Potato Soil Health and Ecology: Experiences from Michigan Potato Production

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Introduction

Potatoes (*Solanum tuberosum*) are purchased as fresh, chipping, frozen, or starch products and tubers must meet a high quality standard in terms of cosmetic and physical appearance from producers. Potato production in Michigan (MI) ranks seventh nationally with a farm gate value of nearly $208 million annually. Approximately 70% of production in the state goes towards the chip processing industry. Over the last decade some MI growers in certain production areas have been experienced declining yields and marketability issues. These quality problems have reduced the marketable output. Many growers have a perception that formerly productive fields are no longer performing to expectations. Nearly 90% of major diseases that impact crops (including potato) are caused by soilborne pathogens. Soilborne disease complexes such as Verticillium wilt caused by *Verticillium dahliae* (Figures 1 and 2) and potato common scab (PCS) caused by *Streptomyces* spp. (Figures 3 and 4) are recognized as a major cause of yield and quality declines. The amount of acreage affected by potato common scab (PCS) caused by *Streptomyces* spp. (Slack, 1992, Loria et al., 1997, Stevenson et al., 2001) continues to be a concern for commercial potato production in MI and is on the rise. Growers in MI believe that soils have suffered from compaction, and intensive use of pesticides and fertilizers, which degrades soil organic matter and reduces microbial diversity vital for maintaining soil health. Though soilborne disease complexes are recognized as a cause of yield and quality declines, soil ecology is not adequately understood. To better understand soil ecology, a soil health project was initiated to expand baseline information about pathogen interaction with biotic and abiotic soil factors.

The activity of microorganism is concentrated in the top layer of the soil that constitutes less than 1% of the total soil volume. Microorganisms in the soil are integral to carbon, nitrogen, sulfur, and phosphorous cycling, decomposition of organic matter, and degradation of waste and pollutants. Additionally, microorganisms affect the physical properties of soil, maintain soil structure, affect water holding capacity and infiltration rate, crusting, erosion and compaction. Bulk soil (the soil outside of the rhizosphere) contains approximately 10,000 bacterial species per gram of soil. The rhizosphere is the zone of soil influence by the roots, can contain as many as three times the diversity of bulk soil. Less than 1% of many of these bacteria can be isolated in the laboratory. . Many of the soil organisms in the rhizosphere are beneficial to plant health and can have significant impacts on disease control.

Materials and Methods

Web-based grower survey A web-based survey instrument was developed and vetted to determine grower's perspectives and perceptions of important production issues. The purpose of the grower survey was twofold: 1. Identify grower opinion on key factors driving yield reductions in "mature" and "new" potato ground; and 2. Ask growers to suggest fields for soil sampling.

Field sampling In fall of 2012 and early spring of 2013, 22 separate fields with varying levels of potato history were sampled on a grid sampling scheme and analyzed for both biotic and abiotic soil properties including pH, buffer pH, cation exchange capacity, organic matter, calcium, potassium, magnesium, phosphorous, *Verticillium* spp. colony forming units (CFUs)/10 g of soil, root-lesion nematode populations, and soil microbial structure of collected samples using DNA technology. Soil was sampled in the fall/winter of 2012-13. Soil sampling was restricted to 20 fields that were considered to have high and low marketable yields before cropping (12 growers). Sampling locations were GPS marked (20 samples per field) and 400 samples in total were processed at the MSU soil testing lab and sequenced using DNA technology. At the end of the growing season 20 ha sections of fields affected by PCS were harvested in block samples approximately 2 ha in size, each of which yielded 10 aggregated samples/field.

Parallel sequencing Soil from each sample was used for DNA extraction, using the Mo Bio 101 DNA extraction kit (Mo Bio Laboratories Inc., Carlsbad, CA). Soil genomic DNA was used for PCR amplification of the 16S variable regions and samples were sequenced by the Illumina paired-end technique using the previously described protocol (Kozich et al., 2013) with slight modifications for total bacterial community analysis. Samples were sequenced at the MSU Research and Technology Support Facility.

