Soil Community Structure, Function, and Spatial Variation in an Organic Agroecosystem

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Participants:

Graduate Student:	Douglas Collins
Advisor:	Dr. Craig Cogger
Key Personnel:	Andy Bary, Liz Myhre, Dr. Ann Kennedy, Andrew Stout

Summary

This project examined the spatial variation of soil organisms and other edaphic properties across a large organic vegetable farm with diverse soil physical properties. Our study site, Full Circle Farm (FCF), is located near Carnation, WA (Figure 1). In 2006 we sampled across a 62-acre area to examine spatial variation of edaphic properties at a farm scale. In 2007 we intensively sampled two separate fields with near identical management to examine spatial variation at a field scale. In 2007 we presented research results at a farm walk at FCF (with over 80 participants) and at the WA Tilth Producers Conference.

Introduction

Sustainable farm management requires the maintenance of ecosystem functions such as nitrogen mineralization, aggregate formation, and pathogen control. Given the importance of biological processes in production, growers are increasingly interested in information about the biological status of their soil. While several labs offer soil food web analyses (Diver, 2002) effective guidelines for interpretation of soil biological data remain elusive (Bengtsson, 1998). In particular, the importance of variability to interpreting soil biological data is seldom addressed. Farmers have limited resources with which to monitor soil quality. Many wonder whether to pay for biological sampling and if so how should they sample and leverage results in site-specific management.

Most soil properties exhibit high degrees of spatial structure; "hotspots" of biological activity ebb into areas of little or no activity often over predictable distances (Klironomos et al., 1999). While spatial heterogeneity has typically been viewed as a hindrance to understanding soil biogeochemical phenomena, Ettema and Wardle (2002) suggest "spatial variability may be the key, rather than the obstacle to understanding the structure and function of soil biodiversity." Ignoring spatial variability compromises our ability to competently describe soil communities through typical sampling plans. A spatially-explicit research approach can strengthen our understanding of biological diversity and abundance and better connect those parameters to edaphic properties and biological functions.

One indication that significant agronomic soil functions are being provided is a healthy crop. Likewise, an ailing crop and decreasing yields are possible indications, albeit untimely, that functions, such as good soil structure, nutrient availability, and pathogen control are inadequate. Soil organisms mediate or contribute to all of these essential functions and biological populations are therefore potential indicators of productive soil and good management practices. Doran and Zeiss (2000) identified soil functions that can be influenced by management decisions as "dynamic soil quality" and those properties not easily changed or influenced by management decisions, e.g. climate, clay mineralogy, texture, etc., as "inherent soil quality".

One challenge to the development of biological-based indicators of soil health is that soil organisms are influenced by both dynamic and inherent soil quality. The importance of soil texture and other edaphic properties on biological properties has been demonstrated in several studies. Franzluebbers et al. (1996) found increasing soil microbial activity in coarser textured soils. This finding is in agreement with the general recognition that organic matter decomposes more rapidly in sandy soils than in fine textured soils (Hassink, 1994). However, Thomsen et al. (1999) found more rapid turnover of organic matter in clay-amended soils when the soils were adjusted for soil water potential. Understanding how inherent soil properties affect potential biological indicators will help growers interpret results and make site-specific management adjustments accordingly.

Robertson and Freckman (1995) found that sand and silt were positively correlated with bacterial- and fungal-feeding nematode density, but not with abundance of omnivore/predators or plant parasites. Though the relationship was weaker, pH was also positively correlated with both microbial-feeding nematodes. Avendaño et al. (2004) found that soybean cyst nematode density was positively correlated with sand content, but negatively correlated with silt and clay. Noe and Barker (1985) found that clay content was a factor that determined the population density of three parasitic nematodes at one site, but was not relevant for any of the species at another site. The authors note that where edaphic variables occur at or near biologically limiting levels their specific concentrations can influence local populations (in this case influencing the host-pathogen interaction), but where the edaphic variable is above a threshold other variables play more of a part.

Knowledge of the spatial properties of parameters of interest as well as relationships to other spatially structured and predictable edaphic properties can potentially be used to leverage sampling plans directed at improving management. Researchers have documented associations between specific pathogenic nematode species and soil texture (Avendaño et al., 2004), texture and organic matter (Wyse-Pester et al., 2002) and combinations of multiple chemical and physical soil properties (Noe and Barker, 1985). These results suggest the potential for identifying pathogenic nematode infestations based on edaphic properties. Understanding how edaphic properties can affect other soil biological properties will strengthen their use as soil health indicators and their efficacy for directing management.

Objectives/Performance Targets

There were five primary objectives for our project: 1) use geostatistics to develop maps for soil organisms and edaphic properties, 2) develop biological indicators that correlate to N-mineralization potential and aggregate stability, 3) recommend general biological sampling methods, 4) make recommendations to optimize farm productivity and profitability, and 5) share results with other growers and agricultural professionals.

Materials and Methods

Farm-scale Sampling, 2006. Our 2006 sampling was designed to describe edaphic properties across a 62-acre area of FCF. We created a sampling plan that would evenly cover our sampling area and also serve the needs of a geostatistical analysis. To do this, 84 sites were placed across the sample area. The smallest spacing between sample sites (also called minimum lag distance) was 5 meters. This clustered type of spacing allowed us to accurately describe variation at a relatively small scale (5m), medium scale (90m) and larger scales (>100m). At the time of sampling farm fields had been tilled anywhere from 1 to 30 weeks previous (Figure 2).

Field-scale Sampling, 2007. Analysis of results from the 2006 sampling indicated that plant type and management were both important in influencing biological properties. To better isolate the influence of edaphic properties and to focus on spatial variation of edaphic properties at scales between 5 and 90 m, we decided to sample at a field scale in 2007. Based on results of the 2006 sampling we chose two fields from areas of the farm with contrasting soil texture and placed 42 sample sites within each field (Figure 3). Immediately after completing the georeferenced sampling we gathered a bulked sample within the constraints of the sampling area by moving in a zigzag and taking 20 random soil cores at 0-15 cm for nematode analysis and 20 random soil cores at 0-10 cm for chemical and microbial biomass analyses. Both fields, referred to as field 3 and field 5 by the grower, were planted to spinach in early June within 4 days of each other.

Soil Sampling. The first year's sampling took place over 4 days between 12 and 20 October 2006. Though 84 sites were identified, 3 sites in the large meadow area had to be skipped due to time constraints. The second year's sampling took place over 2 days on 9 and 10 July 2007.

Parameters Tested. Twelve parameters were tested for each sample site in 2006: soil moisture content, bulk density, aggregate stability, organic matter, total nitrogen, nitrate-N, texture, N-mineralization potential, collembolan diversity, nematode diversity, and total microbial biomass. In 2007 we tested the same parameters except for nitrate-N and N-mineralization potential.

Data analysis. We analyzed the spatial variation of physical, chemical, and biological properties at both the farm- and field-scale with kriging using the geostatistical software GSLIB (Deutsch and Journel, 1997). Kriging interpolates unknown values with knowledge about the underlying spatial relationships of known values. This knowledge is derived by fitting a model to a semivariogram, an analysis of the continuity of data values for a specific separation distance in a specific direction. We displayed the kriged maps with ArcMap 9.2 (ESRI Inc., Redlands, CA)

We used linear regression to look at correlations between the attributes we measured at the farm- and field-scale. We also used regression trees to examine associations between potential soil quality indices and edaphic and management properties at the farm-scale. Trees were built with RPART in the R software package (Therneau and Atkinson, 2003, R Development Core Team, 2007). The procedure starts by splitting the entire population to produce two "daughter nodes" with maximum homogeneity. All observations that meet the condition stated at the node are grouped to the left of the node, and observations not meeting the condition are grouped to the right. Trees are grown by further splitting daughter nodes in a similar fashion, and then pruned to a desired size (Maindonald and Braun, 2003).

For regression tree models we used the following predictive variables: total C, total N, NO_3-10cm, NO_3-30cm, NH_4-10cm, NO_3+NH_4-10cm, pH, %sand, % silt, % clay, texture class, bulk density, proportion of soil as aggregates >0.25mm, mean weighted sum of aggregate sizes, and nematode structure index, enrichment index, channel index, and maturity index.

