Current Nursery IPM practices and incidences surveys of soil and foliar pests associated with US and Canadian strawberry transplants

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Summary

In Florida, nematodes, such as sting nematode (*Belonolaimus longicaudatus*), and soilborne fungal diseases caused by *Phytophthora* spp. and *Macrophomina phaseolina*, as well as *Colletotrichum* spp., are very important yield limiting pests of strawberry. Digital color imaging and in-field assessments of plant size were used to characterize the distribution and degrees of plant stunting, strawberry yield, and within row measures of green plant canopy cover associated with the sting nematode. Disease incidence, severity, and crop impacts were assessed from ground survey and analysis of aerial imagery. Aerial imaging surveys of over 20 commercial field locations were seasonally conducted from November 2017 to March 2018 and Nov 2018 to March 2019. Image orthomosaics were created and processed RGB and NDVI maps were oftentimes both visually evaluated and impacted plants enumerated and or analyzed. Strawberry canopy cover, relative yields and enumerations of disease incidence and plant stunting were derived from inspection of drone images and then compared using regression analysis with ground truth field surveys. It was demonstrated that these new aerial imaging techniques and greeenness analysis have great potential to facilitate and increase accuracy and precision in quantifying nematode and plant disease incidence, plant growth response, performance of fumigant and nonfumigant pest management practices, and of long-term impacts within the strawberry cropping system that may be due to transplant quality.

Methods

At and After Transplanting (September-November): Just prior to the planting season, announcements were made through FSGA membership and UF/IFAS Cooperative Extension newsletters regarding the reporting of any in-field production problems of transplant quality. Once we had been notified, field visits to inspect the problem field were scheduled with each grower, at which collection of soil and plant tissue to assist with disease diagnosis took place. The UF/IFAS Plant Diagnostic Clinic, at the Gulf Coast Research and Education Center oversaw the processing and analysis of incoming samples. Once a problem with transplants was reported and the causal agent confirmed, the affected area within the field was flown (Figure 1) using a DJI Phantom 4 Pro quadcopter drone (Figure 2) equipped with a DJI 24mm 20MP camera with an Exmor R CMOS sensor at an altitude of 40 -50 feet.

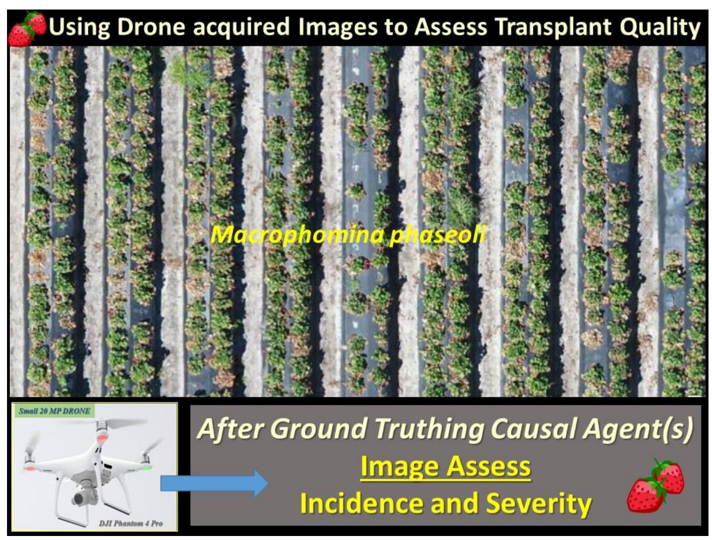

Figure 1. Using Drone Acquired Aerial images to Assess Transplant Quality in a strawberry field.

Repeated 20-megapixel color images (20 million pixels/ photo) were systematically taken and the images commercially stitched to form a single high-resolution map (0.4 to 0.8 inch/pixel) to characterize the states of strawberry plant growth and disease incidence and severity.