Field mapping ArcGIS (ESRI, Redlands CA) was used to analyze and visually display soil sample and DNA sequencing results. Data for each field was entered into a GIS database and Inverse Distance Weighting (IDW) was used to estimate values between points for soil physical properties, microbial diversity, and yield. IDW assumes that points located closer to each other are more related than those farther apart. This principle can be used to approximate the distribution of data and to understand how soil properties are correlated across space.

Results

Web-based grower survey More than 50% of the growers in MI surveyed indicated that yield has decreased by at least 5% or more over the last decade (Figure 5). Additionally, the amount of acreage affected by potato common scab (PCS) caused by *Streptomyces* spp. increased by 11% or more over last decade (Figure 6). Growers in MI identified that soil microbial activity and diversity are important factors related to soil health and limiting yield (Figure 7).

Parallel sequencing Next generation sequencing targeting the 16S rRNA gene, and dual indexing allowed high throughput processing of samples simultaneously. The total number of taxa identified to phyla, class, order, family and genus was 28, 81, 140, 300 and 814 respectively. Sequencing results and information gathered on yield and scab pressure from each point was used to generate multi-layer GIS-based maps.

Field mapping After all data assembled into a database, each field was examined individually for spatial continuity and variability of the sample points using geostatistical parameters. Data was then interpolated with IDW mapping methods and visual correlations were made between scab severity, yield. and biological and physical soil properties (Figure 8). GIS mapping of soil properties enabled the visualization of relationships between measured variables.

Summary

The procedures and methods developed during this study will be used to build a framework on which to construct tools for understanding microbial interactions within soil as well as visualizing pathogen levels across fields as part of an integrated pest management system. These interactions between plants and microorganisms are a growing field of study for plant pathologists and the American Phytopathological Society has organized a worldwide phytobiome initiative which targets an understanding of how the associated microbial community influences or is influence by the plant and how that information can be used to improve crop productivity (www.phytobimes.org). Soil microorganisms respond quickly to changes, and rapidly adapt to environmental conditions and stress. Changes in microbial populations or activity can precede detectable changes in soil physical and chemical properties. Because microbes serve as indicators of soil health an Increased understanding of plant-associated microorganisms will lead to better management of soil health. This project was used to develop baseline data on soil interactions to serve as a foundation for future research to improve soil ecology in Michigan potato fields and strengthen Michigan's potato industry's competitive position by increasing yields.

Soil health and soil ecology has become a focus of the potato pathology laboratory at Michigan State University and the Michigan Potato Industry. As new molecular tools become available and costs decrease, the ability to understand the soil molecular ecology will increase. These molecular tools along with geostatistical and geographical tools have aided researchers in looking at soil ecology from a whole field perspective. The long-term goals of these projects include using the baseline data to develop a trans-disciplinary tool combining DNA technologies, GIS and computational biology at the subfield management scale so that growers can easily monitor soil conditions, soil biodiversity, and pathogen levels. Additionally, the development of DNA based detection to map specific soil-borne pathogens of potato. The hope is to incorporate predictive and conditional probability maps into integrated soil borne disease management in commercial potato production. This technology will improve productivity, reduce chemical inputs, and improve soil quality for disease-free and sustainable high-quality crop production.

