Precision agriculture: challenges and opportunities in a flat world

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Abstract
Precision Agriculture has witnessed unprecedented growth in the last decade, especially in countries such as the United States, Germany and others. This paper will present the broad concept of precision agriculture with several examples of precision nutrient management from several countries. There, farmers and practitioners have overcome the challenges associated with precision nutrition management and converted them into opportunities by harnessing the global information and developing local precision techniques suitable for their region, operation and resources. With increasing global population and limited or decreasing arable land available for crop production the question arises "will we be able to overcome the future challenges and seize them as opportunities?" Precision agriculture management coupled with genetic improvements in crop traits will play a crucial role in meeting global demand for food, feed, fiber and fuel in the near and distant future.

Key Words
Precision agriculture, opportunities, challenges, global proliferation.

Introduction
Precision Agriculture has witnessed unprecedented growth in the last decade, especially in countries such as the United States, Germany and others. While the rest of the world has been relatively slow in embracing precision agricultural practices, the change is coming. From Australia to Zimbabwe, precision agriculture is growing across the globe. This is clearly evident by the number and diversity of manuscripts published in the area of precision agriculture in international journals and also by the variety of papers presented at the major international conferences on precision agriculture from different countries around the world. Publications and presentations may not be a scientific metric to account for the geographical spread but it indeed is a reflection of changing times and the proliferation of precision agricultural techniques and concept.

The advent of precision agriculture that occurred in the developed world about two decades ago involved application of advanced and innovative technologies. Precision agriculture in developed countries continued in that direction and today it is more sophisticated and complex than before. Interestingly, there are a number of definitions and concepts that can be found in literature pertaining to precision agriculture. The one that is most commonly cited and used by practitioners is the one that consist of several "R"s of Precision Agriculture. Robert *et al.* (1994) proposed three "R"s, the Right time, the Right amount and the Right place. Later, the International Plant Nutrition Institute added another "R" to that list, "the Right Source", and more recently, Khosla (2008) proposed an additional "R", the Right manner. For example, in precision nutrient management, "Right manner", refers to the method of placement of nutrient in the soil, (i.e.) broadcast versus banding, dribbling, injecting, etc. The "right manner" aspect may be not be very important for agriculture practiced in the developed world, however, it is of great importance for global precision agricultural practices.

The concept of "R"s does not mandate utilization of advanced technologies to practice precision agriculture. For example, it may take a suite of auto-pilots or high resolution guidance system on a 1000 hectare farm in the USA or Brazil to practice precision agriculture or it may take a group of skilled labors/farmers to practice precision planting on a 0.5 hectare field in a small farm in India or Asia. While the scale of farming is certainly contrasting in the two scenarios, both scenarios involved and implemented the "five R"s to identify and manage spatial and temporal variability, and hence would fall under precision agricultural practices.

Much of the recent research particularly in precision nutrient management has focused on the spatial and temporal aspects (i.e., right place and right time). Agricultural industry has been proactive in providing the innovative tools to realize the spatial and temporal management aspects of precision nutrient management. There is no doubt that significant progress has been made in managing nutrients more precisely across crop fields. However, there are still a number of challenges associated with precision nutrition management. For the ease of understanding, these are categorized on the basis of the four "R"s used in precision agriculture.

The right source

The right source of nutrient is not of grave concern since that has been identified and established for a long time. However, in the dynamic world of precision nutrient management, where the machine based decision is made in "real-time" it becomes imperative that we must realize the limiting nutrient(s) and adequately address the need with the correct source. For example, it is currently not feasible to differentiate the nutrient deficiency of iron versus nitrogen in maize (*Zea Mays*. L) crop field using sensing technology. Unfortunately, most or all of the precision nutrient management research has focused on the macro nutrients (the nitrogen, Phosphorus and Potassium). It is often assumed that other nutritional needs of the crop are met by uniform application. We need a suite of sensors that could identify the unique reflectance signature for various nutrient deficiencies in crop species.

The right place

Since inception of precision agriculture "the right place" aspect has received the most attention by scientists and practitioners. There are a number of sampling techniques and designs that allow us to characterize and quantify the scale and pattern of spatial variability in fields, such as grid soil sampling, site-specific management zones, smart sampling, soil electrical conductivity measurements, etc. However, we still need an economically feasible technique of quantifying the spatial variability in soil and crop properties at a scale that exists in the heterogeneous fields.