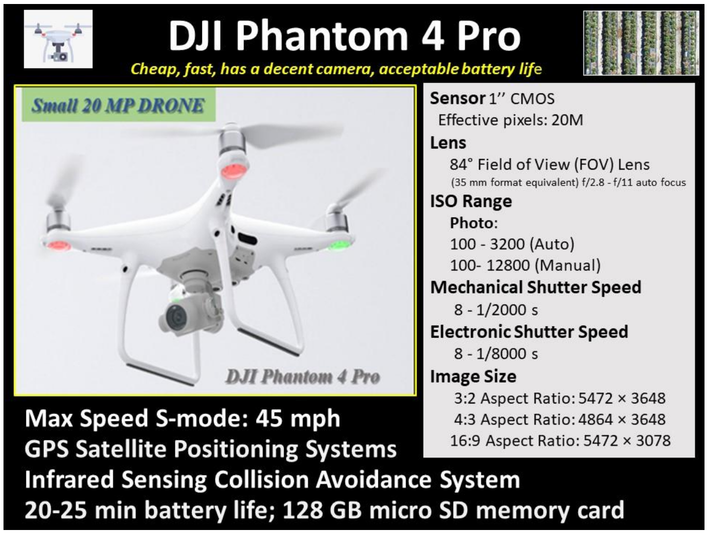

Figure 2. A DJI Phantom 4 Professional Series drone.

Image orthomosaics were created using DroneDeploy™ cloud software platform with an image resolution of 10 to 20 mm per pixel. Processed RGB and NDVI maps were oftentimes both visually evaluated and impacted plants enumerated and or analyzed using ESRI™ ArcGIS v10.33. Data to correlate goodness of fit between in-field assessments and aerial images were made to determine its value as a disease assessment tool. Both within-field and aerial image estimates of disease incidence and severity derived from 20 plant count data and analysis of means within plant status categories. The field was flown on an "as needed" periodic basis to visually monitor plant status during the course of the growing season to account for replanting and or production delays, and to conclude with an end of the season aerial to estimate impacts to crop production, if any, using green pixel counts per row to document canopy / vegetative cover, hoping that none are visual. We used plant counts within specific categories of dead, missing, decline, stunted, wilted, as well as those suffering from varying degrees of canopy dieback (browning of older, outer foliage) as examples of plant symptoms that are easily quantifiable from the air.

Post Transplant Assessments (December-March): In production fields where transplant problems have occurred, assessments of plant growth were made as appropriate during the course of the season to characterize differences in plant size, health, and vigor within transplant problematic fields (Figure 3). If warranted, final end of season impact assessments included characterizations of overall disease incidence (i.e., Anthracnose, Phytophthora crown rot, Charcoal rot, root galling, plant stunting, etc.) and severity were visually determined and recorded along with crop loss assessments provided as estimates by each affected Florida strawberry grower.

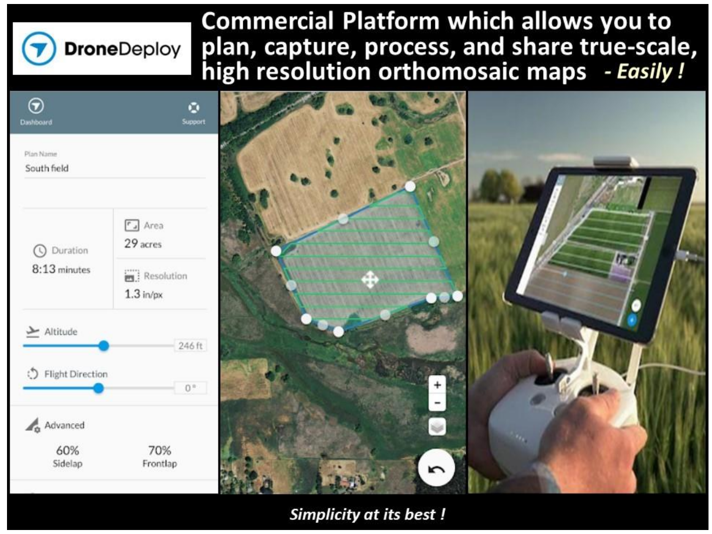

Figure 3. Drone Deploy™, a commercial software platform to plan, capture, process, and share true-scale high resolution orthomosaic maps.