Results and Discussion/Milestones

The research portion of this project was focused at addressing objectives one through four:

- *Objective 1. Use geostatistics to develop maps for soil organisms and edaphic properties*

Soils within the area of the farm sampled varied greatly in texture. There was a strong gradient of increasing sand and decreasing clay from west to east (Figure 4a-c). Sand ranged from 5-54 % while clay ranged from 9-27% and silt ranged from 35-76%. Four texture classes were identified: sandy loam, loam, silt loam, and silty clay loam. Silt loam was the predominant texture class (Figure 5).

The proportion of soil composed of aggregates was higher in the western, more clay rich, area of the farm (Figure 6).

Collembola (Figure 7) and nematode (Figure 8) populations were highly aggregated at the farm scale but areas of highest populations did not overlap.

Total C (Figure 9), N-mineralization potential (Figure 10), and microbial biomass (Figure 11) were all highest in an area of the farm managed as a meadow. The ratio of bacteria to fungi ranged from 1.3-3.7 (Figure 12) and pH ranged from 4.86 to 6.84 (Figure 13).

- *Objective 2. Develop biological indicators that correlate to N mineralization potential and aggregate stability*

Correlation analysis indicated that N mineralization potential was most strongly positively correlated with total C (R=0.79), microbial biomass (R=0.74) the nematode maturity index (R=0.57), and weeks since tillage (R=0.58) and negatively correlated with bulk density (R=-

0.65) and pH (R=-0.40). Regression tree analysis is capable of finding non-linear relationships among many different variables. The regression tree for N mineralization potential indicated that variance in laboratory nitrate mineralization was largely explained by soil C; the highest mineralization rates were associated with soil C greater than 7.9% and in less C-rich soils the amount of C also explained the most variance (Figure 14). The nematode EI explained some of the variance in soils with C between 3 and 7.9%, with EI values less than 80.4 being associated with higher mineralization rates. The regression tree model explained 67% of the variance, while soil C alone explained 59% of the variance (100 X the square of the correlation, 0.79, between soil C and mineralization).

Much of the variation in total nematode density across the farm was explained by the time since the last tillage. Sites tilled less than 2 weeks before sampling had the lowest nematode populations (mean = 2.37 log nematodes 100 cc^{-1}). Among the sites that had not been tilled recently, nematode populations were higher in soils with pH values greater than 6.11. These soils had mean concentrations of 3.21 log nematodes 100 cc^{-1} while the more acid soils had mean nematode concentrations of 2.84 log nematodes 100 cc^{-1} (Figure 15).

The proportion of aggregates greater than 0.25mm (PROP AGG) was negatively correlated with sand (R=-0.70) and total C (R=-0.45), and positively correlated with silt (R=0.70) and clay (R=0.61). The regression tree analysis of PROP AGG indicated that soil texture parameters explained most of the variation in aggregate stability (Figure 16). Soils with clay content less than 13.5% had a lower proportion of aggregates (mean = 0.67) than sites in more clay-rich areas (mean = 0.89). Within these clay-rich sites, silt also influenced aggregation; sites with silt content greater than 63.5% had higher proportion of aggregates (mean =0.91) than sites with less silt content (mean =0.84).

Though biological indices were not the best predictors of PROP AGG, regression tree analysis of the nematode structure index indicated that areas with PROP AGG greater than 0.93 were associated with the highest nematode structure index (SI, Figure 17). The many different physical parameters that affect PROP AGG may also be affecting farm management and SI. For example, the eastern, sandier area of the farm is more intensively farmed and has received more historical manure application and cultivation than the more clay-rich areas to the west. Both of these forms of agricultural intensification can negatively affect nematode taxa that are indicators of community structure. These nematodes are omnivores and predators that have larger body sizes and longer life cycles than the bacterivore and fungivore nematodes that are favored by physical disturbance and nutrient enrichment.

- *Objective 3. Recommend general biological sampling methods*

In the field-scale analysis we found clay content ranged from 10- 17 % in field 3 and from 16 – 31 % in field 5 (Figure 18). Clay was significantly negatively correlated with nematodes in field 3 (R = -0.57) but not in field 5 (R= -0.20). The mean nematode populations from the georeferenced sites were 1155 and 131 nematodes $100cc^{-1}$ (3.06 and 2.11 log nematodes $100cc^{-1}$) for fields 3 and 5 respectively. The bulked samples overestimated nematode populations at both sites; there were 1400 and 158 nematodes $100cc^{-1}$ (3.14 and 2.19 log nematodes $100cc^{-1}$) for fields 3 and 5 respectively.

Semivariogram analysis of the nematode distribution in field 3 indicated that nematode populations were strongly autocorrelated – meaning that the nematode density at a specific site is predictive of nematode densities at nearby sites. On the other hand, there was little spatial structure in the nematode populations in field 5. The range of autocorrelation, or patch size, in field 3 was 20 m. The range was not different for bacterial-feeding and fungal-feeding nematodes.

Two contrasting strategies for sampling nematodes to characterize agroecosystems are described in the literature (Yeates, 1999). The first is to select 5 or 10 patches each of 1-2 m^2, which in total reflect the contribution of plant, soil, and topographic variation in the area, and in each to collect 5 soil cores. The second is to take composite cores at 20 equally spaced sites along a serpentine transect of a random 2-ha area than mix thoroughly by hand. We approximated this comparison by taking both geo-referenced samples and bulking samples within the same area, though our site was only 0.09ha. Bulking provides only an average value and, as we demonstrated, these values overestimated nematode population means by 17% from not bulking. Selecting smaller patches to sample provides information about local variability. If coupled with information about other edaphic properties it can also provide context about effects of edaphic properties on populations within the local area.

The current study emphasized that physical and chemical parameters can vary greatly at the farm and even field scale. We found, as others have, that the effects of physical and chemical properties on biological populations were not consistent from field to field (Wyse-Pester et al., 2002). We conclude that soil physical and chemical data are not a priori evidence of soil biological populations, but within certain ranges the variation in these properties can affect biological variation. Thus, careful mapping of inherent soil quality parameters should be the first step in monitoring soil biological populations.

- *Objective 4. Make recommendations to optimize farm productivity and profitability*

The geostatistical approach employed in this project yielded valuable information about spatial variation of chemical and physical properties across Full Circle Farm. These properties are not easily affected by management so the maps may provide utility for years to come. For example, the detailed texture maps provided by this project may aid in future farm planning. Similarly, the pockets of soil acidity and trend in soil carbon content that were discovered should also be considered in soil management. Specific management recommendations follow:

1. Address soil acidity.
   Through mapping soil parameters we discovered that large areas of the farm have soils with pH less than 5.7 and some areas are as low as 4.8. The grower, Andrew Stout, had done some recent soil testing of his own so our sampling reinforced his inclination to apply lime to the most acid fields. We met with Andrew and his farm manager Amy Sills

in early February 2008 to discuss soil management. We recommended 2 applications of agricultural lime plus Sulfa-Mag™.

2. Smooth organic matter distribution across farm.
   As with many small farms in this area, Full Circle Farm was once home to a small dairy. Though we have no historical record of manure applications beyond the 5-year period of current management, it is logical that manure would have been spread both closely to the barn and also in areas that were not flooded and were workable earlier in the spring, such as the areas of higher elevation near the barn. The result is C-enriched soil near the barn. The less C-rich and heavier soils in the western area of the farm could benefit from applications of compost to increase their organic matter content. Organic matter levels are sufficient, or perhaps even too high, at the eastern edge of the farm. Amendment applications in these areas should be done with nitrogen-rich materials that do not increase soil carbon to the degree that compost or manure does (e.g. fish meal).

3. Rest the intensively farmed eastern side of the farm.
   Fields located on the sandy loam and loam soils on the eastern edge of the farm (figure 5) are the most intensively cultivated. They drain better, are workable earlier in the spring and later in the fall, and are the most desirable fields for the salad greens often planted there. Taking an opportunity to rotate with a cereal-legume mix cover crop would provide several benefits: rotation can help break pathogen cycles; the growth could be harvested for making compost; and the lack of tillage can enhance larger-bodied soil organisms and increase soil aggregation.

To encourage farm managers at Full Circle Farm to think about the spatial variation on their farm and to use this information in management decisions we framed a 2X3 ft. poster of the background aerial photo in figure 1 and gave it to Andrew Stout.

