Relative Yields and End of Season Plant Size Assessments As Surrogate Measures of Strawberry Yield

J.W. Noling* and Marjorie Cody

*University of Florida, IFAS, Citrus Research & Education Center,
700 Experiment Station Rd., Lake Alfred, FL 33850*

Additional index words. *Fragaria* spp., crop loss, nematode damage function, methyl bromide

A strawberry plant sizing methodology was used to characterize and relate relative differences in strawberry crop yields to commercially hand harvested yield in each of five large scale field trials from Fall 2008 to Spring 2013. In each year, marketable strawberry fruit were hand harvested on two- to three day intervals season long from 48 to 66 individual plots, each plot typically representing 436 plants and 73 m (240 linear feet) of plant row. End of harvest season surveys were conducted each year to count the numbers of strawberry plants within four plant size and dead categories in each plot at the Florida Strawberry Growers Association (FSGA) Research and Education Farm in Dover, FL. Strawberry yields from commercially hand harvested large plots were well correlated with relative yield values estimated from the number of plants in each of the four plant size and dead categories within the plot. For each year's analysis, best-fit linear or quadratic functions explained 40% to 91% of the variability between harvest fruit yield (kg/ha) and estimated relative yield. Assessments of plant size distribution and relative yield were also descriptive of plant growth and yield differences between various preplant soil fumigant treatments. As much as 75% to 97% of the variability between fumigant treatment means of the two strawberry yield parameters was accounted for by mulitple regression analyses. Biological, environmental, and cultural practices and conditions that affected strawberry production levels and plant size distribution were identified.

The sting nematode, *Belonolaimus longicaudatus*, is a major yield limiting pest of Florida strawberry (Noling, 2009) and a variety of soil fumigants are extensively used to manage the nematode (Noling, 2008; Noling, 2009; Noling, 2010; Noling, 2011; Noling and Cody, 2012). Characterizing strawberry yield losses due to the sting nematode is not a simple or inexpensive proposition given the long 6–7 month strawberry plant growth and fruit harvest cycle. In a typical season, strawberries are harvested on a 2–3 day interval over a picking season lasting upward of 120 days. Allocating the required time and resources to ensure accuracy and continuity of harvest yield information over the entire picking season is oftentimes not possible and or cost prohibitive to achieve.

Previous research demonstrated that a chronological record of total fruit picked from a strawberry plant during the entire season could be used for assessing differences in fruit yield among different size classes of sting nematode stunted plants (Noling, 2009). In these studies, the relationships between fruit weight and numbers of fruit stems per plant with average canopy diameter were always well described by quadratic, polynomial functions. This work suggested that it was possible to accurately assess field scale changes in strawberry crop productivity due to sting nematode from end of season assessments of plant sizes. It was also demonstrated that differences in cultural practices (e.g., irrigation and rates of fertilization rates, etc.) could significantly influence strawberry fruit production but result in similar proportional yield reductions in the presence of sting nematode when express relative to plant canopy size. This would suggest that characterizing the degree of plant stunting, in lieu of soil sampling and nematode population assessments, provides an accurate method for estimating strawberry crop losses due to the nematode under diverse environmental and crop production practice. It is fortuitous that no other key insect or disease pest causes such a gradient of plant stunting associated with initial soil population density. Given the strong relationship between fruit yield and plant size and canopy dimension (Noling, 2009), the objective of these studies were to evaluate and compare estimates of relative yield based on plant size distribution in commercial strawberry fields as surrogate measures of actual strawberry fruit yield (kg/ha) within large field plots treated with various soil fumigants.

Materials and Methods

End of season plant size assessments were carried out in 2008, 2009, 2010, 2011, and 2012, in the same 1.2 ha (3 acre) commercial strawberry production field at the Florida Strawberry Growers Association (FSGA) Research and Demonstration Farm in Dover, FL. Each year, single preplant applications of methyl bromide chloropicrin and various alternative fumigants were evaluated for sting nematode management and impacts on strawberry yield. Yield variability associated with sting nematode control among the different fumigant treatments provided the means by which to examine the relationship between actual yield and estimated relative yield. Strawberry plants were always arranged in staggered double rows per bed, with plants spaced 30 cm (12 inches) apart across the plant bed and spaced 35 to 38 cm apart along the row. In each year, strawberry fruit were hand harvested on 2–3 day intervals; season long, from 48 to 66 individual plots. Each fumigant treated plot typically represented 436 plants and 73 m (240 linear feet) of plant row. Strawberry fruit were only harvested as marketable fruit from the inner 2 rows of plants from each 2 row plot. As harvest proceeded, marketable fruit were then packaged in-the-field into 2.2-kg clamshell packages. Clamshell packages,