Results

Plant mortality due to charcoal rot, caused by *Macrophomina phaseolina*, was identified in commercial fields with varying degrees of plant infection and decline (Figure 1). The use of Drone Deploy™ (Figure 3) allowed us to plan, capture, process, and share true-scale high resolution orthomosaic maps. An orthomosaic map is a detailed, accurate photo representation of an area, created out of many photos that have been overlaid and stitched together and geometrically corrected ("orthorectified") so that it is as accurate as a map. Using Drone Deploy™, users plan individual missions, using Google Earth™ to first establish the boundary coordinates for the field to be flown (Figure 4). The program then allows you to determine the front and side overlap features which determines the size of the grid network that the drone will fly within the field.
During flight, drone acquired images are collected every 3 to 4 seconds dependent upon flight speed. Once the flight mission has completed within the field, the images are transferred to a labelled site-specific folder on your computer. At this juncture, the internet Drone Deploy™ website is contacted to allow information to be forwarded / uploaded to a Drone Deploy™ database. Drone Deploy™

loads all of the images and stiches them all together to form a larger, single image georectified map. Drone Deploy™ allows the user to determine which map projection (NAD 27 / Florida West), plant health (NDVI) or orthomosaic, and resolution in which to develop the map. The map is then exported for further analysis regarding assessment of nematode and or disease incidence and or severity (Figures 5).

Figure 4. Using Drone Deploy™, users plan individual missions.

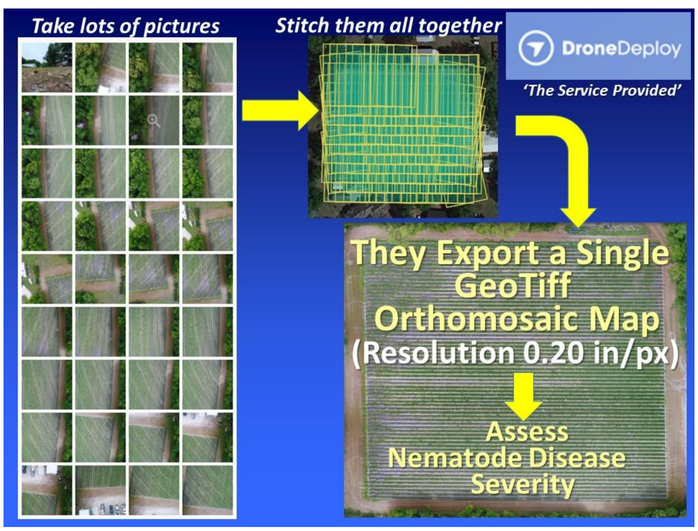

Figure 5. The sequence of events which occurs from flight of the drone within the field to export of the GeoTiff Orthomosaic map.

An example of a GeoTiff Orthomosaic field map generated within and exported from Drone Deploy™ is provided in Figure 6. The map illustrates the significant loss in strawberry plant populations (grey areas) in a commercial strawberry field in Plant City, FL. Plant losses, based on soil and root tissue samples submitted to the UF/IFAS Disease Diagnostics Laboratory confirmed the causal agent as *Macrophomina phaseolina*. Infected plants were removed from the plant bed which exposes the black / grey plastic mulch covering the plant bed.

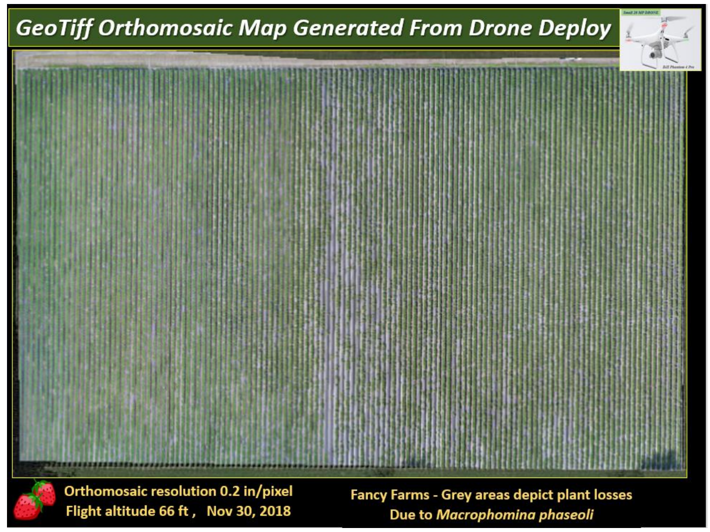

Figure 6. Example of a GeoTiff Orthomosaic Map generated with Drone Deploy™ software platform.