Impacts of Results/Outcomes

The project has produced several important outcomes to date:

1. The farmer is now more aware of the extent of spatial variation of soil physical and chemical properties on the farm. With this knowledge he is motivated to address soil health issues with site-specific management. Specifically, he is incorporating new amendment application strategies and cover-cropping techniques with guidance from our soil property maps and recommendations.

2. Results of our project were shared with visitors to the field day at Full Circle Farm in July 2007. We focused on soil health monitoring and spatial variation of soil properties. Attendees were given hands-on demonstrations in determining soil texture, infiltration, and bulk density. We also used soils gathered from the farm to demonstrate how diverse the soils were in their physical properties across relatively small distances. The participants included farmers, students, and extension personnel and they all gained a greater appreciation of how soil physical properties can impact soil health monitoring.

3. Discussion of this project was at the core of a presentation given by Collins at the Tilth Producers of Washington Conference on November 11, 2007. Most conference attendees are growers so it is an excellent venue to reach those most interested in adopting new management practices. Evaluations from the presentation indicated that those who attended found that the information was presented well, was of high quality, and was useful. This is an indication that the presentation was conducive to learning and may lead to management changes on the part of growers. Growers that attended the talk and wish to include biological parameters in soil health monitoring will be assisted by the presentation in designing their sampling programs.

4. The aerial photo of the farm is often referenced by farm staff for farm planning, intern orientation, and tours. There is frequent interaction with the public, so the poster-size photo is useful to give visitors a birds-eye view of the farm. Increasing public interest and knowledge in local agriculture helps support the market for locally grown food.

Economic Analysis

The research at Full Circle Farm has already created interest among the cooperating farmer in using precision agriculture techniques to address the challenges of farming across diverse soil types. While larger farms have adopted precision agriculture to optimize fertilizer and pesticide applications across a monoculture, this technology is underutilized to address problems encountered in diverse row crop operations. While technological solutions cannot replace farmer experience, a spatially-explicit farm plan built on knowledge of edaphic properties could be instrumental in planning multi-year cropping strategies, amendment application, and tillage regimes. Andrew Stout has a keen interest in continuing to monitor soil health and use soil test data in making management decisions. A geographical information systems approach could improve soil monitoring, amendment application and crop planning and potentially reduce costs.

Publications/Outreach

The outreach portion of this project was focused at addressing objective five.

- *Objective 5. Share results with other growers and agricultural professionals.*

Farm Walk / Field Day. The soils research group at WSU Puyallup presented a field day / farm walk at Full Circle Farm on July 30, 2007 and over 80 participants were in attendance. We featured results from our on-farm research at FCF and also discussed related soils research projects. We included hands on demonstrations of soil quality assessment, discussion of relay cover cropping techniques, and explanation of the importance of spatial variation of edaphic properties at the farm scale. Each participant received a booklet with results summary and related information.

Presentation: Tilth Producers of Washington Conference. On November 11, 2007, Collins gave a presentation titled, “Soil fertility and soil biology: The role of soil organisms in maintaining productive soils" to the Tilth Producers of Washington Annual meeting. More than 50 meeting participants attended the presentation. Results from the FCF study were used to demonstrate the variability of edaphic properties across a farm and also the important relationship between total C and N mineralization potential.

Ph.D. Thesis Chapter: Collins, D.P. 2008. Multi-scale variation of soil quality indices and association with edaphic properties**.** In: Collins, DP (2008) Soil Community Structure: Effect of Different Organic Agroecosystems and Edaphic Properties. PhD Thesis, Washington State University, Pullman, WA

Areas Needing Additional Study.

For this project we applied geostatistical and GIS tools to understanding spatial variability of soil physical, chemical, and biological properties across an organic farm. Additional studies could improve the practical implementation of these tools for small farmers. Also, to fully realize the potential of linking soil biological monitoring to management decisions will require further study.

If gains in farm production or efficiency are to be realized by using higher resolution soil sampling methods, then these data need to be available to farmers in a format that is appropriate to their technological level. These data can be presented as transparencies over a photograph, as digital layers in an interactive GIS program, or in some combination, depending on the farmer's desires. Color aerial photographs are widely available on-line[1] and are a relatively easy entry point for growers to approach site-specific sampling and management. Workshops devoted to helping farmers access this information would facilitate adoption of the technique.

Beyond using spatial information or GIS in planning around variable soil edaphic properties, farmers could also benefit from a GIS system for planning farm plantings. Farms like Full Circle Farm have a high degree of variability in crops from bed to bed compared to monoculture farms. A GIS system would be helpful to plan and track crop plantings and to produce long-term cropping systems plans. These systems can be technologically intensive to use, but farmer interest and Extension expertise could help smaller farmers adopt these technologies that are already employed by larger farms (Aschmann et al., 2003).

Monitoring soil health can assist growers in evaluating their management decisions and in achieving their goal of improved soil health and sustainable yields. Biologically based soil indicators are valuable to managers because they suggest the niches available within the soil ecosystem, integrate recent soil conditions, and reflect valuable soil processes. However, as Doran and Zeiss (2000) suggest, an effective soil health indicator must also be understandable to land managers and be easy and inexpensive to measure. Measurements of population abundance, such as microbial biomass, nematode density (or bacterivore, fungivore, omnivore

[1] For example: http://websoilsurvey.nrcs.usda.gov/; http://seamless.usgs.gov/

density), and collembolan density are easier to understand and likely more valuable to land managers than more information-rich, but complex community indices (e.g. EI, SI). The price of biological tests is still greater than the price of an individual chemical analysis. However, biological indicators, which integrate recent and historical conditions, may provide more timely information about dynamic nutrient pools and substantiate the added cost. Future studies should link soil health tests to plant yield and also account for variation in inherent soil quality.

References:

Aschmann, S, R. Caldwell, and L. Cutforth. 2003. Affordable opportunities for precision farming: A practical way to support sustainable agriculture. Sustainable Agriculture Technical Note 190-1. USDA-NRCS.

Avendaño, F., O. Schabenberger, F.J. Pierce, and H. Melakeberhan. 2004. The spatial distribution of soybean cyst nematode in relation to soil texture and soil map unit. Agron. J. 96:181-194.

Bengtsson, J. 1998. Which species? What kind of diversity? Which ecosystem function? Some problems in studies of relations between biodiversity and ecosystem function. Appl. Soil Ecol. 10:191-199.

De'ath, G. and K. E. Fabricius. 2000. Classification and regression trees: A powerful yet simple technique for ecological data analysis. Ecology. 81: 3178-3192.

Deutsch, C. and A. Journel, 1997. GSLIB: Geostatistical Software Library and User's Guide, 2nd edition. Oxford University Press. 340 pp.

Diver, S. 2002. Alternative soil testing laboratories. ATTRA Publication #IP234/174 [online] http://www.attra.org/attra-pub/soil-lab.html (verified 30March2008).

Doran, J.W., and M.R. Zeiss. 2000. Soil health and sustainability: managing the biotic component of soil quality. Appl. Soil Ecol. 15:3-11.

Ettema, C.H., and D.A. Wardle. 2002. Spatial Soil Ecology. Trends Ecol. Evol. 17:177-183.

Franzluebbers A.J., R.L. Haney, F.M. Hons, and D.A. Zuberer. 1996. Active fractions of organic matter in soils with different texture. Soil Biol. Biochem. 28:1367–1372.

Hassink, J. 1994. Effects of soil texture and grassland management on soil organic C and N and rates of C and N mineralization. Soil Biology & Biochemistry. 26:1221-1231.

Klironomos, J.N., M. C. Rillig, and M. F. Allen. 1999. Designing belowground field experiments with the help of semi-variance and power analyses. Appl. Soil Ecol. 12: 227-238.

Maindonald, J. and J. Braun. 2003. Data Analysis and Graphics Using R - an Example-based Approach. Cambridge University Press, New York. 386 pp.

Noe, J.P. and K.R. Barker. 1985. Relation of within-field spatial variation of plant-parasitic nematode population densities and edaphic factors. Phytopathology 75:247-252

R Development Core Team (2007). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. ISBN 3-900051-07-0, URL http://www.R-project.org.

Robertson, G.P., and D.W. Freckman. 1995. The spatial distribution of nematode trophic groups across a cultivated ecosystem. Ecology 76:1425-1432.