Acknowledgements

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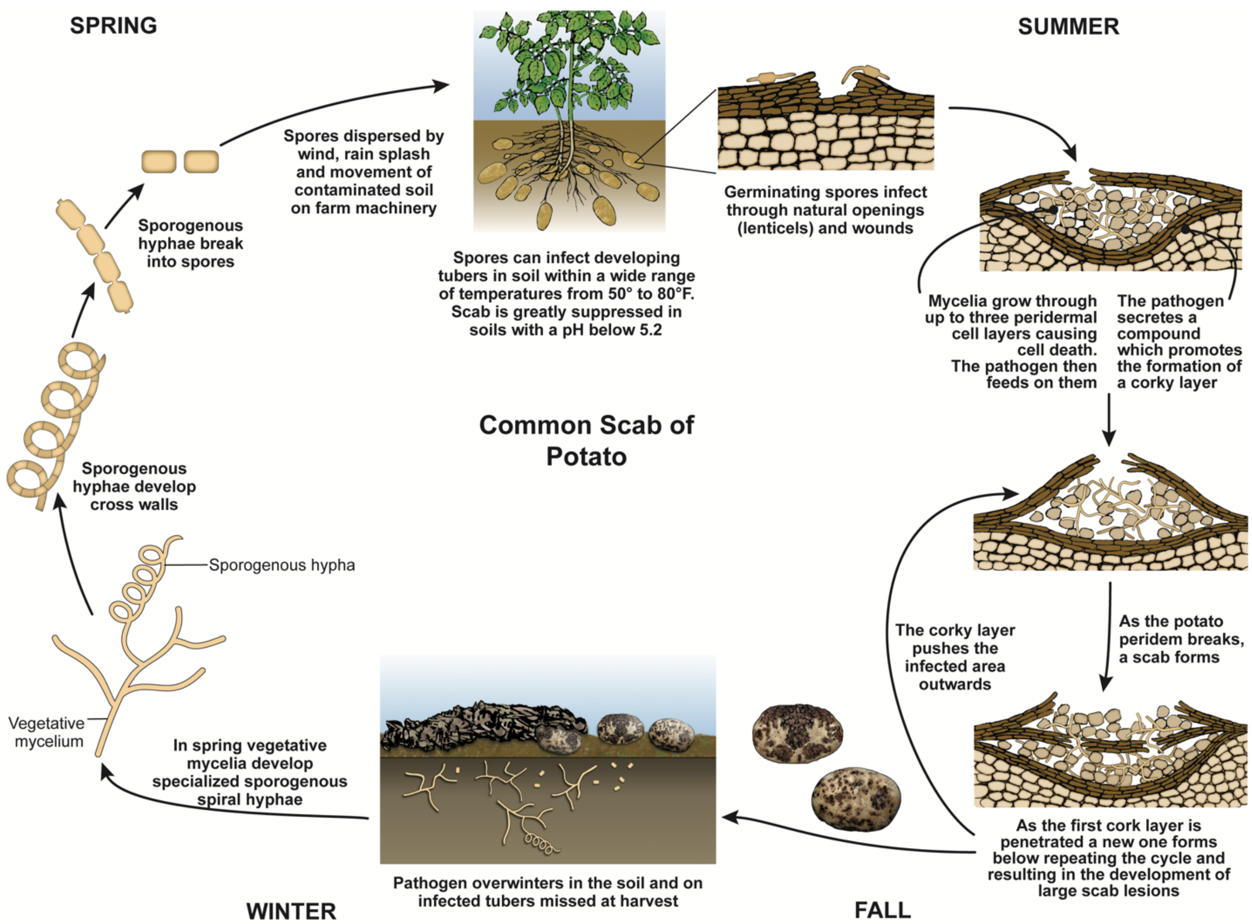

Figure 1. Disease cycle of common scab of potato. (Marlene Cameron, Michigan State University)

Figure 2. Potato common scab lesions; lesions start out as small, brownish spots, which enlarge into water-soaked circular lesions within a few weeks of infection. These circular lesions may coalesce forming large scabby areas.

