EPA Region 6 Strategic Agricultural Pesticide Initiative Program
Project # X-976017-01-0

Using Satellite based positioning systems (GPS) to identify and manage populations of plant parasitic nematodes in cotton

by

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Abstract

In 2002 EPA Region 6, Dallas TX funded a Strategic Agriculture Pesticide Initiative grant allowing LSU Ag Center Researchers to explore the use of Geographical Information System (GIS), and Global Positioning System (GPS) technologies to characterize and manage the spatial and temporal variability of plant-parasitic nematodes in cotton. The major nematode species affecting crops in Louisiana are the Southern root knot nematode, *Meloidogyne incognita* and the reniform nematode *Rotylenchulus reniformis.* In these studies, apparent soil electrical conductivity (EC_a) was collected using a Veris® model 3100 sensor cart system. Real-time kinematic (RTK) GPS was used for automated collection of accurate elevation data. Elevation was highly correlated to shallow Veris® sensor data in the Gin Ridge delta alluvial field. Analysis of the relationships between elevation and EC_a yielded R^2 values of 0.76 for the shallow electrical conductivity ($EC_{a\_}$ sh) and 0.89 for the deep. A correlation matrix for selected variables indicated percent clay was highly correlated with $EC_{a\_}$ sh ($R^2 = 0.92$) and negatively correlated with Mean Sea Level (MSL) elevation ($R^2 = 0.80$). Coefficient of variation (CV) values for the five fields in these tests indicate some fields would be better suited for site-specific management of nematodes than others. Coefficient of variation values ranged from 0.42 - 0.65 in the shallow sensor data and from 0.43 - 0.71 in the deep sensor data. EC values ranged from 7.2-148.7 respectively, in the shallow and deep sensor data. Soil samples taken to determine the average clay content by EC_a classes indicated nematode population densities decreased to below economic threshold levels when clay content was 15-20% or greater. Therefore, root knot nematode densities were above economic threshold only in the lower soil EC_a classes that were generally lower than 30 mS/M in all test fields. Using topographic measurements (i.e. elevation), it was determined that root knot nematode levels were above threshold only in the lighter soil on top (upper 3 ft.) of the ridge fields. By capitalizing on selected GPS technologies (Veris, RTK, aerial imagery, and yield monitors), the potential for up to 77% reduction in treatment requirement for root knot nematodes is described. These findings illustrate that use of elevation and topographic maps incorporated with new GIS and GPS technology could improve integrated pest management capability for root knot nematodes in Louisiana. While not a major objective of this research, observations indicate that use of aerial imagery could also be useful in detecting nematode/wilt damaged areas in fields. Improvements in sampling efficiency derived from geo-referenced samples would lead to better use of host plant resistance, crop rotation, and site-specific management of pesticides. Site-specific management would help maximize production and allow programs of optimum environmental stewardship to be implemented.

Introduction

LSU Ag Center scientists launched this project to explore the use of Geographical Information System (GIS), and Global Positioning System (GPS) technologies to characterize and manage spatial and temporal variability of nematodes. The major nematode species affecting cotton in Louisiana are the Southern root knot nematode *Meloidogyne incognita* (Kofoid & White) and the reniform nematode *Rotylenchulus reniformis* (Linford & Oliveira). The cotton disease and nematode loss estimates from 1965 – 2004 range from 2% and 10%. Without adequate treatments for root knot and reniform nematodes annual loess would increase (Overstreet and McGawley, 1999; Overstreet and McGawley, 2000; Overstreet and McGawley, 2001 and Overstreet et al., 2001).

Root-knot nematodes were the major species evaluated in this series of tests. Populations of nematodes are determined from soil sampling. Since these populations are usually not uniformly distributed in a field, a large number of samples, taken in a timely manner, are required to accurately characterize the distribution and infestation levels. Unfortunately, producers usually do not have the time to sample fields in a manner that accurately characterizes the distribution and densities of plant parasitic nematodes. As a result, when damaging levels of nematodes are identified the entire field is treated even though the entire field may not need treating. Sample strategies developed using GIS and GPS technology could reduce the nematode sample requirement and/or collection time. The technologies also have the potential to serve as a basis for developing site-specific treatment strategies that would increase agronomic productivity and environmental stewardship. Increased awareness of the magnitude of these problems would aid in the implementation of host plant resistance and rotation management practices that can lower damaging infestation levels of nematodes.

Apparent soil electrical conductivity measurements represent acceptable GPS technology to aid in identifying contrasting soil properties for environmental and geological purposes. Recently, researchers have used bulk soil electrical conductivity to measure or estimate many chemical and physical properties of non-saline soils, such as clay content (Williams and Hoey, 1987), Cat ion exchange capacity (CEC), exchangeable calcium (Ca) and magnesium (Mg) (McBride et al., 1990), depth to clay pans (Doolittle, et al., 1994), and texture, Ca, Mg, K, and CEC on soils of the Mississippi Delta (Kitchen et al., 2000). The recent advances in collection of geo-referenced apparent soil electrical conductivity (EC_a) measurements also show considerable promise for use in defining soil textural zones within agricultural fields. These data have also been correlated with nematode activity (Khalilian et al. 2001 and Stevens 2002)).