The right time

Availability of 'active remote-sensors" that can be mounted on high clearance fertilizer applicators has coupled the technology of "mapping variability in the crop canopy" and "variably applying fertilizer" simultaneously in "real-time". While the active sensors have been around for about 5 years, their adoption has been slow to come. The 14th annual survey of precision agricultural activities in the USA, indicate that the active sensor based fertilizer application ranks at the bottom of the list (Whipker and Akridge 2009). This could be attributed partially to the timing at which the commercially available active sensors can accurately quantify the variability in crop canopy. For example, research in Colorado, USA, has shown that active-sensors can accurately assess the spatial variability in crop nitrogen (N) needs at the maize growth stage of V12 (Ritchie, *et al.* 1992). Unfortunately, the majority or all the farmers in Colorado complete their N application for the growing season prior to that growth stage. Primarily because farmers are wary of potential delays in getting into the field due to rain, etc., which make them very hesitant in delaying in-season side-dress fertilizer applications. It will take a paradigm shift in changing the thought process of the farmers for them to adopt active-sensing based precision nutrient management or alternatively we need better sensing technology that could sense crop canopy early in the season to provide an estimation of crop nutrition needs, such that it coincide with farmer's "time" of applying nutrients (N) to the crop.

The right amount

After the advent of precision technologies, the right amount of nutrient to be applied across spatially variable fields was initially accomplished by utilizing existing nutrient recommendation algorithms developed by the research and academic institutions / Universities. However, it was soon realized that the traditional algorithm lack the robustness needed for the site-specific aspect of precision nutrient management. The new recommendation algorithms that are being developed are non-regional in approach and in some cases are unique to the site. This has created a new challenge to develop a database of multi-year field observations to create a reliable algorithm for precision nutrient recommendations that is accurate on a broader region. There is an opportunity for a technological innovation that would allow estimation of nutrient balance for each field that would aid in nutrient management and environmental sustainability. Irrespective of the challenges associated with Precision Agriculture and precision nutrient management in particular, the trajectory of precision agriculture, as witnessed over the past 20 years, is indeed correct. We will soon be venturing into the Precision Agriculture, version 2.0, in the future to meet the growing demand for food, feed, fiber, and fuel of the world.

The flat world

We are increasingly living in the "Flat World". If we were to expand our horizon across the globe, we will witness that it is indeed a flat world. In today's environment, an increase in fertilizer demand in Asia, impacts the local fertilizer prices in the USA. Likewise, a bumper crop produced in South America influences the commodity prices in Asia or Europe; or food scarcity in Haiti or Indonesia becomes a cause of concern for everyone. In a growing flat world, we are no longer insulated from external factors. There are clear signs that the global population and demand for high quality food is increasing. On the contrary, our arable land resource is decreasing and is competing with other factors such as population, bio-energy crops, and urbanization. What role precision agriculture would play to meet the increasing demand for food, feed, fiber, and fuel requirement of the world?

Precision agriculture is often misinterpreted by the developing world as complex technological intervention to agriculture, which is meant for large crop fields in the developed world. Precision agriculture and nutrient management however, can and will play an important role in lesser developed parts of the world. In a recent article in Economic Times (Dec 2009) by Dr. William Dar, Director General of ICRISAT (International Crop Research Institute for Semi-Arid Tropics), asserted that "*ICRISAT staff was able to increase grain yields of nutrient starved soils in Africa by carefully micro-dozing the nutrients to the crops*". This is an excellent example of precision nutrient management on small scale farms without large technological inputs. Like wise, Dobermann and Cassman (1996) fifteen years ago, proclaimed that precision nutrient management in the Rice-Wheat Cropping Systems in Asia, would provide another on-farm revolution. Wong *et al.* 2004 presented several case studies highlighting the methods in which farmers choose to improve their management of in-field variability. They concluded that precision agricultural research needs to focus on improving outcomes and not necessary the tools, to cater best for the needs of the farmers. Precision agriculture has the potential to contribute to increased production in diverse agricultural environments and conditions across the globe. Will we be able to overcome the future challenges and seize them as opportunities? Precision agriculture management coupled with genetic improvements in crop traits will play a crucial role in meeting global demand for food, feed, fiber and fuel in the near and distant future.

Conclusion

There are opportunities for adoption of precision agricultural techniques around the globe. The form of precision practices may be different from one place to another place, depending upon the creative mindset of farmers, practitioners, scientists and consultants local to the area of interest. This paper highlights the broad concept of precision agriculture with several examples of precision nutrient management practices from several countries where farmers and practitioners have overcome the challenges and converted them into opportunities by harnessing the global information and developing local precision techniques suitable for their region, operation and resources.

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