

## Chapter 8

# Precision Agriculture

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### Abstract

Precision agriculture, or site-specific farming, is a management approach that addresses farm- and field-scale variability in order to improve crop production by efficiently matching resource inputs with crop needs. Advances in satellite and computer technologies provide producers with many opportunities to observe, measure, and respond to the needs of their crops by addressing site-specific problems in their fields. In the inland Pacific Northwest (PNW), dryland cereal producers use precision management in many ways, such as section control to reduce herbicide application and Global Positioning Systems (GPS) for reducing overlap. The use of these technologies is relatively straightforward and the payoffs are clear. In this chapter, we primarily focus on a more complex precision management strategy: variable application of nitrogen (N) fertilizer, because N is a main limiting factor in cereal production systems in the inland PNW. The region's climate and topography cause variation in wheat yields within and across fields and therefore in N fertilizer requirements. Synchronizing N supply with crop N demand is a major challenge for improving fertilizer use efficiencies and reducing N losses, which makes it a critical priority for the global research agenda. Precision agriculture technologies provide opportunities to manage complex N, water, and crop

*Research results are coded by agroecological class, defined in the glossary, as follows:*

● Annual Crop    ▲ Annual Crop-Fallow Transition    ■ Grain-Fallow

interactions. This chapter presents information on the principles and assumptions behind precision agriculture, types of precision agriculture tools and equipment available, steps involved in implementing variable rate N application, and sources of support for making decisions about managing variability.

## Key Points

- Precision agriculture is a site-specific management approach that uses technology to manage field variability and achieve specific goals such as crop yield, percentage of protein, and nitrogen use efficiency.
- Precision agriculture assumes that variability in the major factors that affect crop yield and quality can be accurately measured at scales relevant to farm management and that the resulting information can be used to improve the efficiency of crop input use.
- If the above assumptions are met, precision agriculture strategies might result in a win-win-win scenario with improved crop yields and quality, higher economic returns, and decreased environmental impacts from excessive inputs.
- Precision agriculture technologies provide the ability to monitor crop and field variability and help diagnose agronomic problems that occur across fields and years.
- Decisions about adoption of precision agriculture involve the consideration of economic, agronomic, technical, environmental, and social factors.
- Additional research is needed to evaluate the combined effects of precision agriculture on productivity, profit, and environmental quality.

## Introduction

### *What is Precision Agriculture?*

**Precision agriculture** is the management of farm- and field-scale variability to achieve explicit goals such as improved crop yield, grain quality, and **nitrogen use efficiency** (NUE) by more accurately matching

crop needs with specific input requirements. Dryland cereal producers use precision management in many ways, such as section control to reduce herbicide application and Global Positioning Systems (GPS) for reducing overlap. This strategy utilizes data from information technologies with high spatial and temporal resolution, combined with grower knowledge, to inform management decisions that take into account the high degree of variability associated with agricultural production (National Research Council 1997). Precision agriculture has been described as the use of the right input in the right amount at the right time and in the right location (Mulla 2013). These concepts (also known as the 4 Rs) can be used alone or in combination. Improved precision agriculture technologies allow producers to measure multiple interacting variables and to potentially use this information to maximize their profits, use resources efficiently, and minimize environmental damage.

Precision agriculture is a multi-step process that involves: (1) gathering information on spatial and temporal cropland variability, (2) applying that information to develop site-specific management strategies that use precise techniques to match fertilizer, pesticide, or water inputs to crop needs, (3) assessing the resulting benefits and costs, and (4) repeating and/or adjusting management on the basis of lessons learned. Initial mapping provides information on spatial variation, whereas the comparison of multi-year sequences of data provides information on changes over time, which is becoming increasingly important in responding to climate change. (For more information on climate change, see Chapter 1: Climate Considerations.)