This research adds Real Time Kinematic (RTK) GPS as a new technique for use in plant parasitic nematode management. RTK GPS provides cm level accuracy for elevation measurements. Topography measurements represent a quantitative and repeatable spatial measurement tool that proved to be of value in this research. RTK GPS measurements taken on delta alluvial soils indicate that Mean Sea Level (MSL) elevation could be useful in defining portions of fields that support damaging levels of plant parasitic nematodes. Therefore, a second method to improve strategies for precision sampling and/or site-specific management of nematodes is described.

Summaries are provided for research conducted from 2001 – 2004 in the lower Mississippi delta alluvial soils of Northeast Louisiana near St. Joseph, LA. This research demonstrates our ability to conduct site-specific nematode pest management. The major nematode problem in the delta alluvial fields was root knot and the variability in population densities due to soil type illustrate that GIS/GPS technology could help identify precisely the location of damaging infestation levels. The economic benefit for using site-specific applications in management of root knot nematodes is apparent due to the conformation that nematicide treatments could be reduced when using established economic thresholds.

Methods

Apparent soil electrical conductivity (ECa) measurements for texture mapping, elevation data for developing topographic maps and applications of variable-rate treatments were collected using several GPS systems. A Veris® model 3100 sensor cart system (Suddeth et al., 1999), Real Time Kinematic (RTK) GPS systems with cm accuracy in topographic measurements (Clark and Lee, 1998) and a variable-rate granular applicator was utilized to collect data and apply site-specific pesticide applications. The applicator was equipped with a Mid-Tech TASC-6100 rate controller, radar, and a hydraulic valve. A two row Telone applicator equipped with 32 inch coulters was used to apply Telone II at depths of 10 -12 inches.. This research was conducted in small field plots and on-farm. Methods used for statistical and economic analysis included correlation analysis, comparisons of coefficients of variation (CV), and comparisons of nematicide treatment profitability by management zone. Statistical evaluations were accomplished using SAS, SSTool box, Agriculture Research Manager 7, and Surfer.

VERIS

Apparent soil electrical conductivity data EC_a was collected utilizing a Veris® 3100 soil electrical conductivity mapping system, Veris Technologies, Salina, Kansas. Electrical conductivity is defined as the ability of a material (in this case, soil) to conduct an electrical current. The unit of measure is milli Siemens per meter (mS/M). This sensor consists of six coulters, two of which introduce an electrical potential into the soil (Fig 1). The remaining four coulters are spaced to measure apparent soil electrical conductivity (EC_a) over two approximate depths. The shallow (0 – 1 foot) sensor measurement was designated as EC_a _sh and the deep (0 – 3 foot) sensor measurement was designated as EC_a _dp. The Veris® 3100 cart was used in conjunction with a sub-meter accurate GPS receiver, and geo-referenced data was collected at one-second intervals. The standard operating width across fields was 40 feet which resulted in the collection of 100+ data points per acre. The Veris® system logs all data to a data storage device in the operating console. The soil electrical conductivity data derived from the Veris® system was analyzed utilizing SSToolbox, an agriculture-oriented GIS operating in ArcView 3.x., and utilizing Surfer for data interpolation. For purposes of analysis, data collected from test fields was converted from its native *.dat format into ArcView compatible shapefiles. The EC_a point data was interpolated using Kriging to create continuous 20ft x 20ft grid cells representing the EC_a values for the entire project field. Surface data layers were then classed by ranges (management zones) using "Natural Breaks" based on interpolated values for each grid. The number of soil classes or management zones was derived and representative of textural variability of the field. From this data, a sampling scheme was created for the purpose of collecting soil samples for texture and nematode analysis. Previous research was used to determine number of EC_a classes, into which a field is separated for sampling or management purposes. The number of ECa classes will depend upon the desired level of sensitivity and within-field variability (Johnson et al., 2001). Therefore, fields would have a common number of classes only if within-field variability was similar. Whole field Univariate Statistics was used to test for field variability and values for the number of acres, Variance, Standard Deviation and Coefficient of Variation are included in each tabulated report.

Data derived from soil samples pertaining to nematodes and soil properties was utilized to formulate variable-rate nematicide prescriptions for each project field. Variable-rate prescriptions were created by examining the relationships among EC data, soil property data, and nematode data. SSToolbox was used to perform these analyses.

RTK

Elevation data was collected for topographic maps using a GPS topographic collection system consisting of a (RTK) GPS receiver, a RTK Base station, a data radio link for the RTK Base station, and a field computer with software. Data was collected in a shape file format. The base station equipment was comprised of a Trimcomm 900M data link radio, base station GPS dual frequency antenna, and AgGPS 214 dual frequency receiver. A mobile unit was equipped with an antenna rover radio, AgGPS 214 receiver and AgGPS 170 field computer (Trimble Navigation Limited, 645 North Mary Avenue, Post Office Box 3642, Sunnyvale, CA 94088-3642). The mobile unit allowed topography data to be collected without the limitations of using laser equipment. The base station was mounted on a tripod and used as a portable unit when operating beyond the ranges established for a fixed base station (Fig 1).

