Sustainability Aspects of Precision Agriculture for Row Crops in Florida and the Southeast United States[1]

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Precision agriculture or site-specific management is a knowledge-based technical management system, where sensing, information technologies, and mechanical systems enable sub-field crop management that can help optimize farm profits and minimize agriculture's impact on the environment. This technology has been developed over several decades through private sector and university research efforts, with new technologies and applications available every year. Information about a field can be obtained and continuously updated to refine management strategies or solve production issues throughout the season. Precision agriculture involves the use of information about a field to inform optimal inputs needed for profitable production. Growers who use precision agriculture technology have more information at their disposal and usually spend more time thinking about crop management and ways that yields and profits may be enhanced.

Agricultural research has always attempted to determine precise responses to treatments under controlled or known conditions. In research plots, scientists control as many factors as possible, then study variables to determine if there is an association between treatments and a response. Similarly, farmers want as much information as possible from soil tests, pest maps, and other sources to make informed management decisions. In many cases, growers have no way to check responses to rates of materials applied, but experienced growers typically have a good idea of what happens without that input. As soybean rotations for grain crops were introduced, for example, knowledge of soil pH was needed for lime application rates so that good growth of nitrogen-fixing bacteria would occur and thus enhance crop productivity. However, growers have had little way to confirm whether low, medium, or high liming rates were most economical. Early researchers determined fertility levels of the soil on specific sites or fields and made recommendations for proper lime application rates for most economic returns. Variety evaluations, likewise, have been based on matching varieties to locations, soil and climatic conditions, or known pests. Planter technology now allows growers to vary plant populations across the field as moisture or fertility levels change.

In recent years, site-specific farm management has received new life through yield monitors on grain combines, cotton pickers, etc. About 50% of Midwest farms use yield monitors that were purchased with new combines (Griffin 2009). Yield monitors allow farmers to test management on their own farms over large acreages and compare yields and economics so that better management decisions can

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be made for future crops. Global positioning systems have allowed the adjustment of variable-rate applications of water, nutrients, pesticides, or any number of management factors in order to better manage soil variability. Considerable information about the fields is necessary to vary inputs economically. Note that use of this technology does not necessarily mean more profit, due to unknown variables and equipment expenses. Yield maps of the same fields over years can enable farmers to determine the impact of site-specific management on their yields. Profitable site-specific management involves finding the area where benefits of using this technology offset the costs. Optimal site-specific management is very difficult to determine because many factors can influence biological systems. Recent advances in computer technology, communications, and engineering have provided us with a good opportunity to integrate information and change our approach to farm management, especially in relation to pest, fertility, and water management. These are the most expensive areas of input that have a large impact on yield and economics of a farm.

Farmers and consultants continuously work to figure out how to best use these new tools to their advantage. Site-specific management depends on how crops respond to the environment. These responses are due in large part to the belowground environment (influenced by tillage, fertility, drainage, soil properties, nematodes, diseases, etc.); however, the aboveground environment (weather, pests, diseases, etc.) also affects the crop and may be more variable. Farm profitability maps help growers make decisions on which crops to grow and select the best crops to use in rotations. Until crop responses can be predicted for specific management practices applied to management zones, and profit maps show that management is expected to have a profitable return on investment, widespread adoption of site-specific management will be slow. However, since much of the new equipment is set up with GPS guidance and other technology, farmers may use the technology for some applications, such as sprayer cutoff to prevent overspraying treated areas. This does not require specialized equipment. Variable-rate application of fertilizer has been the predominant use of precision technology with information gained from implements that characterize soil by conductivity, pH, OM, etc. Use of this technology is increasing as farmers see how it helps the bottom line and as more technology becomes available on farm equipment and phone apps. Variable-rate planting is increasingly being adopted. Farm subsidy programs are now helping farmers purchase equipment required to implement the new technologies that can help them make decisions regarding appropriate input amounts and locations. Additionally, there is tremendous interest and investment occurring in the area of "digital agriculture."