### ***History of Precision Agriculture***

The concept of tailoring management to spatial variation in soil and other environmental conditions was introduced in the 1920s (Linsley and Bauer 1929), but at that time technology for implementing this approach was not available. By the 1980s, the typical farm size had increased in the **inland PNW** (Duffin 2007; Jennings et al. 1990) and farms encompassed more within-farm variability. Increased awareness of high spatial and temporal variability in crop performance on large-scale farms continues to heighten the importance of precision agriculture. Ecological, economic, and social factors all contribute to high levels of interest in precision agriculture,

especially in the developed world. (For information on federal policies that promote precision agriculture, see Chapter 12: Farm Policies and the Role for Decision Support Tools.)

Variation in geology, soil, terrain, water availability, microclimate, and biota is high across landscapes in the inland PNW. In addition, variability within fields is high. This variation, combined with diverse management legacies and inconsistent weather patterns, creates heterogeneous growing conditions. In the inland PNW, conversion of **conventional tillage** systems to **direct seeding** has further increased variability due to tillage management impacts on soil properties, pests, rotations, and crop performance (Huggins 2004).

The global need to increase food production without increasing negative environmental impacts from agriculture is another reason why interest in precision agriculture continues to increase (Cassman et al. 2002; Tilman et al. 2011). More precise and efficient farming of land that is already in production is critical. By matching inputs such as fertilizers and pesticides to site-specific conditions that regulate crop demand, precision agriculture has the potential to help producers improve crop productivity and economic returns. Applying resources when and where they are needed can also reduce negative environmental effects (National Research Council 1997) by improving efficient use of these resources.

### ***Relationship of N Fertilizer to Climate Change***

Excessive use of N fertilizer can increase the risk of losses of N as nitrous oxide and result in accelerated rates of reactive N entering and cycling through ecosystems. The agricultural sector is the largest contributor to rising nitrous oxide emissions in the US, and nitrous oxide emissions from agricultural soil management are the largest source of agricultural greenhouse gas emissions (EPA 2013).

### ***The Need to Address Field-Scale Variability***

In order to precisely match agricultural inputs to crop needs, it is essential to understand the impact of variability in factors that influence crop growth and development. Soil and crop properties that vary over time as well as across space are especially difficult to diagnose (Huggins 2004).

Present-day soils result from natural processes of soil formation as well as the effects of land use and management practices (Busacca and Montgomery 1992). Geographic diversity in terrain, soil, and climate across the inland PNW results in different dryland cereal production systems that are mapped as **agroecological classes** (AECs). (See Chapter 1: Climate Considerations for details on AECs.) Effective soil depth can be limited by soil profile layers with high clay content and low permeability (Pan and Hopkins 1991). In the driest, westernmost parts of the region, calcic horizons and duripans rich in lime and silica limit productivity. In areas with intermediate precipitation, impermeable clay-rich horizons are limiting; and in the easternmost part of the inland PNW, seasonally perched water tables overlying clay-rich horizons limit rooting depth and cause lateral water flow (Figure 8-1) (Busacca and Montgomery 1992). In the Annual Crop AEC, steep topography creates varied microclimates that affect both the need for and response to nutrients (Fiez et al. 1994a; 1994b). (See Chapter 6: Soil Fertility Management.) For example, north-facing slopes in the Annual Crop AEC are wetter and have seasonally perched water with subsurface lateral flow (Brooks et al. 2012). ●

Landscape-specific processes affect local environmental conditions such as slope, soil depth, and the presence of an impermeable layer of soil (Figure 8-2). For example, across a single hill, variations in slope, aspect, and soil



Figure 8-1. Lateral water movement on a hillside near Troy, Idaho. (Photo: Erin Brooks, with permission.) ●