Standard procedures for taking topographic data on the Trimble Ag GPS 170 Field Computer were used. A benchmark was established each time a field was mapped and a common benchmark was used when several fields were within the range of a base station. A transect interval of approximately 40 ft. was used to collect elevation points. Upon collection of elevation data, the compact flash card was removed from the AgGPS 170 field computer and transferred to an office computer for incorporation into selected GIS programs.

In order to summarize the attributes contained in the 20 ft. grid megasurface for each soil sample point, the grid megasurface was converted to point data. SSToolbox was used to calculate the spatial coordinates for the centroid of each grid cell and edit the database containing those coordinates. The database was then exported (EPAmegasurfacepoints) and added back to the GIS project as a point data layer, with each point containing all of the attributes for each grid cell. Data from this point layer was summarized as attributes in the sample point layer. A function in SSToobox performs this summary by performing a spatial query of all points within a specified distance of each sample point (in this case 30') and editing the sample point layer database to add the average. This layer was named EPA Mega Point Data, and contained attributes for all of the nematode data and soil data derived from the sample analysis at that point.

Data Maps

Spatial data analysis for this project was performed using SSToolbox, an agriculture-based GIS operating in ArcView 3.x., and utilizing Surfer for interpolation. SSToolbox, as an agriculturally oriented GIS, is based on a Client/Farm/Field data structure. A field boundary polygon for each project field was collected in the field using a sub-meter GPS receiver and mapping software. A new "Field" was created within SSToolbox, based on the field boundary of each project field. Elevation data derived from RTK GPS surveys, and the geo-referenced soil electrical conductivity data derived from the Veris® 3100 Soil EC mapping system, and soil properties and nematode data derived from geo-referenced soil sampling, was added to the project as separate point themes (spatial layers), and classified into a chloropleth map based on natural breaks of the relevant attribute (Figs. 2 and 3.).

This placed all relevant data for each project field into the spatial dataset, contained in several different data layers in the GIS project. These were ultimately defined as management zones. Management zones are defined as "a sub-region of a field that expresses a functionally homogeneous combination of yield-limiting factors for which a single rate of a specific crop input is appropriate" (T. A. Doerge et al., SSMG-30).

Each theme, or layer, of point data was interpolated using Kriging to create a new "surface" layer composed of grid cells measuring 20 ft. by 20 ft. This resulted in several new data layers, each containing one attribute. Since the process creating the grid surfaces is identical in each case, each new data layer contained the same number of grid cells of the same size in the same spatial location. The grid cells were assigned an ID number when created, and all of the new layers then had a common attribute field on which to perform a spatial joining of the layers, creating a single data layer containing all of the attributes. This resulted in a single data layer containing all relevant data at identical spatial locations, upon which statistical analyses was performed.

The densities of plant parasitic nematodes were recorded in one-acre grids in all test fields. This information was then used to identify and consolidate regions in fields with damaging levels of root-knot nematodes. These data formed the basis for developing nematode application plans and prescription plans.

Verification Tests

On farm evaluations for nematode management were conducted at selected locations in Northeast Louisiana. Treatments were applied in either randomized complete block designs or strips across fields, depending on the objective and methods of harvest. Variable-rate application techniques were conducted with the nematicide/insecticide standard Temik 15G applied at 5 lbs product/acre. Broadcast and variable rate treatments were applied as a side-dress post emergence application with a target application window of early pinhead square. Telone II was applied with a two row applicator equipped with 32" coulters so the fumigant could be placed at a 12" soil depth. Telone II was applied at 3 gal/product per acre. Data collection and management was facilitated through the use of Agriculture Research Manager (ARM). The ARM program provides for complete organization and record keeping. Other data analysis was performed using SAS.

Soil and Nematode Samples

Soil samples were collected for identification and quantification of plant-parasitic nematodes. Root-knot nematodes are the primary plant-parasitic nematodes for this project. Fields were selected based on the past history of nematodes, reasonable accessibility, and size. Field sizes ranged from 25 – 95 acres. Larger fields were not chosen because of time constraints associated with data collection. Generally, the fields were sampled in the fall after stalk destruction until the onset of winter rains. However, some spring samples were collected. Duplicate sampling was often done for confirmation of results.