Therneau, T.M and E.J. Atkinson. 1997. An introduction to recursive partitioning using the rpart routines. Technical Report #61. Rochester, MN: Department of Health Science Research, Mayo Clinic. [online] http://mayoresearch.mayo.edu/mayo/research/biostat/techreports.cfm (verified 25March2008).

Thomsen, I.K., P. Schjønning, B. Jensen, K. Kristensen, B.T. Christensen. 1999. Turnover of organic matter in differently textured soils. II. Microbial activity as influenced by soil water regimes. Geoderma 89:199-218.

Wyse-Pester, D.Y., L.J. Wiles, and P. Westra. 2002. The potential for mapping nematode distributions for site-specific management. J. Nematol. 34:80-87.

Yeates, G.W. 1999. Effects of plants on nematode community structure. Annu. Rev. Phytopathol. 37:127-149.

Figure 1. Full Circle Farm and Surrounding Topography

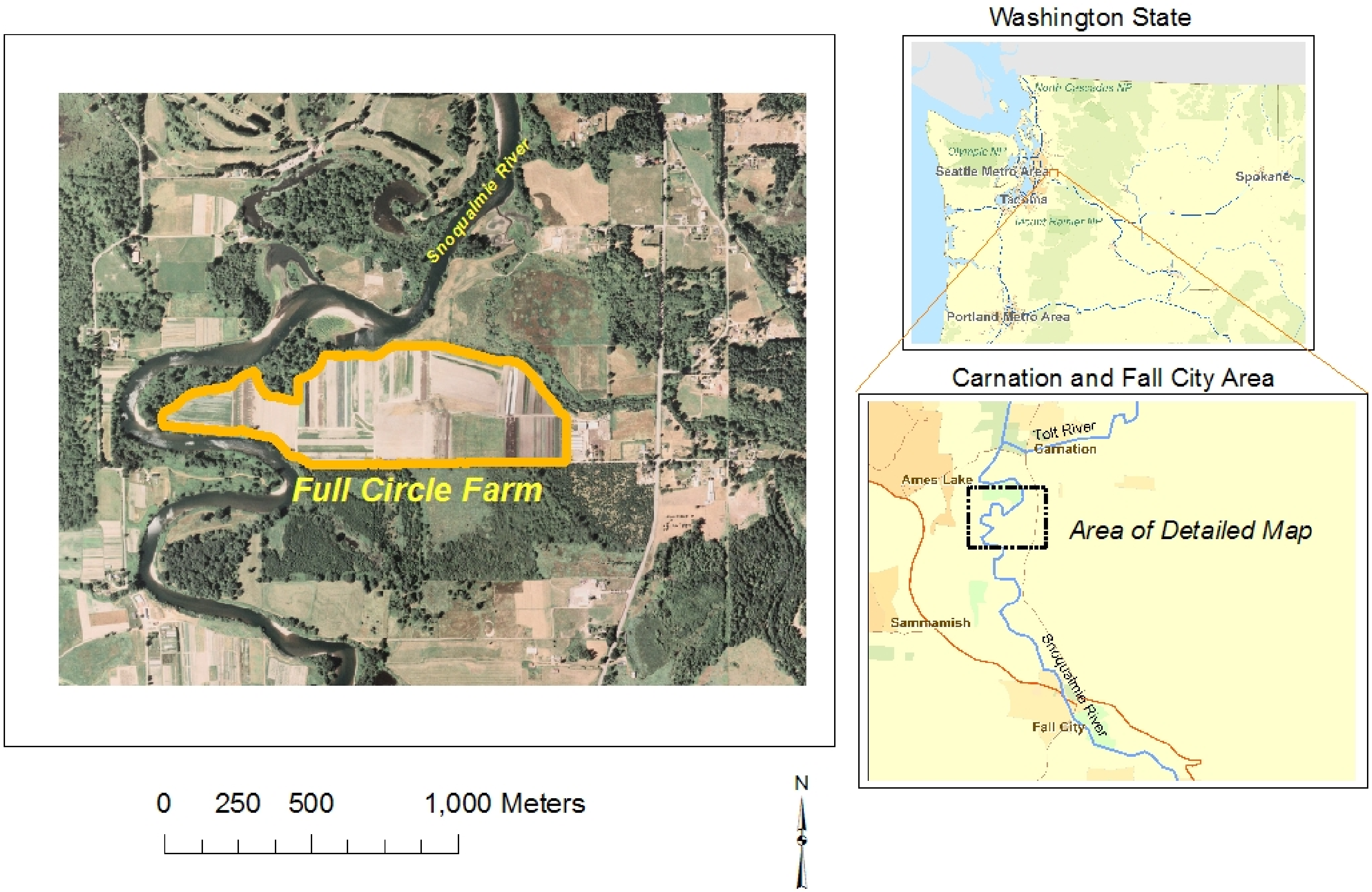
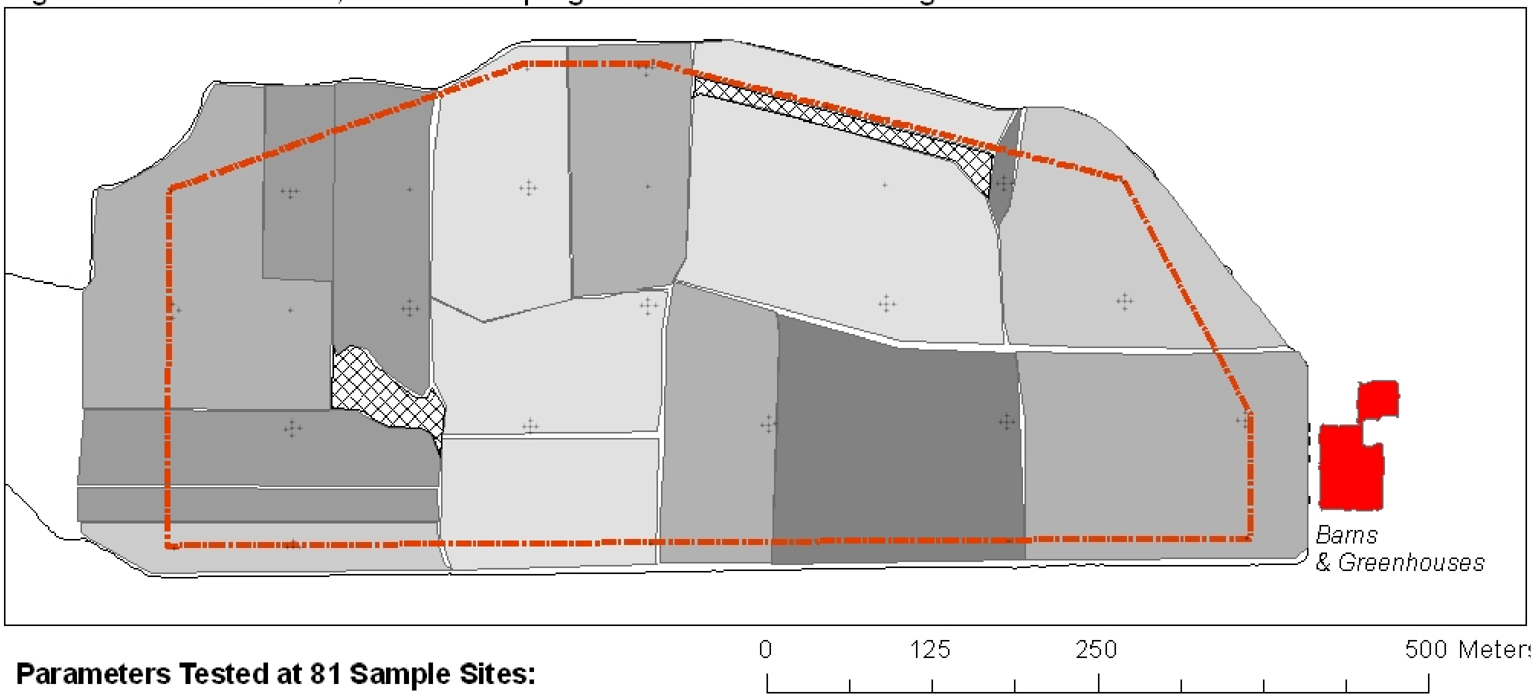


Figure 2. Full Circle Farm, fall 2006 sampling sites and weeks since tillage.