Good Sampling is Key to Good Decisions

Obtaining good samples or information about an area of management is the key to making good decisions. When growers sample by using zone sampling (areas that yield the same or respond similarly), they learn more about the field and areas where responses begin and end. Many growers have run a harvester or grain combine over the field for many years; they know what areas or zones have similar yields or soil types, and can sample accordingly. Likewise, drone images of fields before harvest can provide maps of vegetation indices (e.g., normalized difference vegetative index (NDVI), which provides a good indication of variability in plant growth across a field). Grid soil sampling is more intensive than zone sampling and is usually done when nothing is known about the sites. Sampling field soils for nutrients has been studied intensively. Presently, zone sampling, as appropriate for field crops, has come to the forefront in the southeastern United States. Zone sampling requires knowledge of where crop yields differ in areas of the field and what zones respond similarly. Rapid development of sampling procedures that allow continuous sampling of soil moisture, organic matter, cation exchange capacity, and pH will lead to more extensive data for better management decisions. There is a vast amount of information on crop water use, and much is known about the water-holding capacities of most soils. There are now incentives for growers to conserve water, which have led to conversion of irrigation systems to variable rate irrigation (VRI) to improve water management through irrigation systems. Use of site-specific pest management is being researched in the Cotton Belt, where many pesticide applications are made under conventional cotton production methods. Disease and insect pressure are good examples of sporadic pest problems that are difficult to predict. Under certain circumstances, an underlying issue may be the cause of the pest or disease problem; in some of these cases, soil amelioration (drainage, liming, etc.) may correct the problem for years to come. Traditional integrated pest management (IPM) is based on quantification and qualification of pest populations to determine if control measures are economically justified. There has always been a tremendous challenge to quantify pest populations and their potential economic damage in a reasonable and reliable way. The many appropriate field level sampling procedures in practice today reflect the diversity of pests, their potential for rapid population growth and dispersal, their potential for economic damage, and the types of control measures available.

Use of Precision Agriculture Technologies in Pest Management

The abilities to spot-treat areas of the field in need of pest control and to manage a healthier crop through adjustment of inputs within the field rather than at the field level are at the forefront of site-specific IPM research and application. These have tremendous potential to reduce costs and environmental impact. Disease, weed, and nematode site-specific management is a rapidly developing area. Site-specific farming provides a more precise way to sample and manage fields. By linking soil, crop, pest, disease, and environmental features into one program, crops can be managed more effectively and with fewer trips across the field, resulting in improved economic returns and reducing potential negative impacts on the environment.

There has been rapid development in methods and equipment for site-specific soil sampling and yield monitoring. Sampling strategies to provide appropriate pest data, especially for insects and weeds, are also under development. Site-specific management for weeds is probably the newest of the pest disciplines. However, it could one day offer the most economical and environmental benefits of any of the site-specific management areas. Soil fertility remains relatively constant over a period of years, making site-specific management decisions easier than they are for weeds, which may change within one growing season (depending on the crops and herbicides used in the rotation). Options for site-specific weed control include variable-rate soil applications that depend mainly on soil type, and site-specific postemergence applications. The goal of site-specific postemergence application is to treat only those areas with weeds present and to treat them with the appropriate material at the right rate. Weeds tend to spread as seed or vegetatively and are likely to infest larger areas the next year. Identifying weed type and density "on-the-go" is critical to successful site-specific postemergence weed control. Several technologies integrating machine learning and computer vision are revolutionizing weed detection and targeted applications. An example of a directed-spray system is the "See and Spray" system developed by Blue River Technologies (http://www.bluerivertechnology.com/). With ongoing challenges related to increasing herbicide-tolerant weed populations, these technologies enable the application of alternative herbicide chemistries that would not be possible with regular broadcast application. The more information known about each field, the better the site-specific management decisions can be. This offers more potential for increased profit. The remaining challenge will be to develop methods to quantify the field environmental conditions so that models can be developed to link all aspects of agriculture production within a system of precision or site-specific farming.

When developing sampling strategy for site-specific application, it is important to know the goal. For example, yield data, while useful for planning next year's activities, may not be beneficial in determining what to do in the present season. These data are not as time-sensitive as sampling for pests, especially insects, which may require a nearly immediate response if a predetermined threshold is exceeded. If data are to be used in a production model, they must be adequately precise to ensure that the proper management decisions are made. Therefore, sampling for the purpose of developing a soil fertility map, as required in many precision agricultural activities, may be different than sampling to aid a pest management decision.