Disease incidence was assessed by counts of the numbers of missing, dead, and decline plants were numerally assess by row using a 4 button multi-tally counter. In addition to disease incidence, plant densities by plant size category were made by direct observation and counts using the same Drone Deploy™ Plant Health NDVI orthomosaic map. After per row counts were made, the data was immediately input into an Excel spreadsheet for subsequent statistical analysis. In the example above, strawberry plants were counted into plant sizes of small (<8"), medium (8-12"), and dead / missing categories. The numbers of large plants (.12") was derived by subtraction of the total number of plants possible per row. When undetermined, row spacing's were assumed at 16 inches between adjacent plants within rows.

To determine whether orthomosaic maps could be effectively used to assess plant size impacts caused by nematodes and soilbone pathogens, ground truthing survey of plant counts into the various size and status categories needed to be collected to determine if it could be used as a surrogate for quantifying plant responses. In general, plant size distributions were enumerated for a variety of fields in which different chemical treatments were being field evaluated. Rows were physically walked, and plant sizes were counted using handheld button counters. At the ends of each row, the numbers of small, medium, dead / missing plants were recorded to a data sheet on a clipboard. These numbers would compare with counts by row derived from the orthomosaic maps.

Relative strawberry yields were estimated via assessment of strawberry plant sizes and using drone acquired digital imaging of strawberry plant canopy. The numbers of plants in four plant size categories were systematically enumerated and recorded in each row. For this assessment, plant size categories, measured as average canopy diameter, were dead (0), small (<8" canopy diameter), medium (>8 and < 12") and large (>12"). Using plant sizes, fumigant treatment evaluations based on relative yield were determined from damage relationship developed from studies conducted previously in commercial fields with recurring histories of sting nematode problems. Digital field imaging technology were used to characterize and relate differences in relative strawberry crop yield (based on plant sizing) to within row, green vegetative cover. As illustrated above, relative strawberry yield was computed as the sum contribution of plant counts within each of the different size categories determined in each row. Small, Medium, Large, and Dead / Missing plants were assumed a relative yield (based on previous research) of 17%, 48%, 100%, and 0% of maximum yield potential of each individual plant.

Using Drone Deploy™, the orthomosaic maps were translated to RGB (red, green, blue) NDVI maps using the Plant Health feature within Drone Deploy™ (Figure 7). The NDVI orthomosaic files were imported into ArcGIS, another UF license geographic information system (GIS) for working with orthomosaic maps and geographic information. The buffer tool of ArcGIS was used for creating rectangular boxes around entire lengths of strawberry row framed by the plastic mulch and calculating percent greenness (the overall percent strawberry canopy cover within the bed) and for enumerating category counts of plant sizes within the row. The data from these individual row observations was then compiled and analyzed for disease or treatment impacts.

Percent Greenness per strawberry row was independently calculated within ArcGIS using either the Drone Deploy™ orthomosaic digital color map or the RGB (red, green, blue) NDVI maps (Figure 8). Percent greenness obtained from either analytical approach was then correlated with relative yield values for each strawberry row at the Florida Strawberry Growers Association Research Farm in Dover, FL on March 7, 2019. Relative yields (based on plant sizes) were always well correlated with percent greenness, regardless of the map source used to calculate greenness. In general, the R-squared value, a statistical measure of how close the data are to the fitted regression line, explained as much as 84 to 86% of the variation between relative yield and the two different analytical methods of calculating greenness. Based on previous research, the data above suggests that either relative yield or percent greenness can be used as surrogates in estimating inherent yield differences in fruit production within fields and or between pest management treatments.