Prior to sampling, each field was mapped using a GPS system and segregated into 1-acre grids. Geo-referenced elevation data was collected with Trimble's RTK system. Apparent soil electrical conductivity data was collected using a Veris ® 3100 sensor system. The rationale for use of 1-acre grids was to provide as much information as possible about the population dynamics of nematodes. Other increments used to divide the field such as 0.25, 0.5, or 2.5 acre blocks prove to be either too time consuming or not precise enough. The sample point was directed within the 1-acre grid. Management zone delineation was determined by the Veris sensor data. Nematodes were sampled using a Oakfield soil sampling probes (19 x ¾ inches). Soil probes were cleaned prior to collection at each location. Ten soil core samples were taken in each 1-acre block. Samples were taken to a depth of 8 inches from the top of existing rows in the field. The ten cores were deposited in a 2 ½ gallon bucket, mixed together, placed in a quart-sized freezer bag (7" X 9") , and stored prior to analysis. Each bag was identified by field location, sampling date, and grid number. When soil analysis was to be performed, the process for each sample was duplicated.

Nematode soil samples were placed in plastic bags and immediately placed in an ice chest and shade to keep them cool. Temperatures in the ice chest were maintained between 10-20˚C to keep the nematodes alive. The ice chest was transported to the Nematode Laboratory in the Plant Pathology Department at LSU. The samples were stored in a large refrigerator at 16˚C and a humidity of 75% RH until they were processed. Samples were processed within 1-2 months of collection. The temperature in the refrigerator (16˚C) is close to optimum (13˚C) for long-term storage of nematode samples and allows for maximum survival.

Sampling Handling and Custody

Veris sensor data and elevation data collected using the RTK system were immediately transferred to a PC computer designated for data analysis located in the GIS laboratory. Copies of all electronic data were filed for permanent storage on a computer at the Northeast Research Station, St. Joseph, LA and at the Nematology lab in Baton Rouge. Hard copies of all programs and data were stored at both locations. Thus location serves as backups.

Procedures for nematode extraction-elutriation

Each soil sample was removed from refrigerated storage and brought into the preparatory room, and carefully mixed. A 250 cm^3 subsample of soil was placed in a 400 ml plastic beaker. The remaining soil was returned to storage and held for disposal at a later date. A label was added to the beaker identifying the field, sampling date and grid number for each sample. The sample was extracted using an elutriator and then collected on an 8" X 2 ¾" stainless steel sieve, mesh size of 400 (38 µm). The nematodes and remaining soil was collected from each sample and backwashed into a 150 ml glass beaker. The sample was stored in a refrigerator at 1-2˚C for a period of 12-24 hours. After 12-24 hours, 40ml of the supernatant was collected and the rest was discarded. The contents of the beaker were swirled to mix the soil, water, and nematodes into a suspension. The mixture was added to a 50 ml centrifuge tube. One to two additions of 5 ml of water were added to the beaker to rinse out all the contents into a centrifuge tube. The centrifuge tube was placed in a Beckman Couter Avanti J-25 centrifuge and standard procedures were followed for processing (Jenkins, 1964). The final centrifugation was in a sucrose solution, the supernatant was poured through a 3" X 1 3/8" sieve with a 400 mesh opening. The sample was rinsed using a low volume of tap water for several seconds and backwashed into a clean 150 ml beaker. The label was then added to the beaker. Samples were stored in a refrigerator at 1-2˚ C until counted.

Nematode Counting

Each sample was poured into a 3" X 1 ¼" X ½" clear, counting dish. The sample was allowed to settle for several minutes and observed at 40X magnification using an Olympus inverted microscope. All plant-parasitic nematodes were identified to genus and quantified using an eight key laboratory counter. After counting, data were converted to standard volume of soil (500 cm^3) for each genus.

Analytical Methods for Spatial data

Spatial data analysis was performed in SSToolbox, an agriculture-based GIS operating in ArcView 3.x., and utilizing Surfer for interpolation.

SSToolbox, is based on a Client/Farm/Field data structure. A field boundary polygon for each project field was collected in the field using a sub-meter GPS receiver and mapping software. A new "Field" was created within SSToolbox, which was based on the field boundary of each project field. The geo-referenced soil electrical conductivity data derived from the Veris ® 3100 sensor mapping system, elevation data derived from RTK GPS surveys, soil properties and nematode data derived from geo-referenced soil sampling, will be added to the project as separate point themes (spatial layers), and classified into a chloropleth map based on natural breaks of the relevant attribute. Therefore, all relevant data for each project field were placed into a spatial data set contained in several different data layers in the GIS project. These data were in the point data form of, and were used to identify differences in the density of the data (nematodes, soil parameters EC and elevation) and the spatial location of the individual points.

Each theme, or layer, of point yield data was interpolated using Kriging to create a new "surface" layer composed of grid cells measuring 20 ft. by 20 ft. The new data layers contained one attribute. The grid cells were assigned an ID number when created providing all of the new layers with a common attribute field. This step provided a method to spatially join the layers into in a single data layer of relevant data at identical spatial locations. Statistical analyses were performed following the procedures.

