage (stunting) on strawberry plants by counting and recording the number of small, medium, large and dead plants every 7.6 m of plant row within the field, and to do this without having to sample

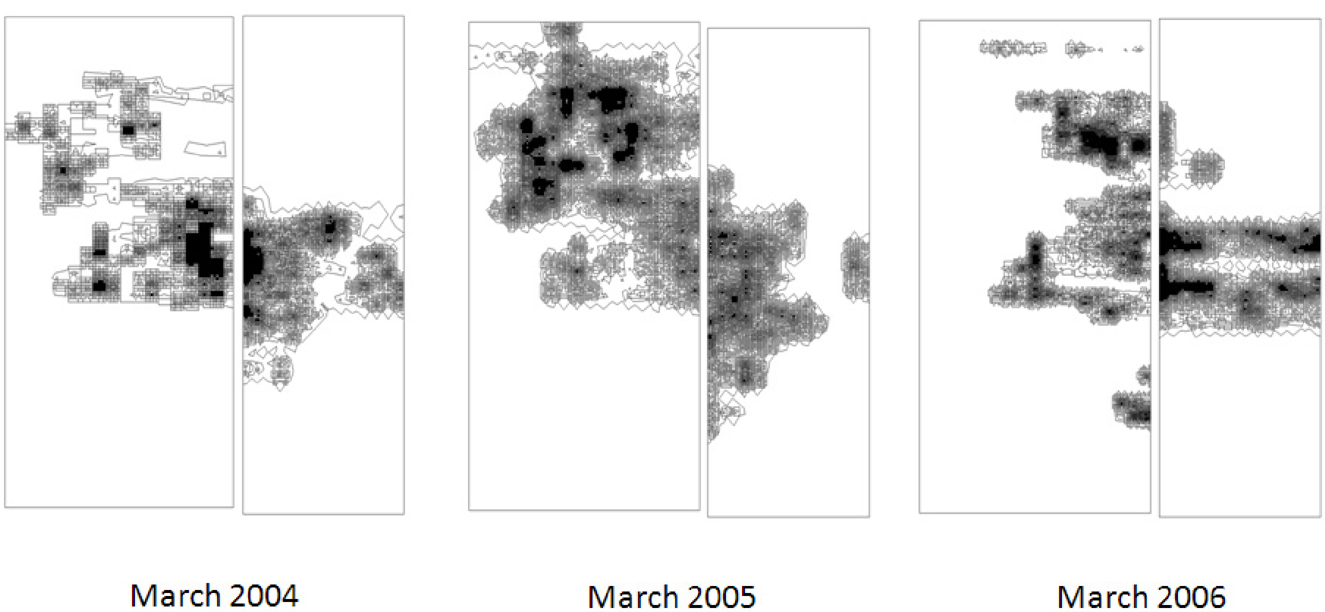


Fig. 3. Field areas impacted by the sting nematode, *Belonolaimus longicaudatus*, during each of 3 years in a 8.1-ha (20 acre) strawberry in Dover, FL. Relative yields were estimated from an end-of-season analysis of field distribution and density of plants within different canopy size categories. White to darkest black scaling indicates an increasing proportional reduction in relative strawberry yield from the nematode-free condition within specific regions of the field.

extensively and enumerate soil populations of the nematode other than to simply confirm a broad field presence. The systematic grid of overhead sprinklers used for freeze protection present in the field provided the opportunity to easily georeference the different counts of strawberry plant sizes per unit length of row.

After the maps were developed, it was quickly discovered that the specific plant size information could only provide an indication of where and when the problem was distributed in the field, and help to identify specific field areas of reoccurring problem for further research. It became clear that being able to develop yield maps would increase the utility of the information as a crop loss assessment tool which could also have near immediate crop management implication. Looking more closely at individual plants, the discovery was then made that fruit individually removed from its stem (peduncle) during harvest left a chronological record of fruit production in the field, and that total strawberry yields might be accurately estimated from an understanding of yield functions describing individual plant yield as a function of fruit number and average fruit weight per plant. Carried a step further, crop yield could then be described as a multiplicative function of total plant number per unit area (summarized by plant size categories) times average number of fruit per plant times the average weight of individual fruit per plant.

In these studies, the relationship between number of strawberry fruit stems per plant and average plant canopy diameter was always very well described by quadratic, polynomial functions for each of the three farm locations. Average fruit weight were always orders of magnitude less for medium and small plants when compared to the large plants. In general, 70% to 75% of the variability in fruit stem counts per plant were explained by changes in canopy diameter. However, even when the same strawberry variety was used, a very different functional relationship between canopy diameter and counts of fruit stems was observed between farm locations. A pooled examination and calculation of the relative number or fruit stems per plant regressed against plant canopy diameter, demonstrated similar proportional effects, however, with a high degree of correlation between plant stunting and fruit production among the three different farm locations (Fig. 1d). These results demonstrated that differences in cultural practices (e.g., irrigation, plant nutrition, etc.) can significantly influence crop productivity but result in similar proportional yield responses in the presence of sting nematode. This would suggest that characterizing the degree of plant stunting, in lieu of soil sampling and nematode population assessment, provides an accurate method for estimating strawberry crop losses due to the nematode under diverse environmental and crop production practice.

It came as no surprise to see higher plant yields and strawberry fruit size to be so positively correlated with plant canopy diameter (Human, 1999; MacKenzie et al., 2003). Sting nematode stunting of strawberry plants is probably the single most important and easily observed symptom in the field. At the end of the season, the degree of stunting is related to the initial population of the nematode occurring in the soil at planting and then as a function of the level of root feeding and destruction which occurs thereafter. What was surprising to discover was the proportional yield reductions in fruit size and stem number of similarly sized plants from different commercial fields having different overall yield potential. Changes in relative yield were closely related to changes in canopy diameter and thus, estimates of ground cover of strawberry foliage. For example, the relative yields computed for the small and medium size plants were 17% and 48% of relative yields assigned to large plants. Estimates of ground cover of strawberry foliage for small and medium plants were computed to be approximately 20% and 50% of the ground cover associated with that of large plants. This would suggest that a damage function describing a continuum of sting nematode stunting of strawberry plants could be developed to improve accuracy of crop loss estimation if individual plants and their canopy area could be easily measured and recorded. A variety of digital imaging and plant sensing technologies which are currently being investigated within U.S. precision agricultural studies might be suitable for quickly georeferencing a continuum of plant canopy size measurements in the field (Martin, 2002). Acquiring canopy size measurements in this way to predict yield would provide considerable savings in time over counting or weighing fruit at each of many individual strawberry harvests. This research has demonstrated that both end of season plant size assessments within the field and of fruit stem counts per plant provide a procedural method in which to estimate relative differences in the severity of stunting and of fruit yield between plants of different canopy dimension. With this information, relative strawberry yield can be estimated at a field scale from the cumulative plant size count data from the three plant size categories.

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