## Advances in Dryland Farming in the Inland Pacific Northwest

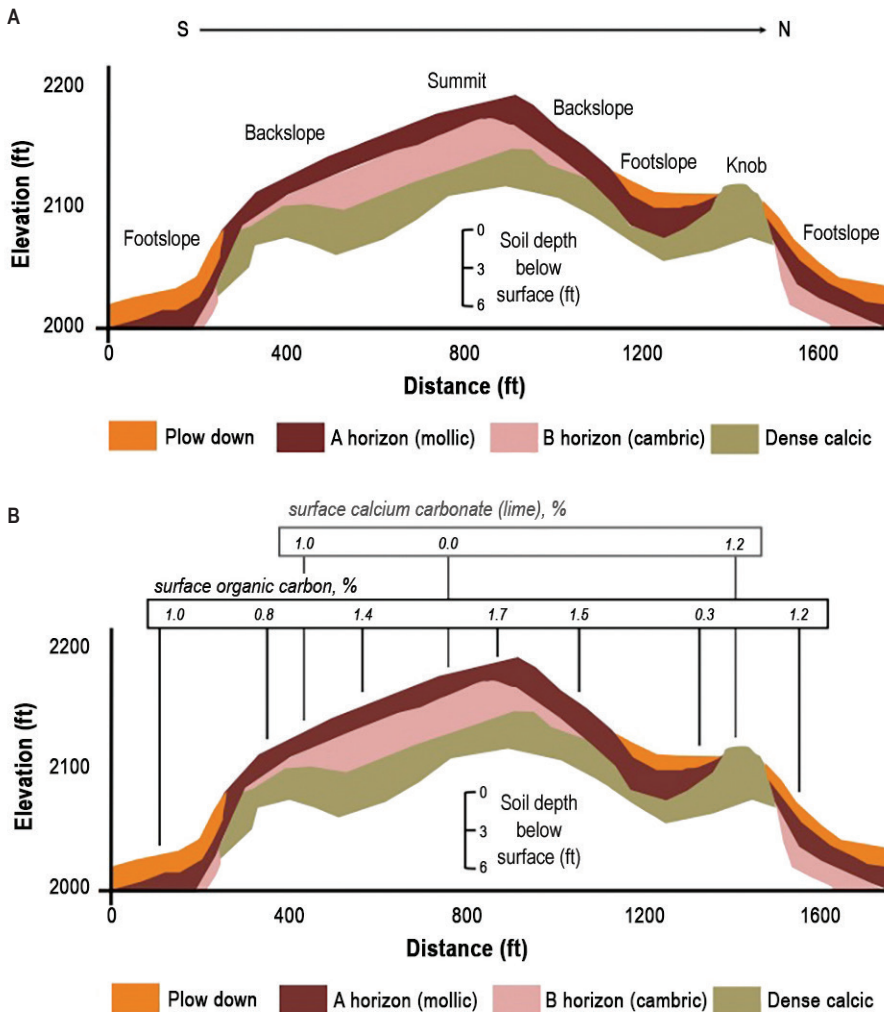


Figure 8-2. Schematic cross-sections of a hill in the Grain-Fallow agroecological class of the inland PNW. Note that different scales are used for horizontal distance, elevation, and subsurface depth. (A) Soil profiles at different terrain positions; (B) Amount of calcium carbonate and organic carbon in the top 4 inches of soil at selected points, indicated by vertical lines, across the same hill. (Adapted from Busacca and Montgomery 1992.) ■

texture affect a suite of interrelated variables including microclimate, snow accumulation, runoff, erosion, ponding, soil **water holding capacity**, and evaporation. In addition, management decisions about tillage, fertilization, rotations, and residue treatment affect soil properties such as nutrient availability and uptake efficiency, soil organic matter accumulation and



decomposition, soil **bulk density**, **pH**, and crop rooting depth. (See Chapter 6: Soil Fertility Management for a more detailed discussion of factors that affect productivity.) The result is a complex within-farm mosaic of areas differing in yield potential (Busacca et al. 1985; Ibrahim and Huggins 2011; Mulla 1986; Rodman 1988). (See Chapter 2: Soil Health; Chapter 4: Crop Residue Management; Chapter 5: Rotational Diversification and Intensification; and Chapter 6: Soil Fertility Management.)