Results and Discussion

The Sharkey series in the lower elevations of delta alluvial fields is a fine textured alluvium formed by the Mississippi River and is poorly drained. Clay type in Northeast LA's Mississippi delta is predominately Sharkey or Tunica. Silty soils in this research are Commerce silt loam and Bruin silt loam and exist predominately on 0 – 1% slopes, and/or on 1-3% slopes. The mixed soil types in the transition areas between silt and clay are Mhoon silty clay loam. These soil types structure the Commerce-Bruin-Robinsonville soil association that exists on natural levees formed by the Mississippi river. Sharkey clay contains >40% Montmorillonite (Anonymous, 1968). This point is significant to these studies because the mix of Sharkey clay content in the soils was highly correlated to ECa that generated a broad range of apparent electrical conductivity values that were useful in identifying variation in root knot population densities. Variation in population densities are listed as mean root knot level by class and are depicted in table 1.

Previous research correlated soil type and plant parasitic nematodes infesting cotton using apparent soil electrical conductivity (EC_a) measurements (Khalilian et al. 2001; Stevens 2002). Tests conducted using field micro-plots showed reproduction of the root-knot nematode was greater in coarse-textured than in fine-textured soils, and population densities were inversely related to the percentages of silt and clay, (Koenning et al., 1996). In Texas, the distribution of reniform and root-knot nematodes were correlated to soil texture (Robinson et al., 1987). Similar to our studies, analyses were made from data obtained using a Veris® 3100 cart to measure apparent soil electrical conductivity. This research also included use of topography in the analytical procedures. The results of these studies represent the first attempts to use new GIS/GPS technology to enhance management of nematode problems infesting the alluvial soils of Northeast Louisiana.

In our first evaluations on the LSU Ag Center's Northeast Research Station, a correlation matrix for selected variables indicated percent clay had a high positive correlation value of 0.92 for EC_a _ sh and a high negative correlation value of -0.80 for MSL elevation. Elevation was highly correlated to Veris® sensor data in the delta alluvial fields. A surface map of Gin Ridge based on 10 EC_a classes (management zones) is compared to a RTK GPS topography map with 10 zones. Analysis of the relationships between topographic features and EC_a yielded R^2 values for the shallow electrical conductivity (EC_a _ sh) of 0.76 and 0.89 for EC_a _dp. The ridges (highest elevations) of fields contained light soil and the swales contained clay or mixed soil. When the delta alluvial fields are measured using Veris sensor data, low EC_a values appear on the ridges and high EC_a represent swales (Fig 4).

Whole field statistics for the Veris sensor data taken for each test site depict high variability within fields due to soil variation (Tables 2-4). Soil samples taken to determine the average clay content by EC_a zone indicated nematode population densities decreased to below economic threshold levels when clay was between 15-20% (Fig 5). Variability within the alluvial soils of Louisiana fields due to clay content causes population densities of root knot nematodes to be variable within individual fields. Therefore, root knot nematode samples that are above economic threshold level will be clustered within the low EC classes (Fig. 6). Since Veris sensor data can be highly correlated to clay content, this make the technology a valuable resource for nematode management within the delta alluvial fields. Furthermore the relationships found for RTK GPS and Veris sensor data indicate both technologies may play a significant role in developing site specific pest management strategies.

Coefficient of variation (CV) values for EC_a for the fields in these tests had values indicating some fields would be better suited for site-specific management such that a higher value indicates more variability between EC classes. The CV ranges were 0.42 - 0.65 in the shallow sensor data and ranges of 0.43 - 0.71 occurred in the deep sensor data (Tables 2 and 3). These values will be continuously recorded in subsequent research and will provide a record for future field evaluations. From these records, benchmark comparison of fields in other regions of Louisiana or the United States could be made. For example these initial studies are indicating values higher than those of fields in the upper mid-west (Personal conversation with Eric Lund, Veris Technologies Salina, KS). However, samples taken from the Loess soils of the Macon Ridge regions near Winnsboro LA data not shown), are similar to the mid-west samples.

Characteristics of the five research fields as determined by the Veris® sensor system indicate many similar values. In EC_a classes 1-3, the mean values were < 30 mS/m, except for the Cemetery N. field. Within classes 4 and above, EC_{a_sh} increased rapidly to values of near 100 in all fields except the Levee field (Table 2).

The Levee field was atypical in comparison to the other fields as it represents a field with 100 percent root knot nematode infestation and low EC_a values which indicate other problems. The EC_{a_sh} values for all classes were < 30 mS/m (Table 2). Similar trends are apparent for EC_{a_dp} except the values are greater. The EC_{a_dp} value of 11 mS/m in class 1 zone for the Levee field indicates a deep sand for that region of the field since it is similar to the shallow sensor values. The remaining class values in the Levee field also indicate that light soil is present to depths of 3 feet and beyond. The EC_{a_dp} values in all the other fields indicate clay content would be sufficient to allow site-specific treatments (Table 3).