Fleischer et al. (1999) discussed how sampling for precision IPM can be done for the development of maps to better manage pests that vary within a field. Developed from the perspective of insect control, many of the concepts and principles apply to the sampling of any precision IPM activity. In traditional sampling, the goal is to get the best estimate of numbers and identify the affected area of the field. In general, a population becomes more difficult to quantify as its density decreases and areas of high population become farther apart. Thus, it is often best to stratify samples to increase the probability of encountering the population. Many of the sampling plans result in sampling procedures that are too intensive and therefore expensive. Nyrop et al. (1999) noted that precise procedures are often unnecessary, and that more general descriptions may be appropriate when using sampling to provide information for decision-making. It is more important to concentrate on the level of pests that trigger a management intervention than to fine-tune sampling designs. Sampling data for pest management should identify where the pests are in the field and at what level. Then, rather than sampling throughout the field, it may be more efficient to concentrate on those areas where the population is expected to change, thus providing boundaries from which maps can be constructed. The size and the location of the pest clusters become more important than the overall mean. With current technologies, it is possible to make targeted applications of pesticides by using the pest maps to design prescription maps that can be implemented by automated application equipment on tractors with onboard controllers. Fleischer et al. (1999) and Delp et al. (1985) concluded that placement of samples is more important in precision IPM mapping because of the need to identify the boundaries of a population. Stratified samples, distributed in a pattern throughout the field, would be used to sample plant disease.

The ability to efficiently map the distribution of pest populations will impact the future of pest management. At present, maps are being used to determine where pesticides should be applied. By integrating the pest population distribution with economic models and incorporating yield and crop value, it will be possible to determine where pest control measures should be applied, or if the potential economic return justifies application at all. By integrating potential pest population growth with density maps, it is possible to determine when a control action would be warranted.

The identification and quantification of plant diseases and the dynamics of their spread have been studied extensively for many years (Gregory 1968). Disease foci in the field could be identified and the surrounding areas at high risk of infection could be predicted based on the anticipated spread of the disease. The potential to predict when and where the foci are likely to occur could be an important tool in the precision application of fungicides, especially protectant fungicides that cannot stop the infection once it has begun (Zadoks 1999). By predicting the advancing front of infection, it would be possible to design precision farming fungicide applications that would enhance disease control for certain diseases and reduce the potential of resistance development. For example, areas with visible and latent infections could be treated with a systemic fungicide mixed with a protectant, while a different protectant fungicide could be applied to the areas that are unlikely to have been infected. This differential fungicide application would not only reduce the chance of resistance development by the pathogen, but would also reduce application costs because many of the protectant fungicides are cheaper than the systemics.

Recent advances in GPS, connectivity ("Internet of things"), computational power, and application equipment have set the stage for rapid advancement of the application of technology to pest and disease control. New management tools have the potential to provide novel and more efficient methods of pest and disease control while reducing input costs and possible resistance of the pest to pesticides.

Conclusion

Several aspects of precision agriculture have been adopted as many producers gain access to technology, such as zone soil sampling and yield monitors, precision planting and spray equipment, variable rate irrigation based on zones, etc., through their agri-supply dealers. Growers had to make relatively few changes to adapt to using genetically modified crop seed technology; they still had to plant seed and spray herbicides, but they did not have to purchase additional inputs or modify equipment. Biotech seeds allowed growers to do things as they had been doing them, but made it easier, less expensive, and less labor-intensive until weed resistance became a problem. In precision agriculture or site-specific management, the equipment and techniques are continuing to be developed and improved. It is more akin to movement from horses and mules to the tractor, which required money, development of equipment, and much learning. There is enough industry support and research being conducted that rapid advances are being made. Additionally, many young farmers grew up with computers and smartphones, making use of this technology a natural and easily understood part of farming. Most new equipment is sold with the technology already integrated, and equipment dealers are training farmers in using the equipment and technology.

High investment costs for growers have required fertilizer dealers to purchase variable-rate equipment because there can be wide use over many farms, making the adoption of this technology rapid. Doerge (1999) and others have listed several reasons growers are making the decision to invest in precision agriculture technology: 1) better information for diagnosing crop problems; 2) on-farm experimentation, especially variety trials; 3) improved identification of management zones; 4) quantitative evaluation of whole-field improvements, such as drainage, etc.; 5) benefits at harvest through improved truck scheduling and drying logistics, and better marketing with greater confidence of meeting contract obligations; and 6) off-farm uses, such as knowing crop yield potential for insurance purposes or determining rental prices for land dependent on yield history. Precision agriculture technology will continue to improve and adoption will increase, offering more benefits to producers and making it common technology on farms in the 21st century.

A key to the successful use of precision ag technology will be the availability algorithms that translate data, such as weather data, UAV imagery, and yield maps, into actionable information that can be used by growers to improve efficiency and profitability of their operations. A second important factor will be availability of education and training for growers to inform them on how to use the technology as well as technical support when problems arise.

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