The Role of Precision Agriculture in Closing Maize Yield Gaps

By Steve Phillips and Kaushik Majumdar

The specific set of agricultural technologies needed to address our goals for global food security will vary amongst regions, but precision agriculture (PA) has often been identified as a key component in developing high-production, high-efficiency systems.

Precision maize planting using automated guidance and planter section control.

Precision agriculture is often associated with technology or other data-gathering methods to make site-specific decisions regarding farm management. However, it has evolved into more than just tools and technology, it is an approach to whole-farm management that recognizes and incorporates spatial and temporal variability into the decision-making process for producers with varying levels of access to technology.

The key component of PA in many regions is a global navigation satellite system such as the Global Positioning System (GPS). The satellites are used for precise navigation of equipment and geo-referenced positioning to collect high-resolution information from crops and soils. GPS-based manual guidance technologies have been popular for a decade or so in several countries, but in recent years, more producers and custom applicators have switched to automated guidance. A recent survey conducted in the Midwest USA, indicated that over 80% of custom applicators are using automated guidance (Erickson and Widmar, 2015). Other highly adopted automated technologies are GPS-enabled sprayer section control with nearly 75% of custom applicators offering this service and harvest monitors (nearly 60% usage among farmers).

Automated guidance results in greater accuracy of each pass across the field during planting, fertilization, and pesticide application resulting in optimization of inputs and a reduction in field time by approximately 17% (Watson and Lowenberg-DeBouer, 2004).

In maize production, the elimination of skips and multiple seed drops within the row greatly improves the stand establishment and results in increased yield and profitability. Wade and Douglas (1990) reported that uneven plant distribution can reduce grain yield up to 30%, while Doerge et al. (2002) similarly reported that individual plant yields were maximized when plants were within 5 to 7 cm of equidistant spacing. Mechanized planters that can deliver precisely spaced, single seeds are ubiquitous in developed farming systems, but socio-economic barriers in many developing countries have limited the opportunities for adoption of this technology and much of the maize is planted by hand. Even in these conditions, precision seeding (equidistant spacing) has been shown to increase yield by an average of 1,130 kg/ha compared with the farmer practice (Chim et al., 2014).

Abbreviations and notes: N = nitrogen; P = phosphorus; K = potassium.

Adoption of these automated types of technologies that don't depend on site-specific information to extract value has been rapid and steady, while adoption of others that require agronomic calibration (such as variable-rate technology) have been slower growing. However, the adoption of these services has been increasing at a faster rate the past few years as prescription methodology has improved (Erickson and Widmar, 2015). One of the site-specific technologies that is growing rapidly in popularity for maize production is variable rate seeding. Most of these applications are map-based, with management zones created using soil sampling data, crop yield history, and other soil and crop information collected using remote or proximal sensing. It is well documented that areas within fields possess different characteristics that affect crop performance and should be managed accordingly. The basic objective is to increase seeding rate in those areas where yield potential is higher and plant fewer seeds in areas of lower yield potential. A study in Virginia that is part of the IPNI Global Maize project (IPNI, 2017a) is evaluating the effect of variable rate seeding on maize yield. In 2015 and 2016 a comparison

Table 1. Maize grain yield (t/ha) following variable or fixed seeding rates. IPNI, 2017a.		
	2015	2016
Variable rate	15.6 a	12.5 a
Fixed rate	14.6 b	11.9 b

Variable rate = seeding rates ranged from 59,280 to 79,040 seeds/ha; Fixed rate = seeding rate was 71,630 seeds/ha. Means within a column followed the same letter are not significantly different at p<0.10.

was made between maize grain yield from a crop planted at a single seeding rate of 71,630 seeds/ha and one that was variably seeded at rates ranging from 59,280 to 79,040 seeds/ha based on soil types and historical yield maps. In both years, the variable rate treatment yielded significantly more grain than the single seeding rate (**Table 1**).

In the USA, variable rate fertilization is the most common site-specific PA technology with nearly 70% of dealerships offering the service and nearly 50% of the market area utilizing the technology (Erickson and Widmar, 2015). Similar to variable rate seeding prescriptions, fertilizer management zones are established on a variety of parameters that may include soil fertility, soil physical characteristics, yield, and other information. The redistribution of fertilizer in the field is intended to improve nutrient use efficiency (NUE) by minimizing over-application while simultaneously increasing rates to areas of the field with higher than average yield potential. While some studies have shown variable rate technology to result in reduced average fertilizer rates and higher NUE (Thomason et al., 2011), the practice does not necessarily mean that overall fertilizer input will be reduced. **Figure 1** illustrates variable rate P and K application maps for a field in Virginia. These figures are both examples of variable rate nutrient applications that did not result in any change in total fertilizer applied compared with the recommendation that would have followed a random composite soil sampling. The difference is that in the case of a single rate application of P, only 60% of the field would have received the correct rate while 20% would have been under fertilized by approximately 17%, and 20% of the field would have received 28% more P than was required. The result for a single fertilizer rate of K would have been more accurate with about 70% of the field receiving K within 4% of the recommended rate, while 25% would have been over fertilized, and only 5% under fertilized.