Considerable variability within fields and across years has been reported by researchers and farmers in the inland PNW. Some of this variation can be inferred from county soil surveys, but the coarse scale (1:20,000) of these maps obscures the fine scale heterogeneity of multiple characteristics. Figure 8-3 compares a Whitman County soil survey map of a field at the Washington State University Cook Agronomy Farm to a soil survey and a soil organic carbon map of the same field using finer resolution. Detailed field-scale maps reveal more variability and are therefore more useful for identifying spatial patterns and prescribing site-specific management. Year-to-year and within-field variability continue to generate interest in site-specific rather than uniform rates of agricultural inputs (Huggins 2010; Huggins and Pan 1993). Precision agriculture in the inland PNW can potentially address constraints on agricultural productivity due to the impacts of landscape variation and management, such as soil texture, compaction, effective rooting depth, drainage, acidification, and erosion. (More information can be found in Chapter 6: Soil Fertility Management; Chapter 2: Soil Health; and Chapter 3: Conservation Tillage Systems.)

### ***Steps in the Process of Site-Specific Management***

Precision management involves the following steps carried out by growers in consultation with industry, research, and Extension advisors as necessary (Figure 8-4):

- Specify goals (e.g., grain yield or protein concentration) of the operation. It is important to match the scales of measurement and management as closely as possible for crops, soils, and terrain. For instance, it is inefficient to collect data on a scale that is finer than what is treatable by available equipment. If an input can be applied only on a scale of feet, then it is wasteful to measure it on a scale of inches (Pierce and Nowak 1999).

## Advances in Dryland Farming in the Inland Pacific Northwest

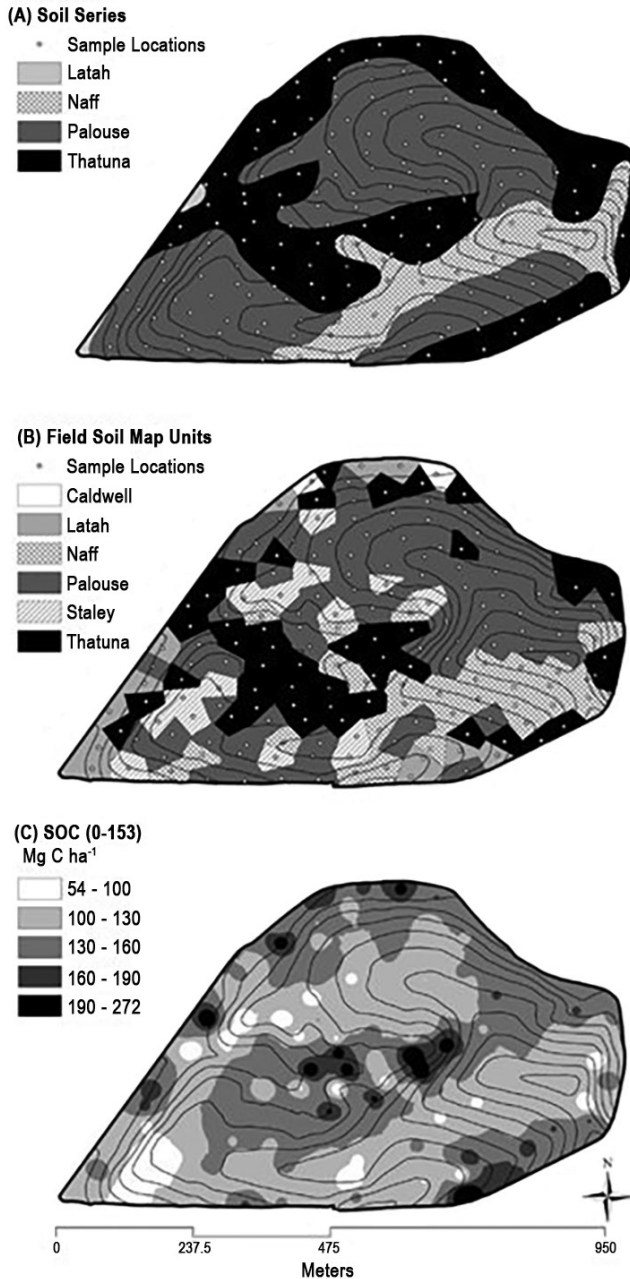


Figure 8-3. Maps of (A) soil series, (B) field soil map units, and (C) soil organic carbon (SOC; at 0–60 inches) for the 92-acre Washington State University Cook Agronomy Farm. Data for B and C were obtained by sampling alternating points from a systematic, non-aligned grid of 369 geo-referenced sample locations at a resolution of  $\pm 10$  feet. (Source: Huggins and Uberaga 2010.)