The established economic threshold for root knot on cotton is 250 nematodes per 500 cc of soil. In initial tests, root-knot nematode population densities clustered in EC_a zones 1-5. The low and high EC_a for the corresponding section of the field was 16.6 mS/M - 26.2 mS/M. Root-knot nematode population densities were below economic threshold in EC_a zones 5-10 (Fig 4). Similar results were obtained in subsequent testing. Root knot levels for the fields tested ranged from 0 to over 25,000 per liter of soil. Population densities are concentrated in the lowest EC_a classes (Table 1).

Geo-referenced soil samples collected from the Northeast Research Station Gin Ridge field, and nearby alluvial fields in Tensas Parish LA contained above threshold levels of root-knot nematode for each of five fields. After tests for homogeneity and ANOVA were performed, it was demonstrated that root knot levels were significantly variable by EC Class which indicates soil textural differences by zone in four of five test fields. The statistical interpretation was more difficult to interpret as compared to the soil and EC graphs (Figs. 5 and 6). However, it was reveled that root-knot nematodes were above threshold in the Levee field within each of the seven classes (Table 5). Therefore, differences in nematode levels as measured by laboratory counts were great enough to justify use of site-specific GPS technology as a control technique in four of the fields, and this fact could be verified statistically. Using the LSU Ag Center's Cooperative Extension published guidelines for economic threshold; the percent reduction in the requirement for a nematicide was calculated as 34, 33, 35 and 43 percent, respectively for the Gin Ridge, Cemetery N., Cemetery S., and Ken's Corner field (Table 6).

The percent reduction in nematicide required as compared to whole field treatments has dramatic implications on management. This implies that costs of treating nematodes could be broken down into ECa classes' i.e. soil management zones. Since most of the nematodes will be present in zones with low ECa values, comparative analysis could be calculated for various combinations of zones and deducted from whole field costs. In the final analysis of economic, yield lost or gained minus the cost of application would identify the treatment options that provided net gains.

Development of techniques that would provide methods for calculating site-specific prescription boundaries for nematode management without the rigorous task of collecting soil cores and counting nematodes would be of value. RTK GPS produced MSL elevation values for the fields in this test series and the values ranged from 70.7 MSL – 91 MSL. All the fields were contiguous and had individual elevation changes of 3.85, 4.2, 9.7 and 4.6 feet respectively, for the elevation classes (Table 4).

Veris® sensor and RTK procedures for estimating percent reduction in nematicide treatment requirements compared favorably to values obtained from laboratory counts of nematodes in soil core samples. Veris® sensor techniques projected reductions in the percent of a field requiring treatment of 21, 38, 33, 68 and 1 percent, respectively, for the five fields evaluated. These values compared to reductions of 34, 33, 35, 43 and 0 percent, respectively, for nematode counts taken from soil cores. The RTK technique resulted in reductions of 24, 40, 46, 80, and 33 percent, respectively, for the test fields (Table 4). Generally, results were similar for each technique, except in the Kens corner field. The difference could be explained due to the fact that very small areas outside of the boundary had nematode counts above threshold. Variation in the sensors could have been due to changes in either soil moisture or temperatue. A test conducted in 2004 indicated changes in EC_a greater than 20% due to weather variability in the spring (Fig 7). In the case of both techniques, the counts were only slightly above economic threshold and with further evaluation it is possible the counts would be considered unimportant due to the sub-soil content. Some fields have unusual sub-soils that can only be detected using the EC_a_dp measurements or through use of deep core samples. Selected field views from the cemetery field north illustrate the potential to reduce nematicide use in a field with high nematode counts but with shallow top-soil in parts of the field. Two prescriptions were developed using the combinations of infrared imagery, NDVI imagery, yield monitor data and Veris® sensor for finding nematodes. Prescription A, which was developed using established thresholds for root knot nematode reduced nematicide use by 50%. Prescription B which is based on aerial imagery reduces nematicide by 77%. The images indicate the latter prescription was more accurate. This shows that high nematode counts can sometimes be deceiving and that consideration of the sub-soil strata may be required in some instances (Fig 8).

Spatial information collected using RTK GPS is more stable over time compared to data collected with Veris sensors, therefore 5 sample fields were linked together as a contiguous management unit (Fig 2). The attributes of the 5 fields are described in Table 4. There were several apparent advantages of using topographic maps as a means of defining management zones for nematode management. The original USDA soil survey maps were based on elevation and contours. The precision of RTK would provide more accurate definition of changes in texture and soil type compared to early survey techniques. Presently, there are numerous tractors in the Delta equipped with GPS capable of collecting topographic data. Some of the tractors are equipped with RTK. Topographic maps would aid drainage remediation and could assist with interpretation of yield maps. Conversely, there would be apparent limitations for total reliance on topographic maps as compared to Veris® sensor maps. Geo-referenced elevations would not be useful when land leveling was previously practiced since soil-type mixing will have occurred. The ultimate in precision measurements at the present time is use of RTK GPS. More farmers have invested in GPS systems less accurate than RTK. While spatial information collected with the aid of Veris® sensors would be less stable than RTK spatial information, Veris® data would not be limited to surface views. The maps developed using the Veris® sensor cart provide subsurface measurements that range to a depth of 3 ft. This mapping feature is often useful when topsoil has been moved through land forming practices. Key features that limit yields are often more pronounced in the deep EC_a classes. Examples of such key features could be either deep sandy soil with limited micronutrients or heavy clay that limits moisture and root development.