including partials, were counted and recorded for each harvest and fumigant treated plot. Strawberry yields were summarized from all individual harvests and expressed as kg/ha and as flats per acre (8-lb flats/a). During harvest, all deformed, diseased, or freeze damaged fruit were discarded.

At the end of the strawberry harvest season in March or April of each year, strawberry plant size distribution was determined by counting the number of small, medium, and large plants within each two row fumigant plot. Plant stand densities were also enumerated to account for any dead or missing plants within each 2-row harvest plot. 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 to assist in plant sizing determination. Based upon canopy diameter, plants were classed during the end of season survey into one of three canopy diameter categories: small ($\leq$ 20 cm), medium (>20 cm and $\leq$ 30 cm) or large (>30 cm) plant sizes. Based on previously determined yield relationships (Noling, 2009a), relative strawberry yield within each 2 row plot was then estimated from the cumulative plant count data from the four plant size and dead categories. Using the plant count data, relative strawberry fruit yields, relative to large plants, were calculated according to the following relationship: Dead = 0%; Small = 17%; Medium =

48%; and Large = 100%. The range in relative yield values was used to reflect the effects of nematode induced stunting of each individual small, medium, large, and dead plants as losses in plant productivity relative to the productivity of large plants. An overall relative yield value was computed as the cumulative sum of individual relative yield contribution of the 872 plants, divided by the maximum possible relative yield value of 872 for each 2-row plot. The relationship between actual strawberry yield (kg/ha; or numbers of flats/a) provided by the contract commercial harvester and estimated relative yield was then compared using the Dynamic Fit procedure of Sigmaplot v12.3 (Systat Software, Inc., Chicago, IL 60606).

Results and Discussion

Highly significant correlations ($P < 0.0001$) were always observed between actual harvest fruit yield (kg/ha) and relative yield derived from annual end of season plant size assessment (Fig. 1A–1E). For each annual analysis, best-fit linear or quadratic functions explained as much as 40% to 91% of the variability between harvest fruit yield (kg/ha) and relative yield based on estimated yield contribution using the number of plants in each of the three plant size and dead categories. With the exception
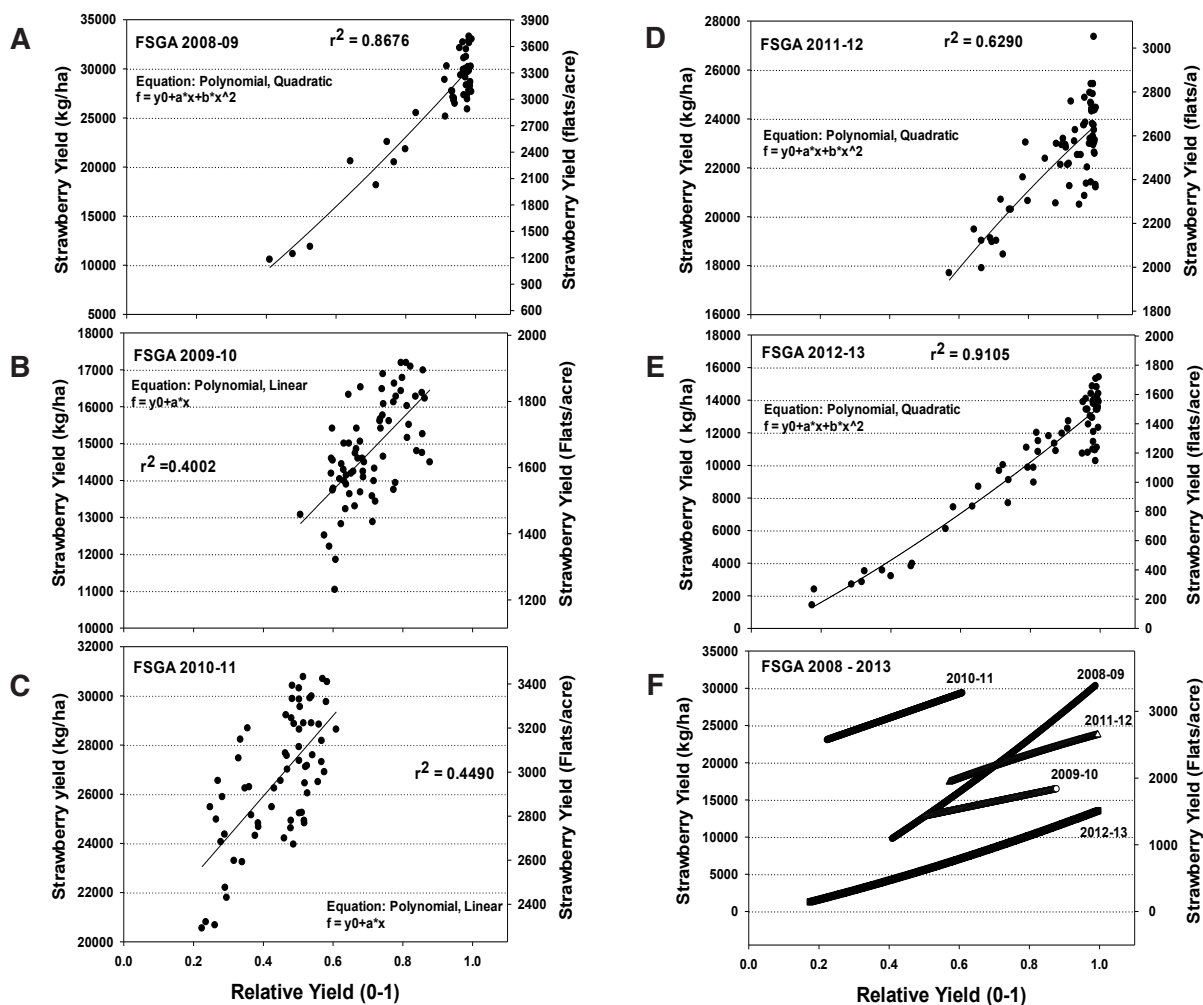