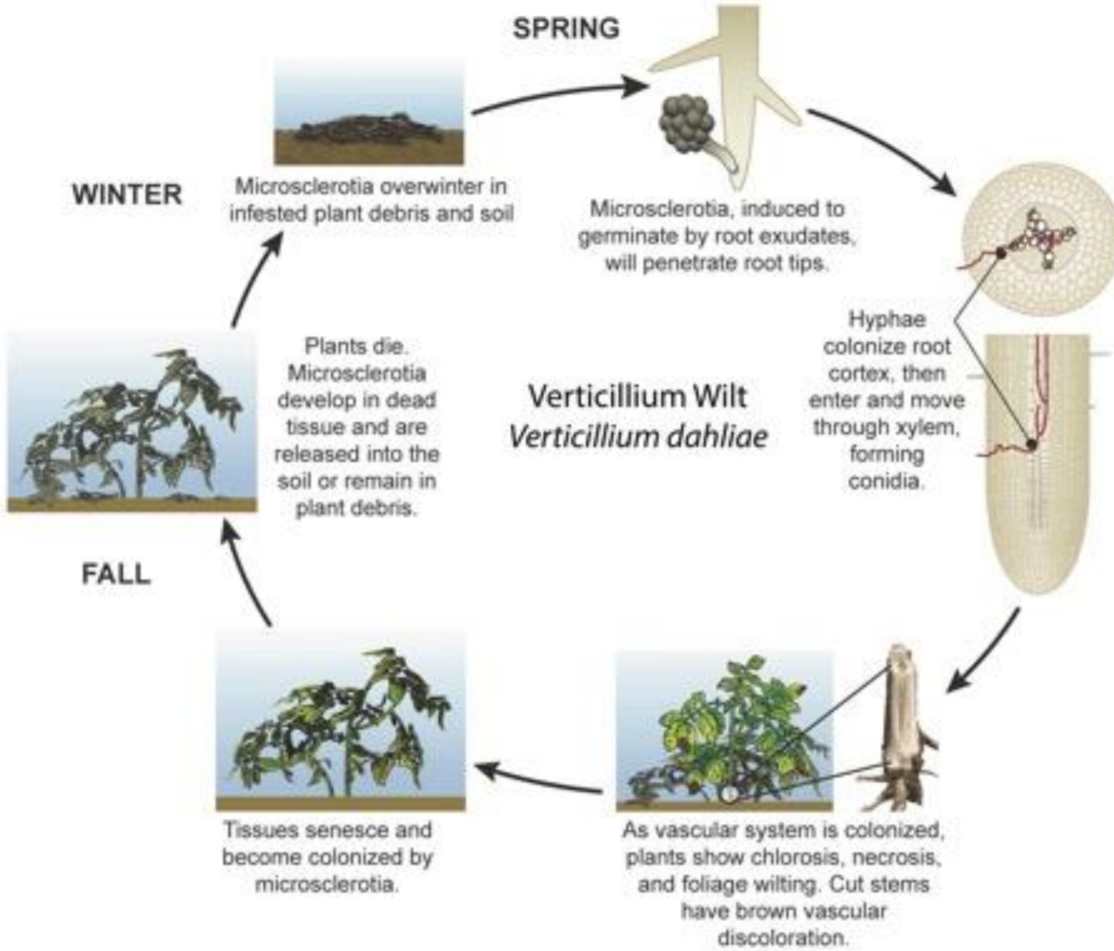

Figure 3. Disease cycle of Verticillium wilt of potato. (Marlene Cameron, Michigan State University)

Figure 4. Severe symptoms of Verticillium wilt results in tuber stem-end discoloration. (Michigan State University)