Summary

Based on this work, distributions of root-knot nematode could be identified on a field by field basis by zone sampling and/or grouped together for pest management purposes (Figs. 2 and 3). Analysis using Univariate statistics indicates that high levels of variability were apparent in the fields used in this research. Variance and standard deviation values for shallow and deep Veris® sensor and RTK data points indicates the value of having dense data sets as a tool for detecting high within-field variability. Coefficient of Variation (CV) values computed for the fields in these tests indicate some fields are more suited to site-specific treatment than others The CV ranges of 0.42-0.65 in the shallow sensor data and ranges of 0.43-0.71 in the deep sensor data are often 2 fold higher than values obtained from soils in the mid-west part of the US. (Personal conversation with Eric Lund, Veris Technologies, Salina, KS.). We do not have a basis for comparing CV values obtained for the RTK system.

These finding illustrate that use of elevation and topographic maps incorporated with new GIS and GPS technology could improve integrated pest management capability for nematodes and other early pest and/or agronomic practices. While not a major objective of this research, we found the use of aerial imagery could also be useful in detecting nematode/wilt damaged areas in fields. The improvements in sample efficiency derived from technology that includes geo-referenced sampling would lead to better use of host plant resistance, rotation and site-specific management of pesticides. Site-specific management would help maximize production and allow programs of optimum environmental stewardship to be conducted.

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Figure 1. Veris® 3100 Soil EC Mapping System.

Table 1. Whole field Univariate Statistics and Mean Root knot Level – Region 6 EPA Pesticide Initiative Program, 2001 – 2004.

		Whole Field Statistics Veris Sensor Data[1]				Mean Root Knot Level by Class[2]									
Field Name	Acres	Variance	St. Dev.	Coef. Var.		1	2	3	4	5	6	7	8	9	10
Gin Ridge	79.3	200.3	14.2	0.65		2251	5202	4077	1980	888	462	100	0	0	0
Cemetery N.	24.5	136.1	11.7	0.42		16250	23055	12116	16030	0	45	0	--------	-------	-------
Cemetery S.	62.0	108.3	10.4	0.42		440	817	879	178	203	90	0	0	-------	-------
Ken's Corner	85.5	274.1	16.6	0.38		585	835	895	810	158	0	0	0	0	0
Levy Field	71.1	31.3	5.6	0.42		733	958	996	1016	442	610	400	--------	-------	-------

1. Whole field statistics were determined using surfer as a part of the GIS SS Toolbox program.
2. Mean root knot levels by class were developed using Veris sensor data and natural breaks to identify EC.

Table 2. Whole field Univariate Statistics and Mean $EC_{a\ sh}$ by Class – Region 6 EPA Pesticide Initiative Program, 2001 – 2004.

		Whole Field Statistics Veris Sensor Data[1]				Mean Point Value for EC_{a_sh} mS/m by Class[2]									
Field Name	Acres	Variance	St. Dev.	Coef. Var.		1	2	3	4	5	6	7	8	9	10
Gin Ridge	79.3	200.3	14.2	0.65		8.2	12.7	17.4	22.4	28.3	33.9	40.1	46.9	55.0	61.9
Cemetery N.	24.5	136.1	11.7	0.42		16.1	28.4	38.5	54.8	70.0	77.0	91.0	--------	-------	-------
Cemetery S.	62.0	108.3	10.4	0.42		11.8	17.0	22.5	27.9	33.9	40.9	47.5	64.3	-------	-------
Ken's Corner	85.5	274.1	16.6	0.38		14.6	22.0	27.3	31.9	37.0	41.7	45.2	49.8	56.7	69.7
Levy Field	71.1	31.3	5.6	0.42		7.2	11.2	14.0	16.0	17.8	20.3	27.6	--------	-------	-------

1. Whole field statistics were determined using surfer as a part of the GIS SS Toolbox program.
2. Mean point values for Veris sensor shallow data (0-12").

Table 3. Whole field Univariate Statistics and Mean $EC_{a\ dp}$ by Class – Region 6 EPA Pesticide Initiative Program, 2001 – 2004.

		Whole Field Statistics Veris Sensor Data[1]				Mean Point Value for EC_{a_dp} by Class[2]									
Field Name	Acres	Variance	St. Dev.	Coef. Var.		1	2	3	4	5	6	7	8	9	10
Gin Ridge	79.3	651.0	25.5	0.71		32.2	47.9	57.9	75.2	84.1	83.9	94.1	117.8	119.1	122.9
Cemetery N.	24.5	614.6	24.8	0.48		40.1	87.5	103.6	117.3	119.5	112.2	140.9	--------	-------	-------
Cemetery S.	62.0	584.6	24.2	0.43		35.3	39.7	46.9	54.7	73.9	73.0	86.4	70.4	-------	-------
Ken's Corner	85.5	2153.0	46.4	0.52		21.9	41.4	57.1	62.7	84.7	114.9	117.7	122.4	121.9	148.7
Levy Field	71.1	161.1	12.7	0.49		11.0	15.4	19.9	27.0	29.4	35.2	42.4	--------	-------	-------

1. Whole field statistics were determined using surfer as a part of the GIS SS Toolbox program.
2. Mean point values for Veris sensor deep data (0-3').