Another technology used to make variable-rate nutrient applications, particularly for N, is crop canopy sensors. There are several commercially available crop sensors that have been widely researched and the technology is becoming an accepted practice for determining in-season crop N needs in several countries around the world. Melchiori (2010) reported increased partial factor productivity (PFP; kg grain/kg N) in maize using sensor-based N rates compared to a standard fixed rate. Their work covered seven growing seasons in Argentina and evaluated the ability of the sensor to determine optimum

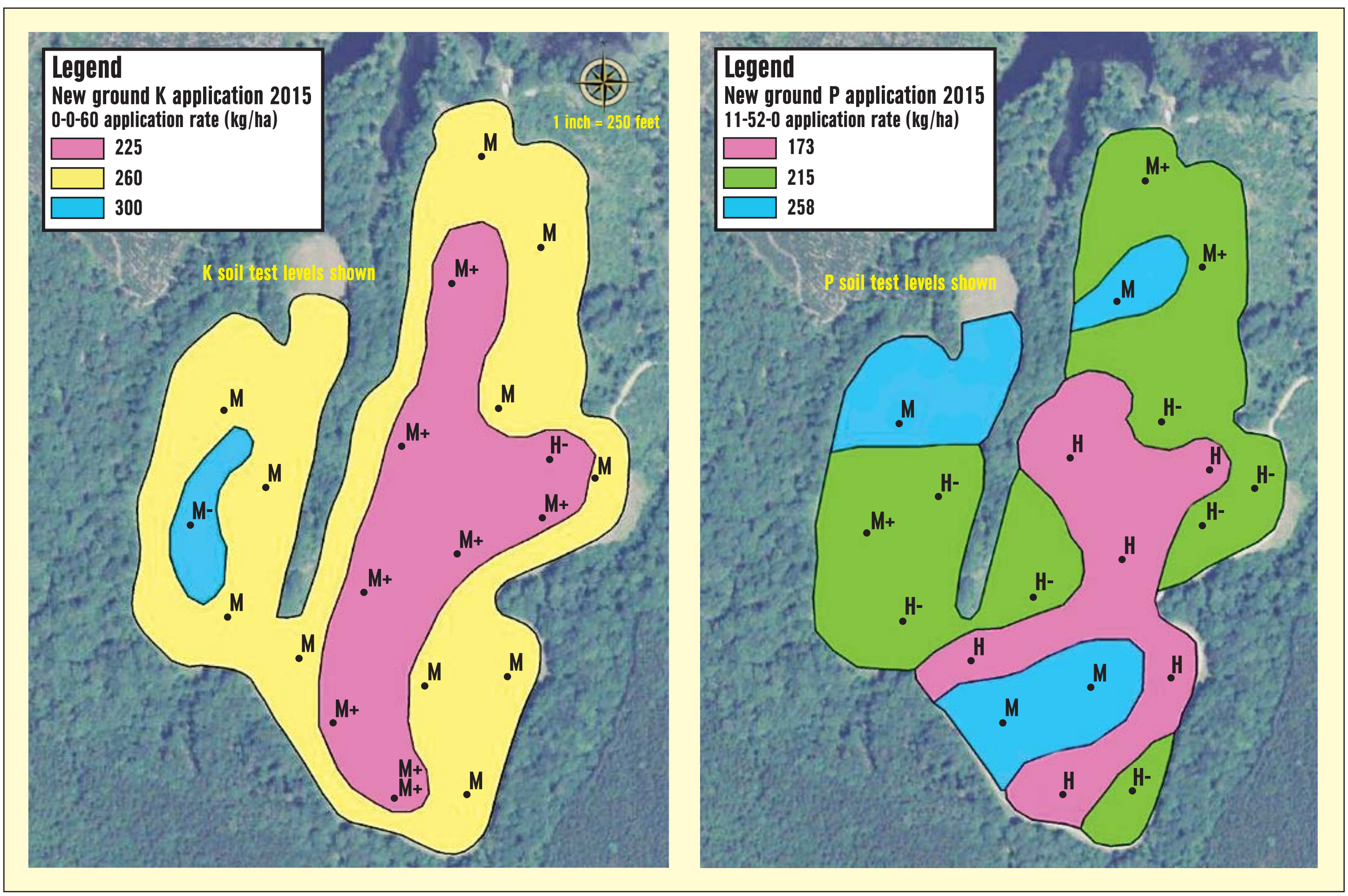

Figure 1. Variable rate phosphorus (P) and potassium (K) application maps, based on agronomic interpretation of multiple soil tests taken with a field. M = moderate; H = high. Thomason et al., 2011.