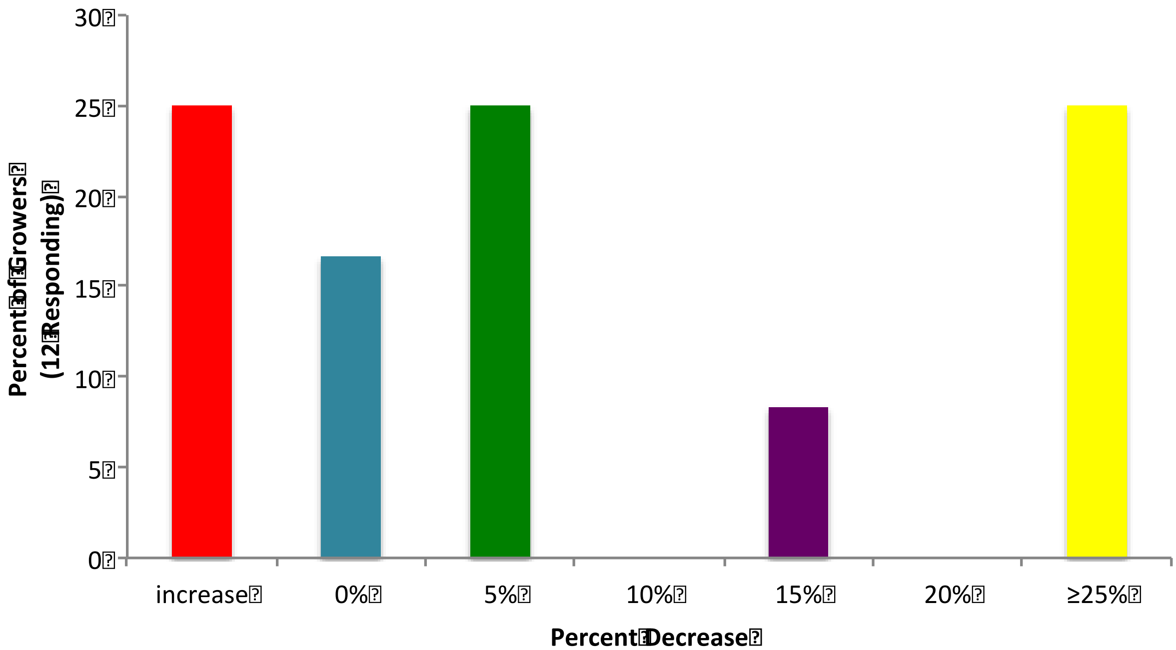

Figure 5. Level of decrease in soil yield acres over last 10 years.

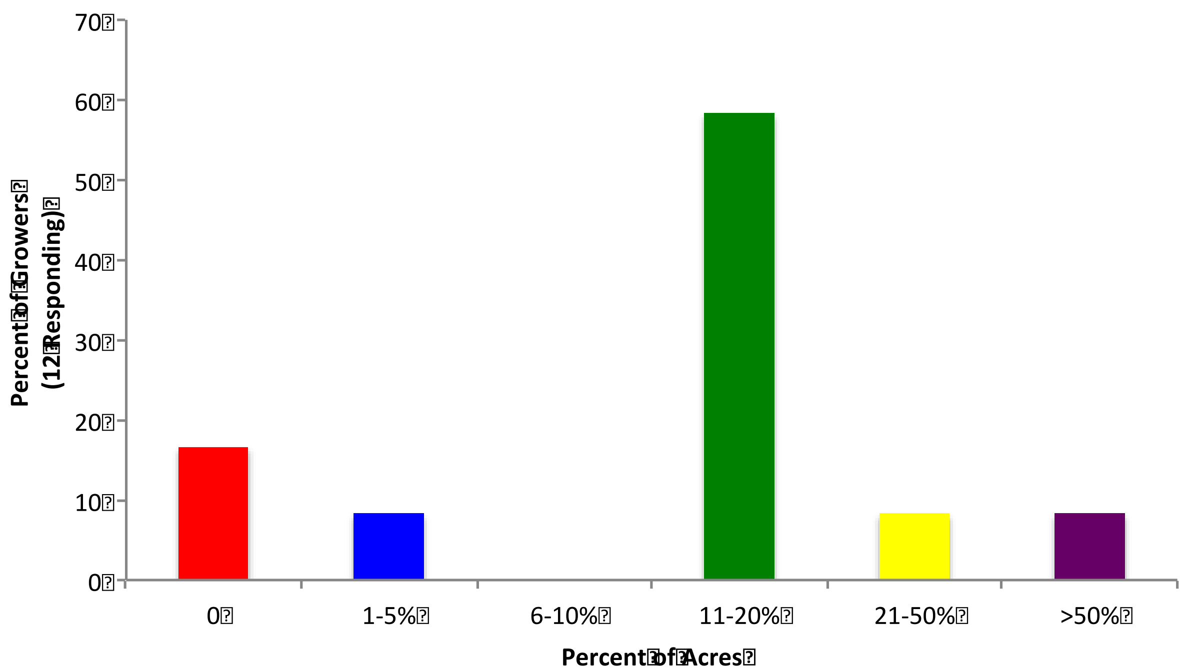

Figure 6. Increase in percentage of acres affected by common scab compared to 10 years ago.