Table 4. Whole field Univariate Statistics and Mean RTK Elevation by Class – Region 6 EPA Pesticide Initiative Program, 2001 – 2004.

		Whole Field Statistics – feet[1]				Mean Surface Value for Elevation by Class[2]									
Field Name	Acres	Variance	St. Dev.	Coef. Var.		1	2	3	4	5	6	7	8	9	10
Gin Ridge	79.3	1.16	1.07	0.01		70.7	71.2	71.6	72.0	72.4	72.8	73.2	73.6	74.05	74.55
Cemetery N.	24.5	1.50	1.22	0.01		73.7	74.6	75.1	75.6	76.25	77.0	77.8	-------	-------	--------
Cemetery S.	62.0	1.15	1.07	0.01		86.8	87.6	88.0	88.6	89.1	89.6	90.2	91.0	-------	--------
Ken's Corner	85.5	7.05	2.65	0.03		73.8	75.2	76.3	77.3	78.3	79.2	80.2	81.2	82.2	83.5
Levy Field	71.1	1.38	1.175	0.01		81.9	83.1	83.8	84.4	85.0	85.6	86.5	-------	-------	--------

1. Whole field statistics were determined using surfer as a part of the GIS SS Toolbox program.
2. Mean surface values for elevation by class as determined using Real Time Kinematic (RTK) GPS.

Table 5. statistical evaluation of root-knot nematode population densities as affected by Veris shallow sensor data

Field 1. Gin Ridge

	1	2	3	4	5	6	7	8	9	10
1	NS									
2	NS	NS								
3	NS	NS	NS							
4	NS	NS	NS	NS						
5	NS	NS	NS	NS	NS					
6	NS	NS	+	NS	NS	NS				
7	NS	NS	+	NS	NS	NS	NS			
8	NS	NS	NS	NS	NS	NS	NS	NS		
9	NS	NS	NS	NS	NS	NS	NS	NS	NS	
10	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

Field 2. Cemetary North

	1	2	3	4	5	6	7	8
1	NS							
2	NS	NS						
3	NS	NS	NS					
4	NS	NS	NS	NS				
5	NS	NS	NS	NS	NS			
6	+	NS	NS	NS	NS	NS		
7	+	NS	NS	NS	NS	NS	NS	

Field 3 Cemetary South

	1	2	3	4	5	6	7	8
1	NS							
2	NS	NS						
3	NS	NS	NS					
4	NS	+	+	NS				
5	NS	+	+	NS	NS			
6	NS	+	+	NS	NS	NS		
7	NS	+	+	NS	NS	NS	NS	
8	NS	NS	NS	NS	NS	NS	NS	NS

Field 4 Ken's Corner

	1	2	3	4	5	6	7	8	9	10
1	NS									
2	NS	NS								
3	NS	NS	NS							
4	NS	NS	NS	NS						
5	NS	NS	+	NS	NS					
6	+	+	+	+	NS	NS				
7	+	NS	+	NS	NS	NS	NS			
8	+	+	+	+	NS	NS	NS	NS		
9	+	NS	+	NS	NS	NS	NS	NS	NS	
10	+	+	+	+	NS	NS	NS	NS	NS	NS

Field 5 Levee

No significant differences.

Table 6. Whole field Univariate Statistics and percent reduction in pesticide treatment requirement for damaging levels of root knot nematode as determined by use of nematode counts, Veris sensor class ranges for shallow EC_a, <30 mS/m and RTK topography. Region 6 EPA pesticide initiative program, 2001 – 2004.

		Whole Field Statistics Veris Sensor Data $EC_{a\ sh}$[1]				Method of Evaluation Percent Reduction[2]		
Field Name	Acres	Variance	Standard Deviation	Coef. Variation		Nematode Counts	Conductivity EC_a_sh=<30	RTK 0 – 3 ft.
Gin Ridge	79.3	200.3	14.2	0.65		34	21	24
Cemetery N.	24.5	136.1	11.7	0.42		33	38	40
Cemetery S.	62.0	108.3	10.4	0.42		35	33	46
Ken's Corner	85.5	274.1	16.6	0.38		43	68	80
Levy Field	71.1	31.3	5.6	0.42		0	1	33

1. Whole field statistics were determined using surfer as a part of the GIS SS Toolbox program.

2. Percent reduction based on nematode counts by EC class (Zone), electrical conductivity >30 and RTK elevation in the top 3 feet of ridge soils.