Fig. 1. Relationship between relative strawberry yield (0–1) computed from end of harvest season surveys of plants of different canopy sizes and strawberry yield (kg/ha) summarized from 2–3 days harvest schedules in the same 5.7 ha (14 acre) commercial strawberry production field at the Florida Strawberry Growers Association (FSGA) Research and Demonstration Farm in Dover, FL during the period 2008–13.

of 2008–09, slope values for regressions of relative yield and its predictor strawberry yield were similar (Fig. 1F). The similar slope values are interpreted to reflect the underlying plant principal imposed describing the proportionality of strawberry fruit yield to the size and dimension of the strawberry plant canopy.

Besides sting nematode, it was clear that other biological, environmental, and cultural practices and conditions had an impact on strawberry production levels and variability during the 5 year period. In some production seasons, culling of freeze damaged fruit obviously had significant and detrimental impact on strawberry production levels of marketable fruit. During the 2009–10 and 2010–11 strawberry production seasons, relative yield was not as well correlated with strawberry yield (Fig. 1B, 1C). During these two production seasons, reoccurring periods of cold weather and freezing temperatures inhibited overall plant growth and resulted in the culling and destruction of fruit over a significant part of the harvest season from January to February. Significantly lower yields of marketable fruit and or of higher frequencies of smaller plants contributed to the inability to describe more than 40% to 44% of the variability between actual and estimated relative yield in the two production seasons. When fruit loss is extreme over a particularly cold Florida winter, estimates of relative yield based on plant size distribution is probably a more accurate predictor of strawberry yield potential given differences between nematode management practices than actual fruit yield where cull fruit are discarded and are not quantified.

In addition to the effects of cold weather on yields during the 2009–10 production season, there were differences in strawberry plant sizes when plants were grown on new plastic compared with those grown as a second or double strawberry crop on the original plastic mulch. Strawberry plants grown on raised beds preserved from the previous year on old plastic were smaller within half of the FSGA experimental area compared to plants grown on new plastic. The overall smaller size could have skewed relative yield assessments to the observed range of tabulated values from 0.5 to 0.9 (Fig. 2B). During the 2012–13 production season, marketable yields were universally low among harvest yield plots because harvest labor was in such short supply that harvesting activities were not initiated at FSGA until mid-January and then were discontinued 6 weeks later at the end of February 2013. The low but hopefully representative fruit yields derived from individual plots which were harvested only 16 times rather than the 30–40 times during a typical production season extending from November to as late as April of each year (Fig. 2A–E).