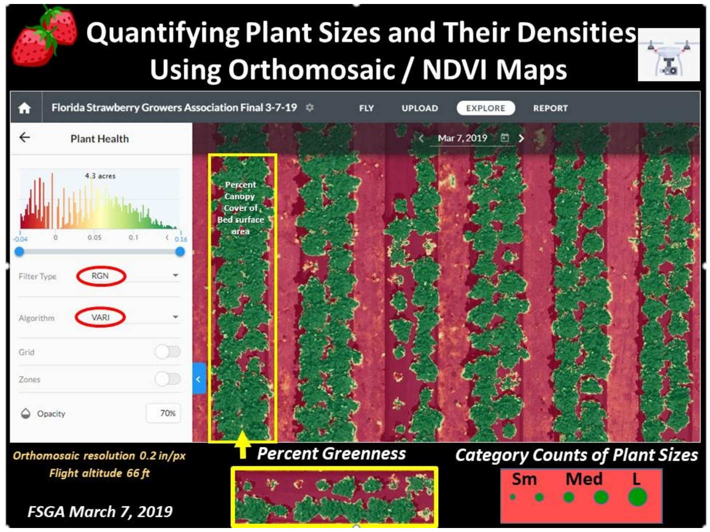

Figure 7. Quantifying Plant Sizes and Their Densities Using Orthomosaic / NDVI Maps.

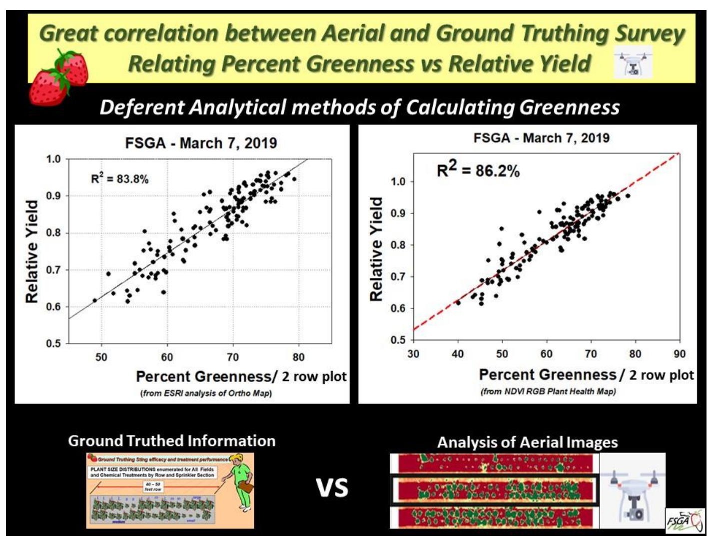

Figure 8. Correlating Aerial and Ground Truthing Survey relating Percent Greenness and Relative Strawberry Yield at the Florida Strawberry Growers Association Research Farm, Dover, and FL. March 7, 2019.

The number of missing (top panel) and total numbers of missing, dead, and decline plants (bottom panel) was independently regressed against their corresponding values obtained from ground truth walk survey of each strawberry row within the field (Figure 9). In general, the R-squared value, a statistical measure of how close the data are to the fitted regression line, explained 97 and 97% of the variation between the two different analytical methods of enumerating measures of disease incidence within the field. The close agreement between aerial and ground trothing, suggests that the aerials can be effectively used for quantifying plant disease impacts.