Parameters Tested at 81 Sample Sites:

Biological
- Collembola (0-5cm)
- Nematodes (0-15cm)
- Microbial Biomass (0-10cm)

Physical and Chemical
- N-Mineralization Potential (0-10cm)
- Aggregate Stability (0-10cm)
- Organic Matter (0-10cm)
- Total Nitrogen (0-10cm)
- Nitrate-N (0-30cm)
- Bulk Density (0-15cm)
- Texture (0-10cm)
- Soil Moisture Content (0-15cm)

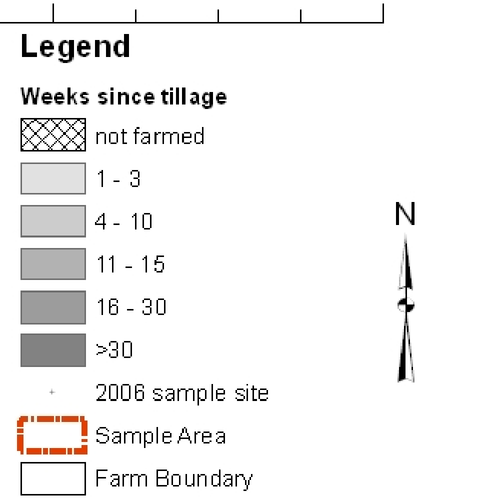
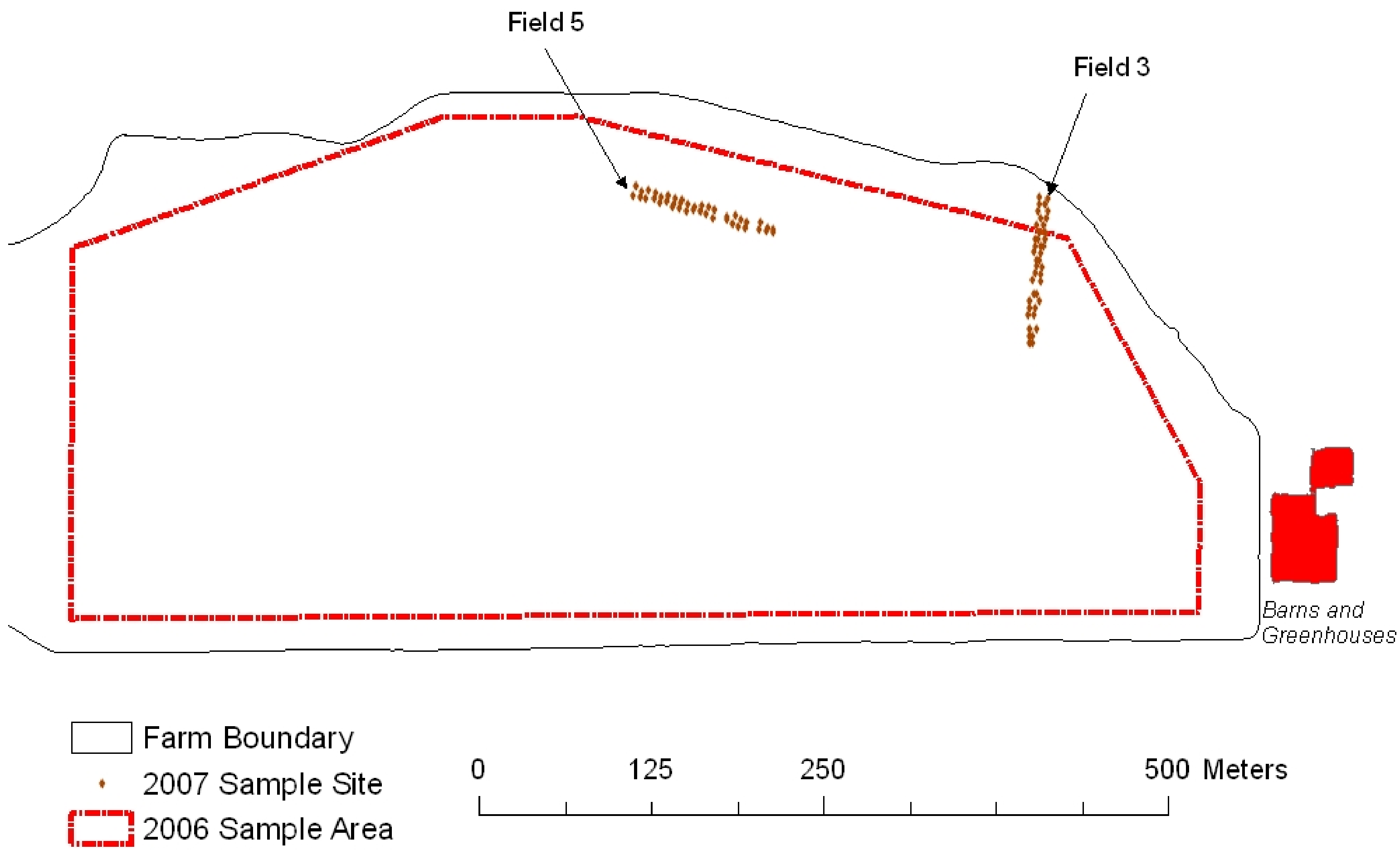


Figure 3. Location of fields sampled in 2007 at Full Circle Farm.



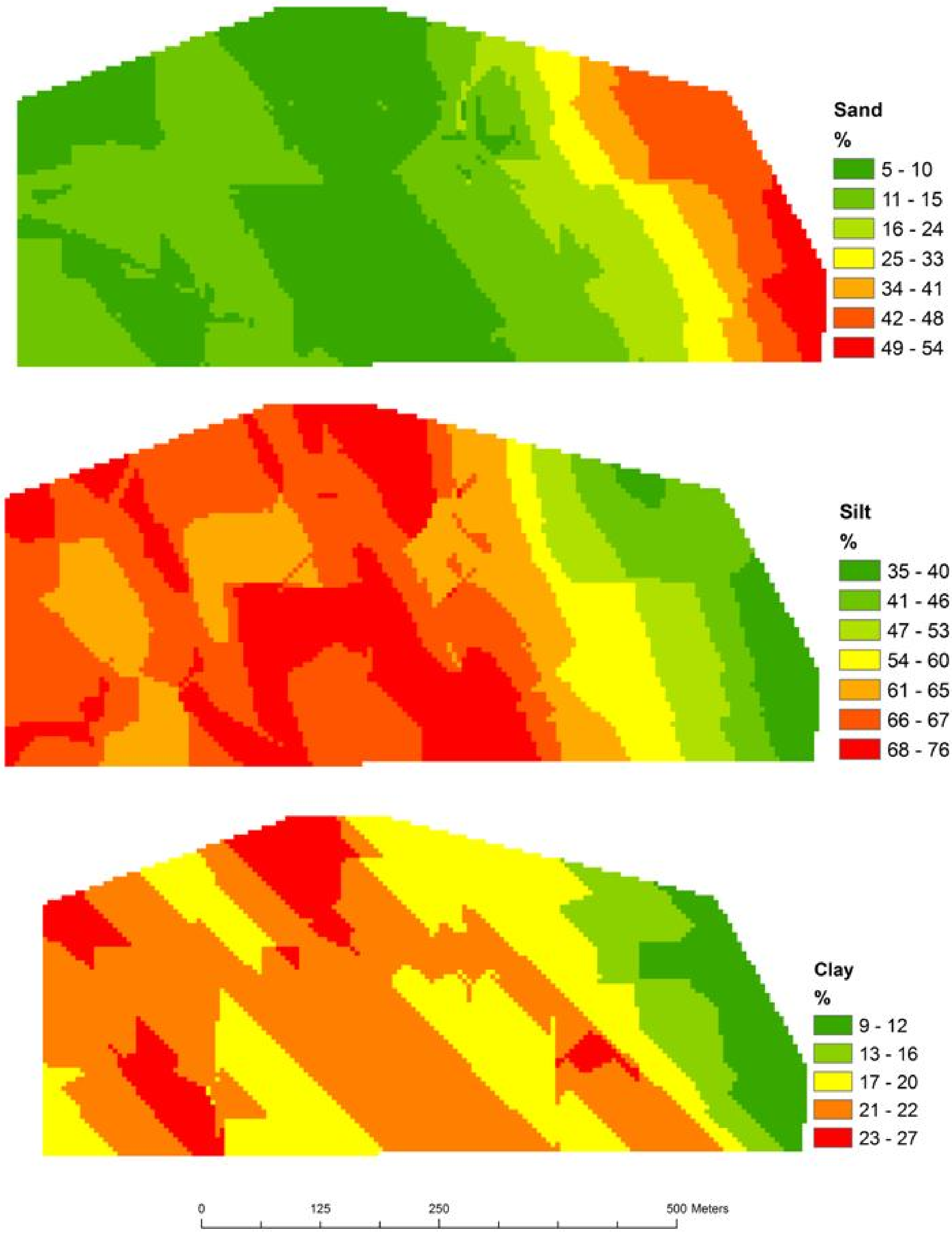


Figure 4 a-c. Percent sand, silt, and clay across Full Circle Farm, 2006.