Other factors could have influence the variability between the two different yield parameters. During 2010–11, only 40 percent of the variability between harvest fruit yield and relative yield was explained by simple linear regression analyses. This high level of observed variability can also be attributed to changes in late season survivorship of fruit bearing plants prior to our end of season plant size assessment. In early March 2011, a farm manager unknowingly shut off water and fertilizer to the field immediately after harvesting was claimed to be complete but weeks prior to the annual end of season plant size assessment conducted at the end of March. Plants which were even moderately stunted by the sting nematode quickly died from heat and water stress which resulted in a tabulated relative yield contribution of zero. This overestimation of normal nematode damage contributed to the situation of Fig. 1F in which high yields were not as well correlated with overall lower relative yield values. Based on these studies, it would appear that the utility and predictive powers of relative yield as a surrogate measure of harvest fruit
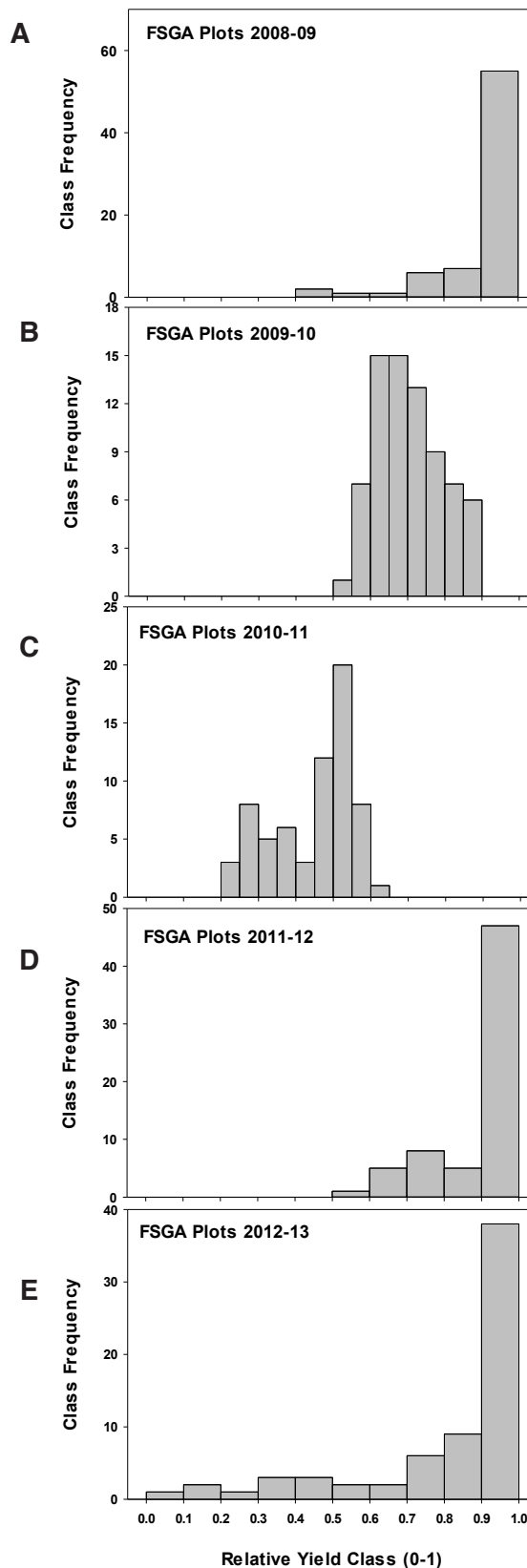