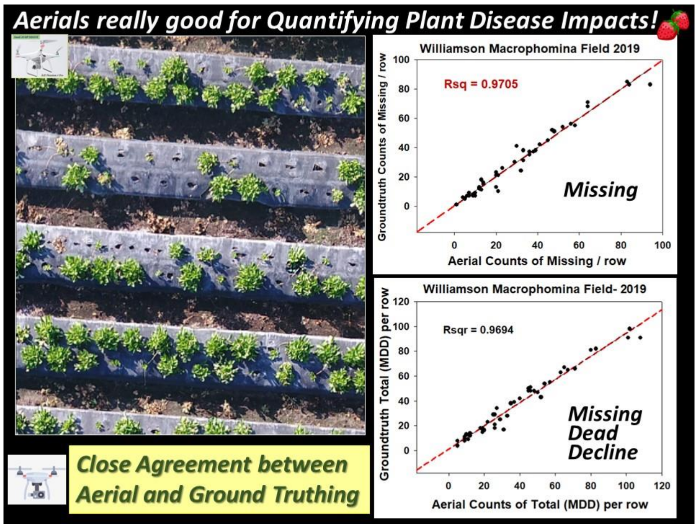

Figure 9. Quantifying Plant Disease Impacts using High Resolution Aerial Images.

The total numbers of missing, dead, and decline plants per plant row was determined from both ground survey (walk-the-row) and from the aerial images and orthomosaic map (remotely sensed) (Figure 10). Disease incidence was regressed against their corresponding values obtained from ground truth walk survey of each strawberry row within the field. For this analysis, the R-squared value, a statistical measure of how close the data are to the fitted regression line, explained 96% of the variation between the two different analytical methods of enumerating disease incidence within the field. The close agreement between aerial and ground truthing, suggests that the aerials can be effectively used for quantifying plant disease impacts, and that fields no longer have to walked to provide accurate assessments of disease incidence.

In another Fancy Farms field (the Phytopthora/Pythium field), the total numbers of missing, dead, and decline plants per plant row was determined from both ground survey (walk-the-row) and from the aerial images and orthomosaic map (remotely sensed) (Figure 11). Disease incidence was regressed against their corresponding values obtained from ground truth walk survey of each strawberry row within the field. For this analysis, the R-squared value, a statistical measure of how close the data are to the fitted regression line, explained 88% of the variation between the two different analytical methods of enumerating disease incidence within the field. Again, the close agreement between aerial and ground truthing, suggests that the aerials can be effectively used for quantifying plant disease impacts, and that fields no longer have to walked to provide accurate assessments of disease incidence.

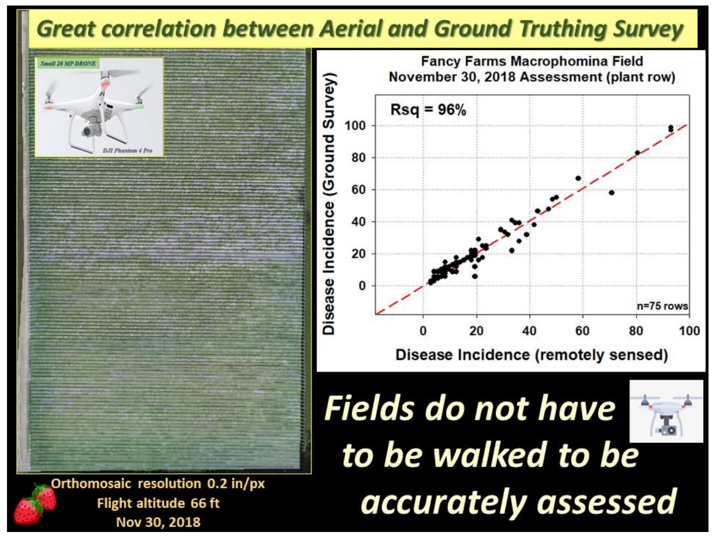

Figure 10. Comparison of Quantifying Disease Incidence using High Resolution Aerial Images and Ground Truthing Walk Survey.

The value of strawberry fruit production from individual strawberry plants *cv*. Radiance was estimated using grower supplied production records and pricing information for the 2018-2019 Florida strawberry production season (Figure 12). Harvest records and pricing information was supplied from the first fruit harvest (Nov 15, 2018) through 19 harvests to the end of March 2019. The field was early planted on Sept 28, 2018. The time weighted average flat price was calculated as $13.36 per flat. Cumulative net revenue was calculated as the 19-harvest sum of total flats harvested per acre and cumulative net revenue using current market pricing. Total net revenue per acre was calculated as $41,803 per acre. Total net revenue per acre was divided by the total number of plants per acre (16,340) to determine the average value of fruit produced per individual plant at $2.66 per plant. This plant value was then used to estimate the economic impact of differing levels of disease induced plant mortality and for plants which succumb to disease at different times during the season.