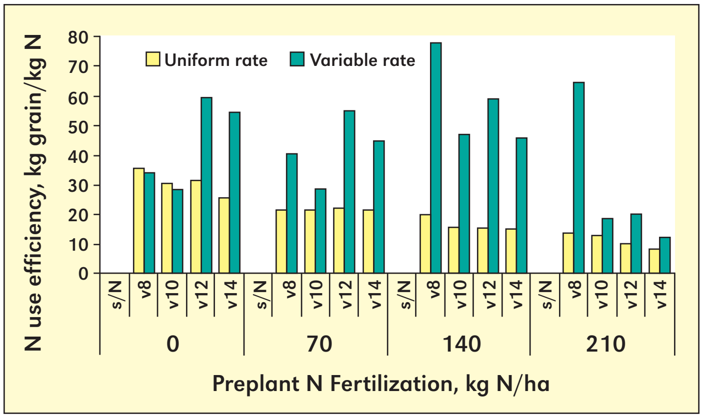

Figure 2. Nitrogen use efficiency (partial factor productivity for N) in maize following N fertilization between V8 and V14 using sensor-based variable rates or uniform fixed rates at varying levels of preplant N fertilization. Melchiori, 2010.

sidedress N rates for maize across a range of growth stages and preplant N rates. Similar to other published studies, they found no difference in grain yield between the methods, but a higher PFP when using the sensor-based system (**Figure 2**).

Relative to economic benefits, some PA tools can save on labor costs (i.e., autoguidance), some can reduce input costs (i.e., automatic section control), and some result in better management for higher yield (i.e., variable rate seeding and fertilization). Griffin and Lowenberg-DeBoer (2005) published a review of 234 studies where PA was found to be profitable in 68% of the cases. Nearly 40% of the studies were done on maize with 73% reporting economic benefits. Silva et al. (2007) also reported on the economic value of PA for maize and found that on average PA was more costly than traditional farming but resulted in higher yields and subsequently higher revenues.

It is a common belief that the value of PA can only be realized in the large-scale, high-profitability farming systems found in developed nations. Thus, PA technologies have often been viewed as irrelevant to smallholder systems because of lower profitability, lack of education and training opportunities, and grower resistance. For some specific technologies, this may be true, but several precision nutrient management strategies exist and are being used successfully in smallholder systems including leaf color charts, omission plots, handheld crop sensors, and web-based decision support software packages.

One PA tool developed specifically for smallholders is the Nutrient Expert® (NE) decision support software (IPNI, 2017b). Nutrient Expert enables crop advisors to develop fertilizer recommendations that are tailored to a specific field or growing environment, taking into account important factors affecting nutrient management recommendations and uses a systematic approach of capturing information to develop location-specific recommendations. Nutrient Expert does not require a lot of data nor very detailed information as in the case of many sophisticated nutrient decision support tools, which can overwhelm the user. It allows the users to draw the required information from their own experience, the farmers' knowledge of the local region, and the farmers' practices. The tool can use experimental data, but it can also estimate the required site-specific parameters using existing site information.

Field testing of NE with farmers in Asia has demonstrated yield gains in grain crops by as much as 1.3 t/ha and increased profits of over US$200/ha. Depending on the local situation, the increased production and profitability occurs in different manners. For example, data from over 400 sites in India show a significant decrease in applied P fertilizer and a simultaneous increase in K resulting in increased grain yield due to improved nutrient balance (**Table 2**). Trials in Indonesia demonstrated a need for increased K fertilizer rates, which resulted in significant grain yield increases (**Table 2**). A third example is in the Philippines where recommended increased rates of P and K over the local farmer's practice resulted in a significant increase in fertilizer cost, but the yield increase led to greater profitability for the farmer (**Table 2**).

Table 2. Nutrient Expert® (NE) performance on maize production in Asia. The baseline for comparison is the standard farmer practice (FP). IPNI, 2017b

	Effect of Nutrient Expert® (NE – FP)		
Parameter	India (n = 412)	Indonesia (n = 26)	Philippines (n = 190)
Grain yield, t/ha	+1.3***	+0.9***	+1.1***
Fertilizer N, kg/ha	-6	-12	+3
Fertilizer P_2O_5, kg/ha	-16***	-5	+18***
Fertilizer K_2O, kg/ha	+22***	+15***	+18***
Fertilizer cost, US$/ha	-1	+16	+37***
Gross profit, US$/ha	+256***	+234***	+267***

*** denotes a significant difference at *p*<0.01.

Summary

Closing maize yield gaps to meet the food production needs for a growing population will require continuous improvement in agricultural system performance and will depend on a combination of technology, agronomy, and management developments. Precision agriculture tools and management strategies can help create the information-driven, evidence-based agricultural systems needed to meet the challenges of the future.

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