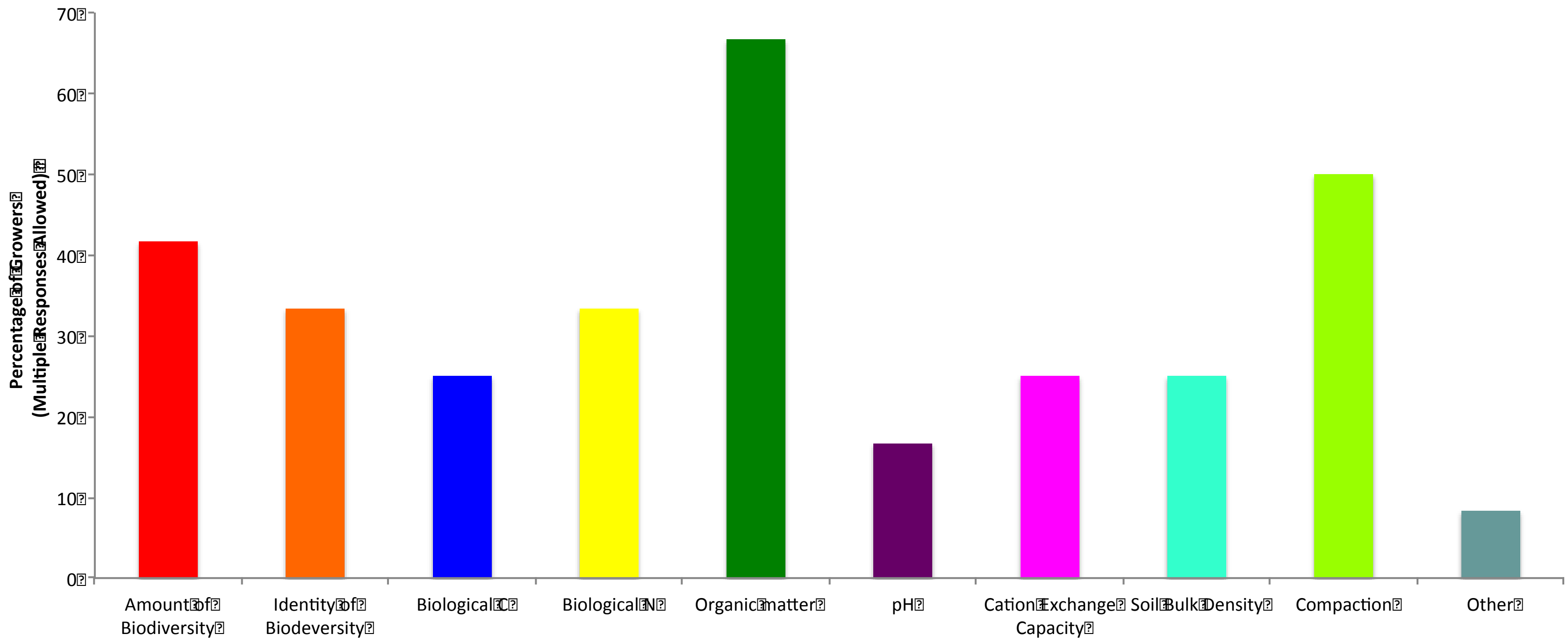

Figure 7. Soil quality factors limiting yield in potato production system.