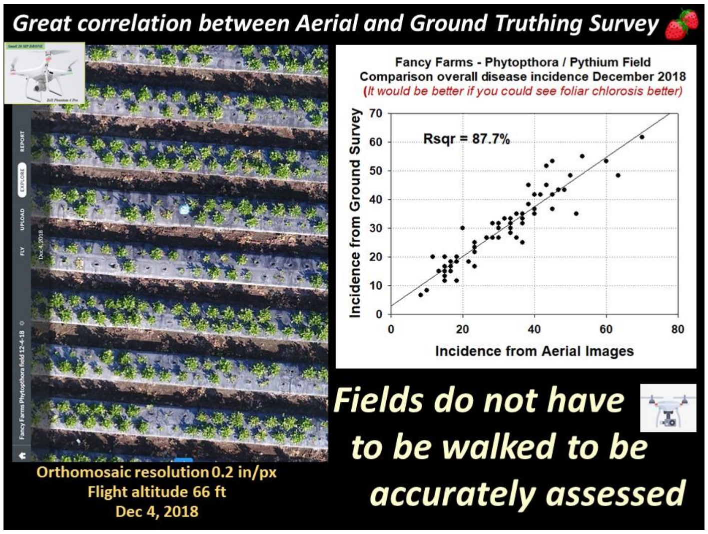

Figure 11. Comparison of disease incidence derived from counts of dead, decline, and missing enumerated from Orthomosaic maps and Ground Truthing Walk survey of a disease infested field.

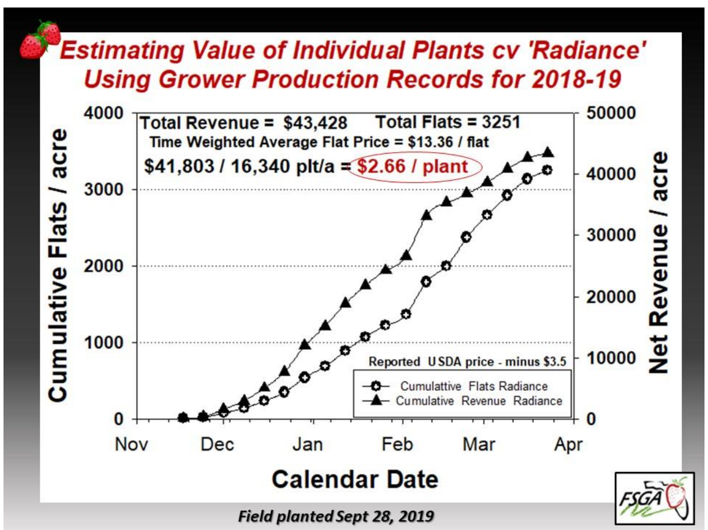

Figure 12. Estimations of the value of strawberry fruit production from individual strawberry plants *cv*. Radiance using grower supplied production records and pricing information for the 2018-2019 Florida strawberry production season.

The value of strawberry fruit production from individual strawberry plants *cv*. Radiance, Brilliance, and Florida Beauty was estimated using grower supplied production records and pricing information for the 2018-2019 Florida strawberry production season (Figure 13). Harvest records and pricing information was supplied from the first fruit harvest (Nov 15, 2018) through 19 harvests to the end of March 2019 for each of the different strawberry cultivars. Cumulative net revenues were as the harvest sum of total flats harvested per acre and cumulative net revenue using current market pricing. Total net revenue per acre was calculated and divided by the total number of plants per acre (16,340) to determine the average value of fruit produced per individual plant for each of the cultivars. A range in plant value of $2.48, $2.66, and $3.21 was calculated for Florida Beauty, Radiance, and Brilliance respectively. These estimated plant values were then used to estimate the economic impact of differing levels of disease induced plant mortality. The economic value of lost plants per acre increased linearly with plant mortality. At typical levels of plant mortality induced by fungal pathogens of 10%, the value of lost productivity hovers around $5,000 per acre for any of the 3 cultivars included within the assessment. This represents a significant loss in productivity and of a new method in which to estimate the economic impact of soilborne plant diseases.