Fig. 2. Frequency distribution of relative yield (0–1) values computed from 48–66 individual 2 row plots of 872 strawberry plants. Relative strawberry yield (0–1) computed from end of harvest season surveys of plants of different canopy sizes in the same 1.2 ha (3 acre) commercial strawberry production field at the Florida Strawberry Growers Association (FSGA) Research and Demonstration Farm in Dover, FL during the period 2008–13.
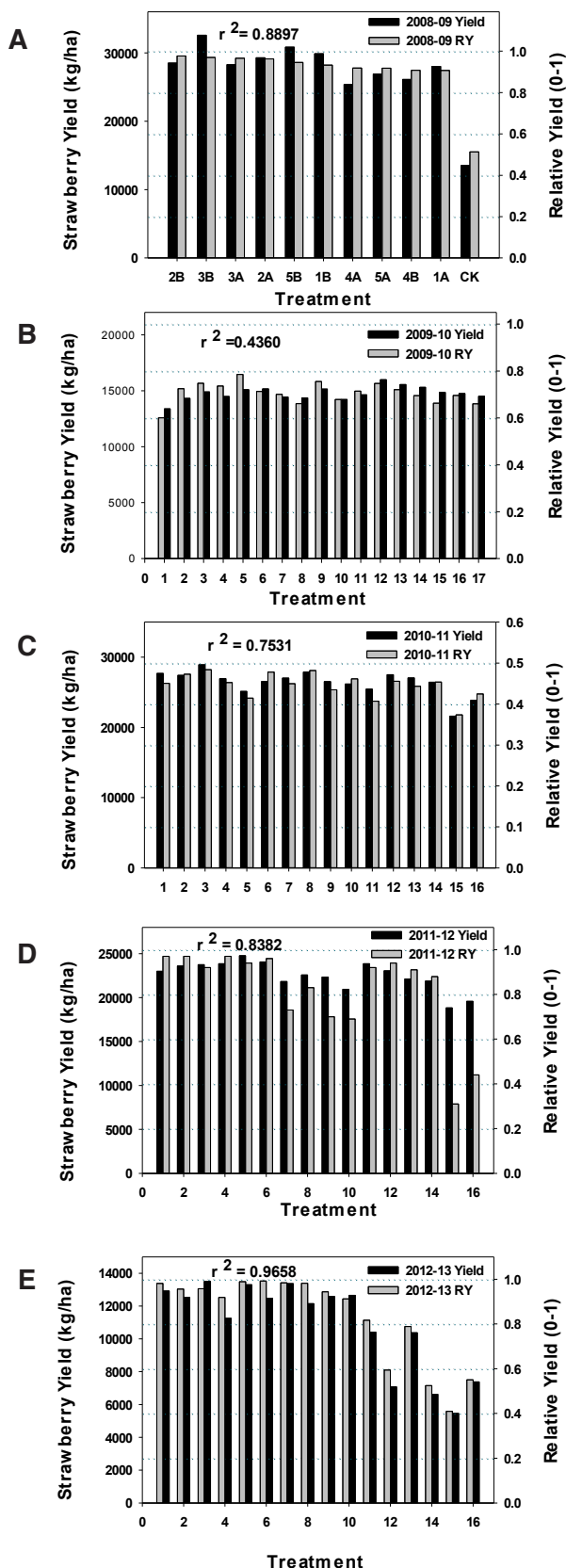
Fig 3. Comparison of strawberry harvest yield (kg/ha) and relative strawberry yield (0–1) computed from end of harvest season surveys of plants of different canopy sizes in the same 1.2 ha (3 acre) commercial strawberry production field at the Florida Strawberry Growers Association (FSGA) Research and Demonstration Farm in Dover, FL, during the period 2008–13.

yield occurs when there is a relatively healthy crop consisting of mostly large plants distributed through the field (Fig. 3 A, D, 3E). In this scenario, as much as 63% to 91% of the variability was accounted for in simple regression analyses between the two strawberry yield parameters. In practical terms, it is much easier to assess overall nematode impacts when nematode stunted plants are more patchily distributed in the field, particularly when plant growth is unaffected by other environmental factors such as cold or droughty conditions.

This research was initially conducted to focus on new approaches to characterizing 1) different nematode management strategies which did not require commercial harvest for yield comparisons; and 2) to describe the typically patchy field distribution of the sting nematode with incidence maps of differential plant stunting caused by the nematode using georeferenced counts of different strawberry plant sizes in the field at seasons end. Previous research has demonstrated the close correlation between fruit numbers, average fruit size, and weight on a per plant basis with changes in strawberry canopy diameter (Human, 1999; Noling, 2009a; Daz et.al, 2006). These studies have shown that strawberry yields ascertained from commercially harvested small plots were generally well correlated with relative yield values determined as a cumulative sum of relative yield contributions from plants of different sizes within the small plots.