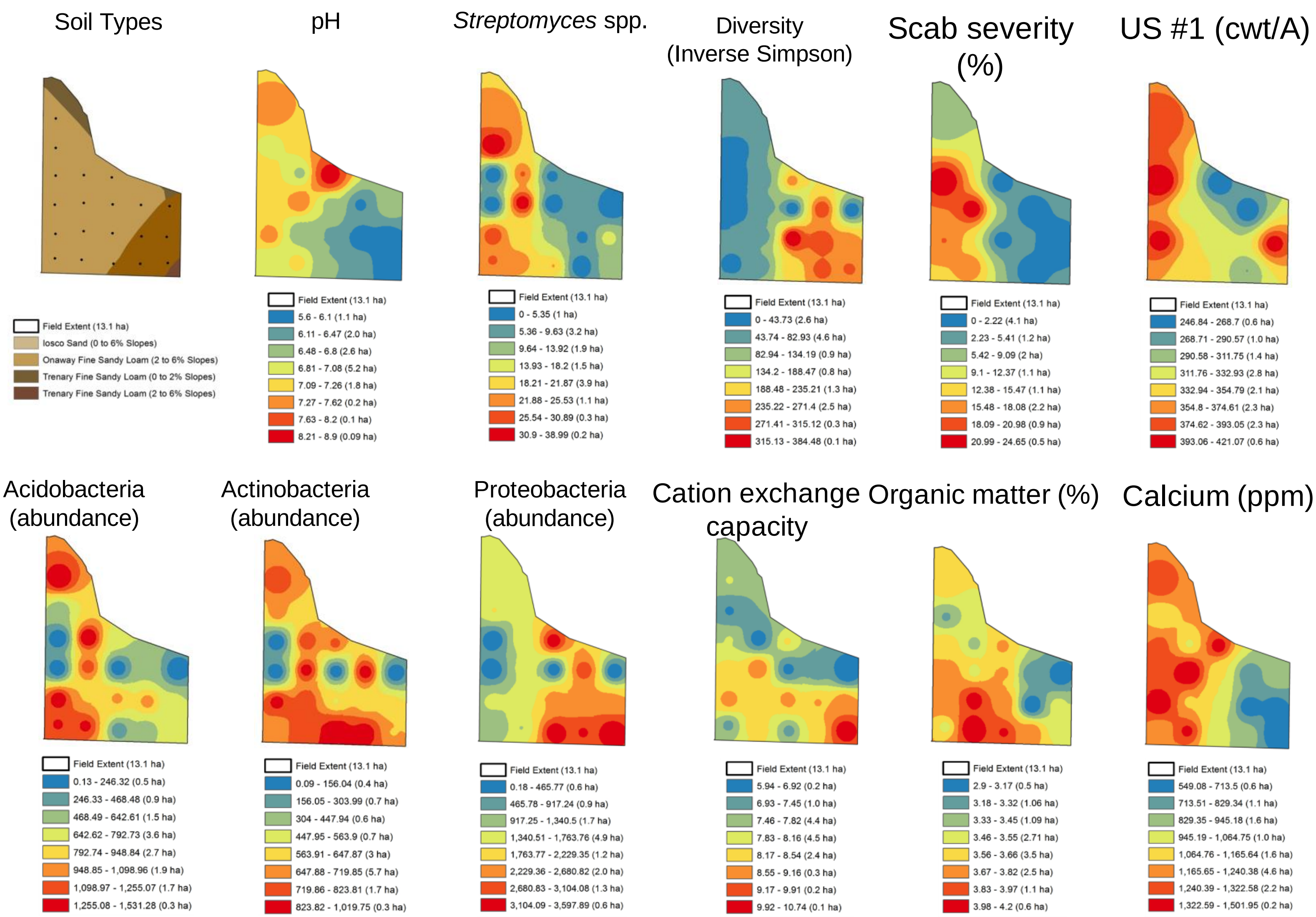

Figure 8. GIS map of slected soil properties measured: Soil type and sampling points; pH; Streptomyces spp. (abundance); Diversity; Scab severity; Potato yield; Acidobacteria; Actinobacteria; Proteobacteria; Cation exchange capacity; Organic matter; Calcium.