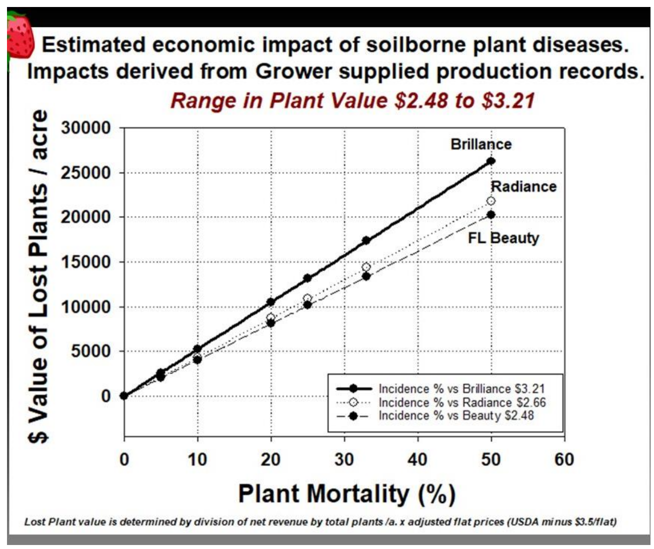

Figure 13. Estimated economic impact of strawberry plant mortality induced by soilborne plant diseases in Florida strawberry fields during the 2018-2019 production season.

The value of strawberry production, as a percentage of total plant value over the entire production season is illustrated in Figure 14.

For this analysis, estimates of percent total plant values are based on grower provided strawberry production and market pricing information during the 2018 -2019 Plant City, FL production season. From this analysis, the value of strawberry fruit produced by each individual plant within the field was estimated at $2.66. It also illustrates that only 20 percent of the net value of $2.66 per plant is realized by January 1, with 40% on Feb 1, 80% by March 1, and 100% by April 1. The analysis allow consideration for per plant fruit production before plants succumb to disease at different times during the season. The analysis forms an integral component to the assessment of plant and fruit yield losses to diseases introduced early into fields from transplants, and accounts for disease progression and severity with time.

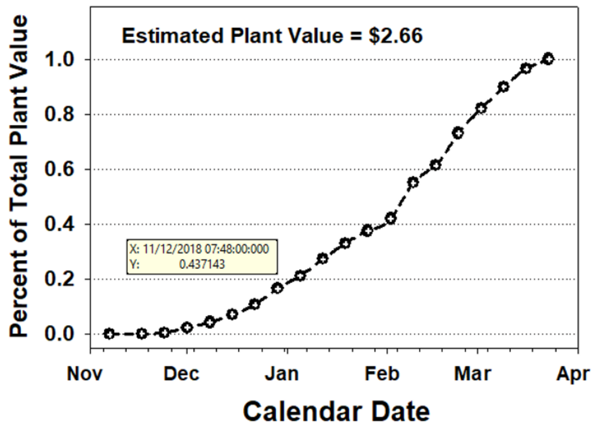

Figure 14. Value of strawberry production, as a percentage of total plant value over the entire production season. Estimates are based on grower provided strawberry production and actual market pricing information during the 2018 -2019 Plant City, FL production season.

In general, these studies demonstrated that high resolution aerial images and the orthomosaic maps which they derive from are cheap, fast, and technologically easy to obtain and process using the commercial Drone Deploy™ software platform. The orthomosaic maps were faster to enumerate plant densities per row into various plant size, greenness, and health categories than to enumerate from walk surveys down each field row. Relative yield, NDVI, or Greenness (counts of green pixels per row) were always well correlated surrogates for strawberry yield. The enumeration of plant densities into the different plant size and health categories (dead, decline, missing) is essential information required to determine economic impacts and crop losses. For the economic analysis, plant net values in fruit production were used to estimate strawberry production losses from disease incidence statistics, and to economically account for disease progression and severity with time.

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