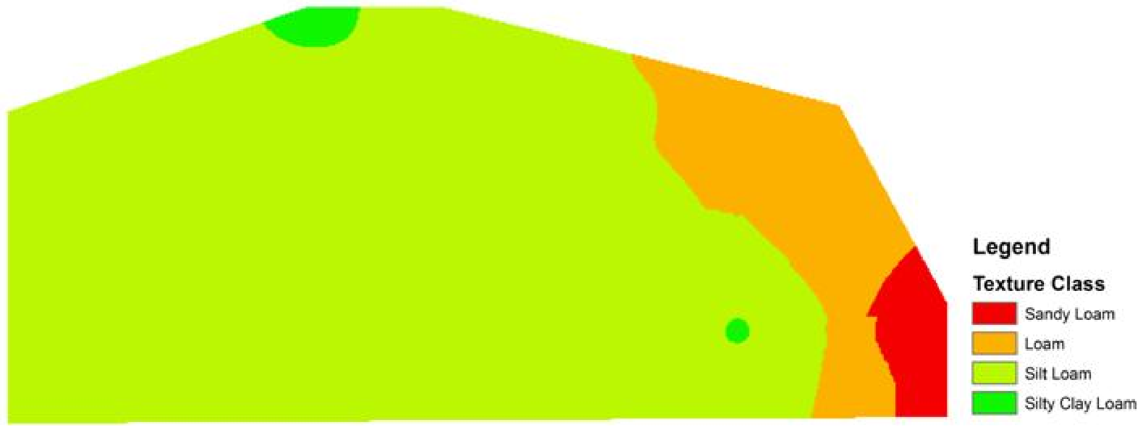


Figure 5. Soil texture classes across Full Circle Farm, 2006

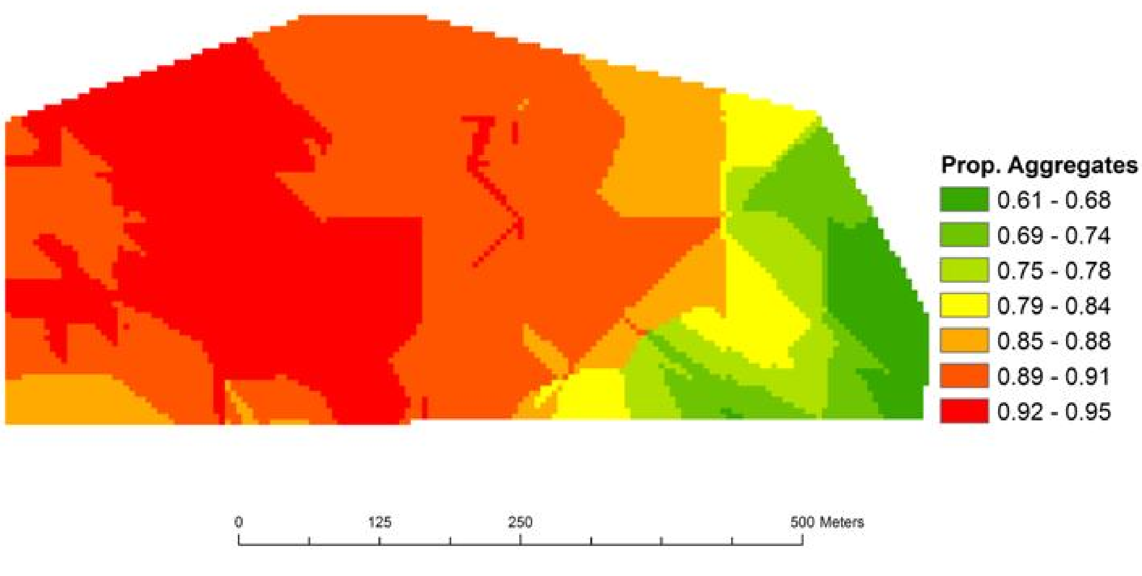


Figure 6. Proportion of soil as aggregates greater than 0.25 mm across Full Circle Farm, 2006.

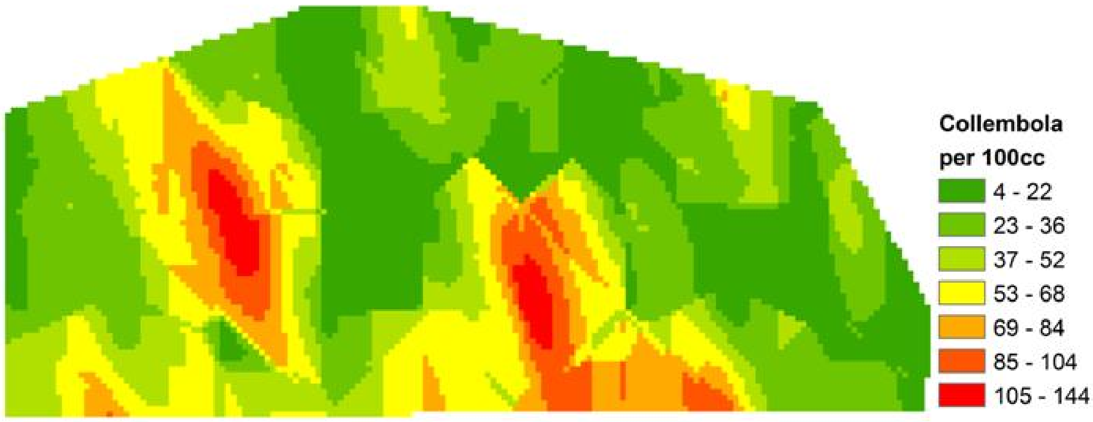


Figure 7. Total Collembola across Full Circle Farm, 2006.

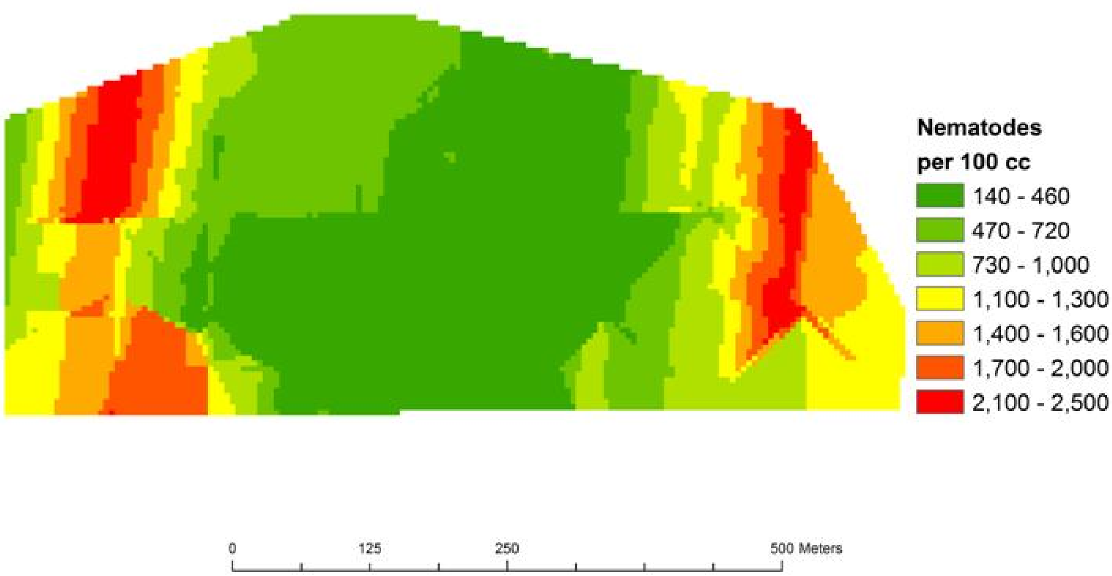


Figure 8. Total nematodes across Full Circle Farm, 2006.