This research also demonstrates that differences in strawberry plant sizes and relative yield were observed between various alternative to methyl bromide fumigant treatments during the five years of study at FSGA (Fig. 3, A–E). In general, plants in plots receiving no fumigant treatment were the most variable in size and produced relative strawberry yields which were usually more than 50% less than that of methyl bromide chloropicrin treatments. With the exception of 2009–10, very strong correlations ($r^2 = 0.75$–0.97) were observed between fruit yield and relative yield among the different fumigant treatments (Fig. 3, A–E).

In summary, the differences in incidence and severity of sting nematode plant stunting among the different preplant fumigant treatments allowed a robust comparison of estimated relative strawberry yield and actual harvested yield. Computation of relative yield is a simple process conducted at the end of the strawberry harvest season by which nematode induced crop losses can be easily derived from simple end of season plant size assessments rather than by hand harvesting over a 12–15 week harvest period. These data further show that the impacts of various nematode management tactics (chemical and nonchemical) on strawberry yield can also be meaningfully determined, on a field by field basis, from post-harvest assessments of counts of different plant sizes.

Literature Cited

Daz, A.K., B. Singh, and R.K. Sahoo. 2006. Correlation and path analysis in strawberry (*Fragaria ananassa* Duch). Indian J. Hort. 63:83–85.

Human, J.P. 1999. Effect of number of plants per plant hole and of runner plant crown diameter on strawberry yield and fruit mass. South African J. Plant and Soil 16:189–191.

MacKenzie, S.J., C.L. Xiao, J.C. Mertely, C.K. Chandler, F.G. Martin, and D.E. Legard. 2003. Uniformity of strawberry yield and incidence of Botrytis fruit rot in an annual production system. Plant Dis. 87:991–998.

Gilreath, J.P., B.M. Santos, and T.N. Motis. 2008. Performance of methyl bromide alternatives in strawberry. HortTechnology 18:80–83.

Martin, F.N. 2002. The use of remote sensing to monitor efficacy of control of soilborne pathogens of strawberry. Phytopathology 92:S51–S52.

Potter, J.W. and J.W. Noling. 1998. Nematode diseases. p. 76–81. In: J.L. Maas (ed.). Compendium of strawberry diseases. 2nd Ed. APS Press., St. Paul, MN.

Noling, J.W. 2008. Large scale demonstration trialing of methyl bromide alternatives in Florida strawberry. Proc. Annu. Intl. Res. Conf. on Methyl Bromide Alternatives and Emissions Reductions, Orlando, FL. p. 101–104.

Noling, J.W. 2009. Industry Wide Assessments of Methyl Bromide Alternatives in Florida Strawberry. 2009 Proc. Annu. Intl. Research Conf. on Methyl Bromide Alternatives and Emissions Reductions. San Diego, CA. p. 311–315.

Noling, J.W. 2009. Nematode management in strawberries. Entomol. & Nematol. Dept., IFAS, Univ. Fla. Florida Coop. Ext. Serv. Factsheet ENY-031 (NG031). 11 pp. <http://edis.ifas.ufl.edu/ng031>.

Noling, J.W. and M. Cody. 2011. USDA–ARS areawide project: Large scale field demonstrations in Florida strawberry 2010–11. 2011 Proc. Annu. Int. Res. Conf. on Methyl Bromide Alternatives and Emissions Reductions. San Diego, CA. p. 261–265.

Noling, J.W. 2011. Estimating strawberry yield and Sting nematode impacts using counts of plant sizes and fruit stems. 2011 Proceedings of the Fla. State Hort. Soc. 124: (accepted, #25).

Noling, J.W. and M. Cody. 2012. USDA–ARS South Atlantic areawide project: Five-year summary of large scale field demonstrations in Florida strawberry 2007–12. 2012 Proc. Annu. Intl. Res. Conf. on Methyl Bromide Alternatives and Emissions Reductions. Orlando, FL. p. 321–327.

Noling, J.W. and M. Cody. 2012. USDA–ARS Areawide Project: Large scale field demonstrations in Florida strawberry 2011–12. 2012 Proc. Annu. Intl. Res. Conf. on Methyl Bromide Alternatives and Emissions Reductions. Orlando, FL. p. 271–279.