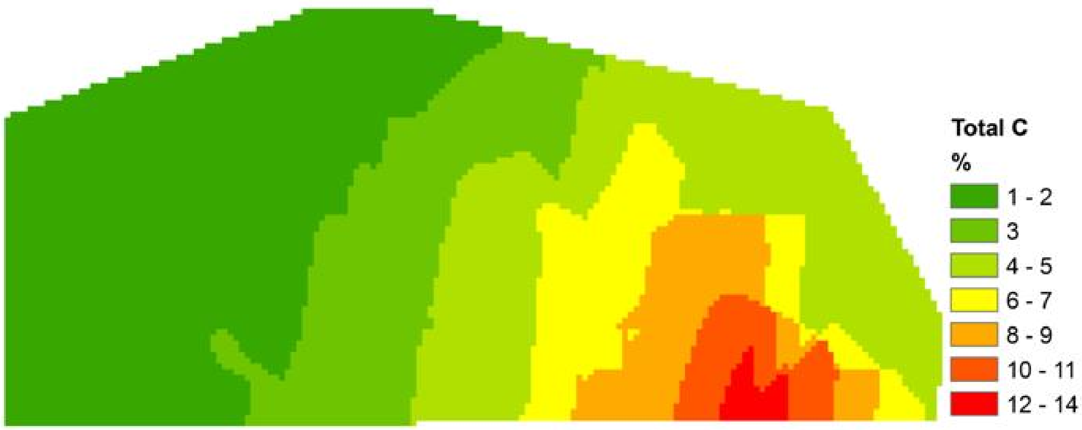


Figure 9. Percentage total C across Full Circle Farm, 2006.

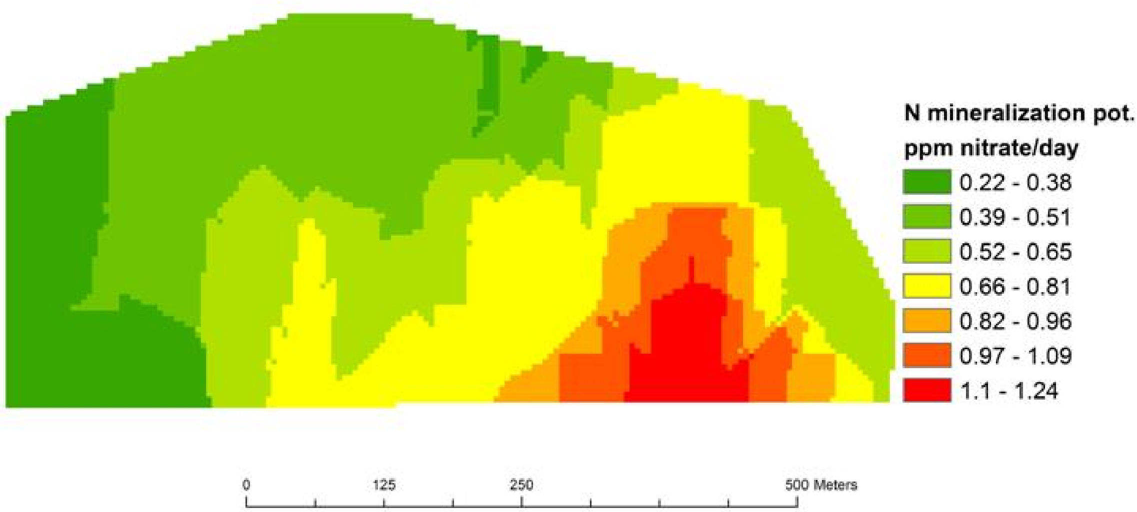


Figure 10. N mineralization potential across Full Circle Farm, 2006.

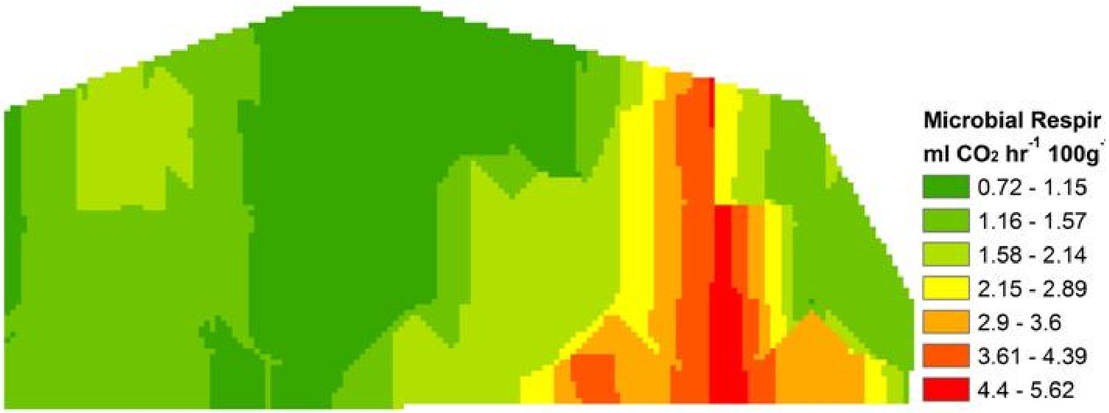


Figure 11. Substrate-induced microbial respiration across Full Circle Farm, 2006.

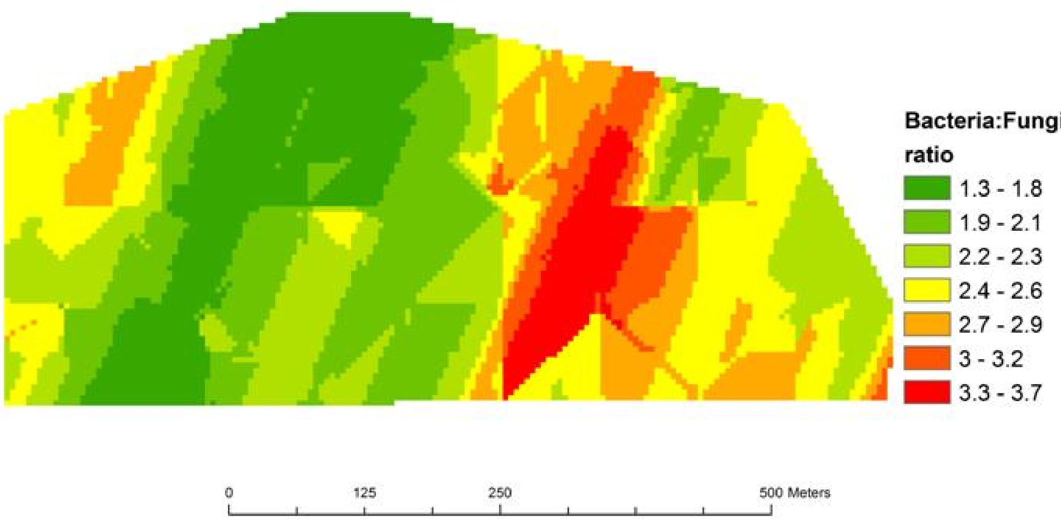


Figure 12. Bacterial to fungal ratio across Full Circle Farm, 2006.

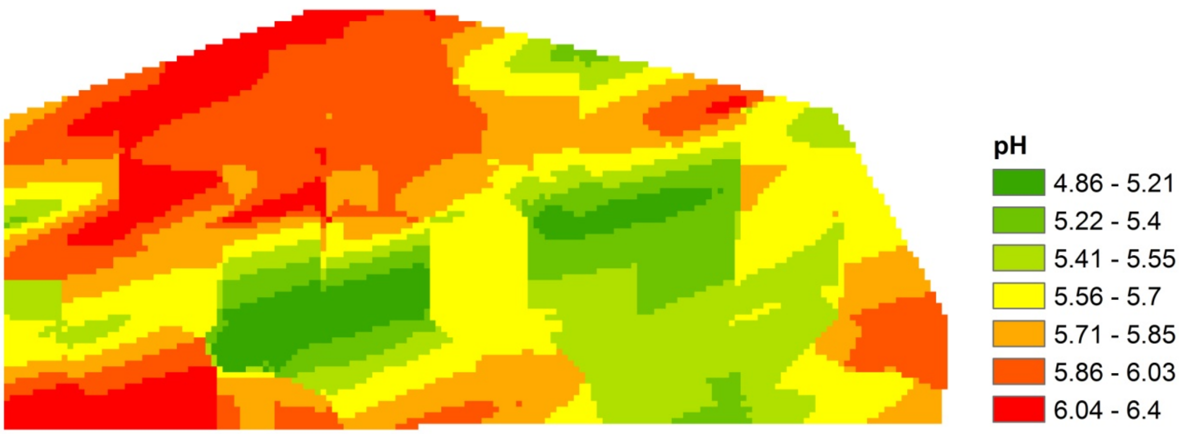


Figure 13. pH across Full Circle Farm, 2006.

Figure 14. Regression tree for N mineralization potential (mg N kg^{-1} day^{-1}) from soil at Full Circle Farm, Carnation WA in 2006. EI= enrichment index.

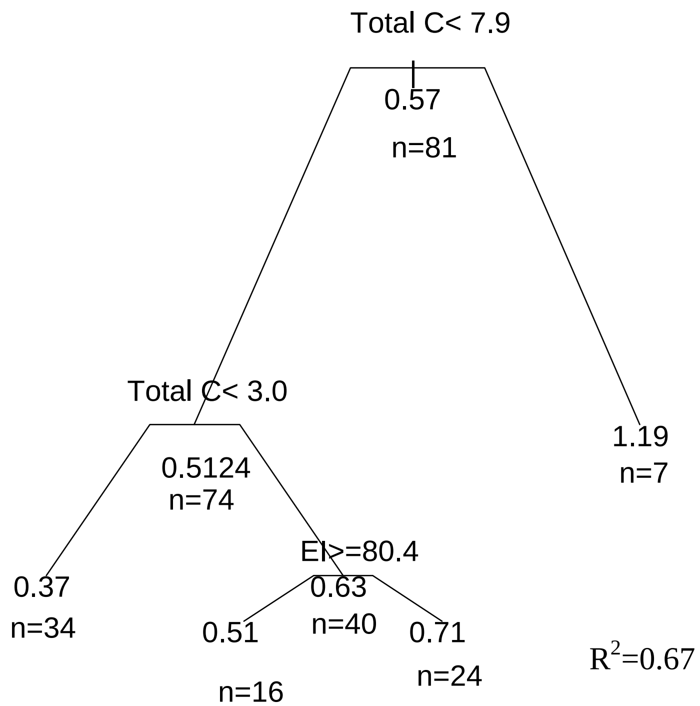


Figure 15. Regression tree for log_{10} nematodes $100cc^{-1}$ from soil on Full Circle Farm, Carnation WA in 2006. Tillage= weeks since tillage.

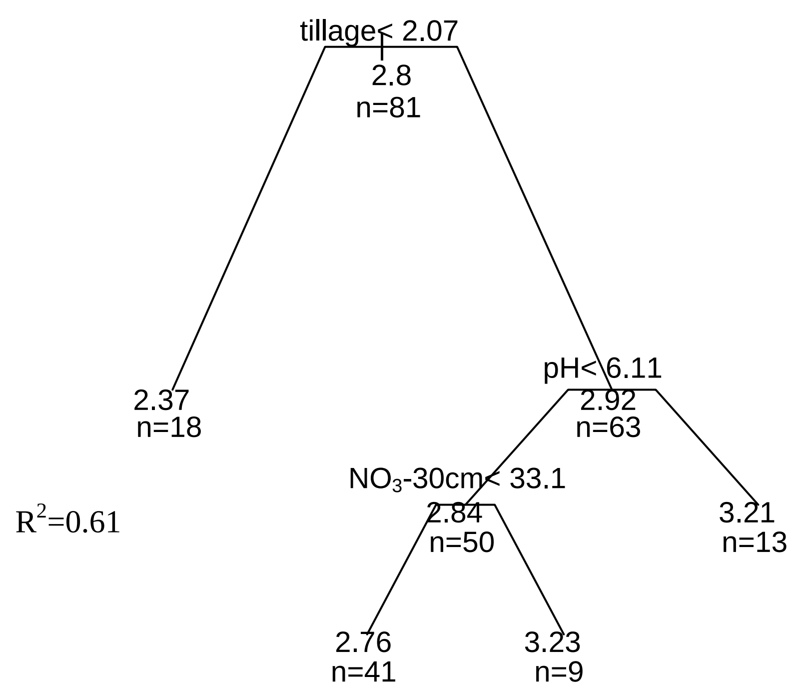


Figure 16. Regression tree for proportion of soil as aggregates >0.25 mm from soil on Full Circle Farm, Carnation WA in 2006.

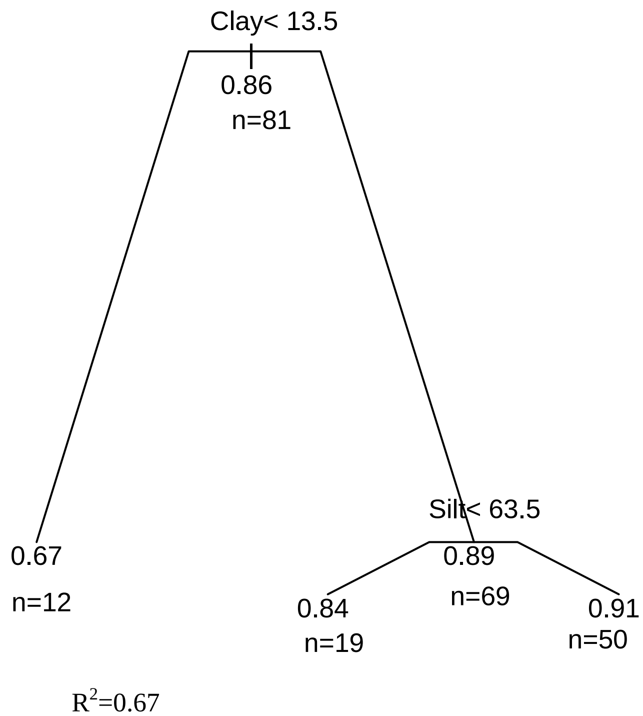


Figure 17. Regression tree for structure index of nematodes from soil on Full Circle Farm, Carnation WA in 2006. PROP AGG = proportion of soil as aggregates >0.25 mm.

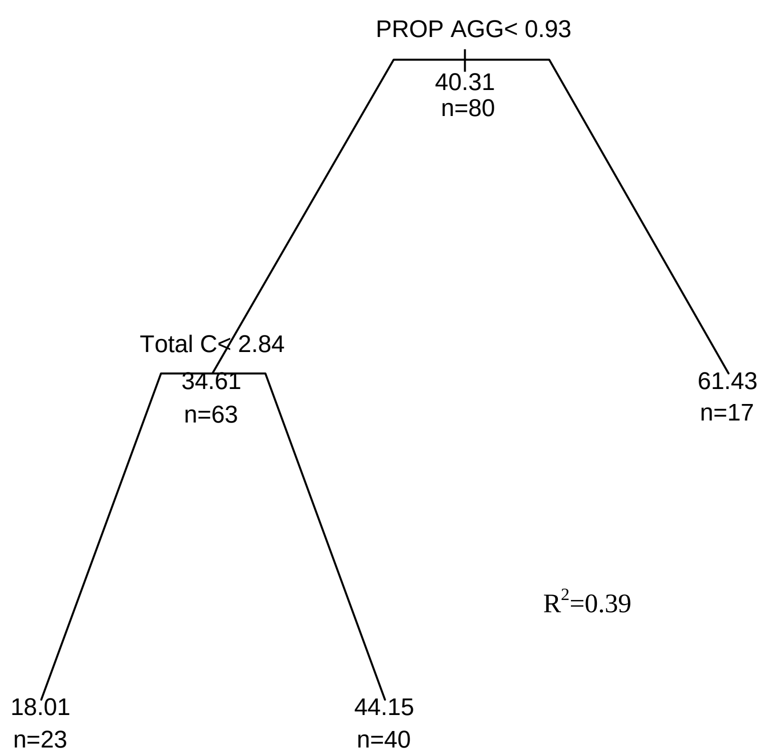


Figure 18. Post maps for percent clay in fields 3 and 5 on Full Circle Farm, Carnation WA in 2007.