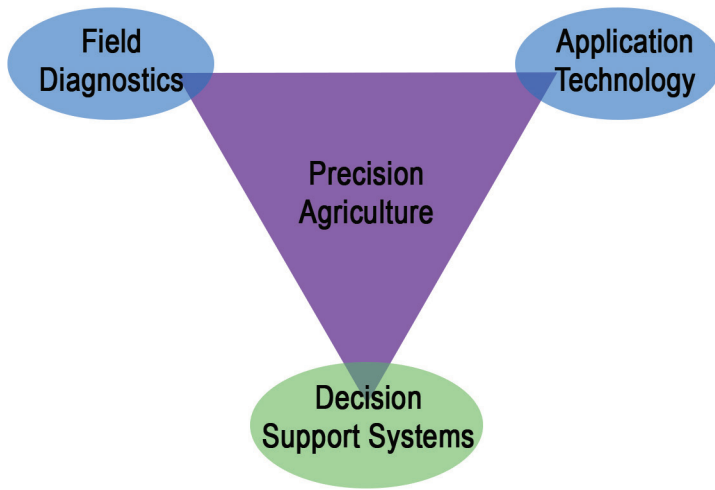


Figure 8-4. Key elements of precision agriculture. (Adapted from Huggins 2015.)

- Obtain accurate, fine-scale data on within-field variability that influences desired outcomes.
- Use the resulting data to generate multi-layer maps that illustrate factors influencing crop yield.
- Use the information from the preceding step to diagnose crop needs and develop prescription maps using computer software. These maps prescribe site-specific management zones (SSMZs) or areas that are relatively homogeneous with regard to yield-controlling attributes (Table 8-1). Management zones should not be confused with the much larger agronomic zones defined by Douglas et al. (1992). Collectively, SSMZs form the basis of a precise management plan (Corwin 2013). Decisions about how many SSMZs should be recognized are crucial. If too few zones are prescribed, areas that are substantially different will be grouped together and variable management will not address site-specific variability effectively. If too many zones are designated, areas that differ only slightly will receive different treatments, and management will be more complicated and expensive than necessary, or controllers will not be able to react to the small distances or time units that are specified. The challenge associated with making this decision is one reason why producers who are

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Table 8-1. Examples of crop inputs that are commonly applied to site-specific management zones using variable rate technology.

Crop inputs applied to site-specific management zones	Sources of information for zone delineation
Gypsum	Grower knowledge, yield patterns, EC <sub>a</sub> maps, soil tests for pH and Na
K	Topography, grid or directed soil sampling, soil survey maps, EC <sub>a</sub> maps
Lime	pH, soil texture
Manure	Soil texture, organic matter, yield patterns, bare soil photos, nitrate nitrogen, crop canopy reflectance
N	Soil texture, organic matter, yield patterns, bare soil photos, nitrate nitrogen, crop canopy reflectance
P	Topography, grid or directed soil sampling, soil survey maps, EC <sub>a</sub> maps
Herbicide	Weed maps, soil organic matter, soil texture
Irrigation	Soil texture, topography, yield zones, EC <sub>a</sub> -directed soil sampling
Seeds	Historical yield maps and topsoil depth

Note: K = potassium; N = nitrogen; P = phosphorus; EC<sub>a</sub> = apparent soil electrical conductivity. Adapted from Corwin 2013.

developing prescription maps for variable application often seek decision support from a precision agriculture consultant.

- Implement the plan during the growing season by applying inputs at the variable rates and locations specified in the precision management plan. Application rates can be fine-tuned using information from field scouting and ongoing data analysis.
- During harvest, use yield monitors to collect information about crop quantity and quality (e.g., grain protein concentration).
- After one year of using precision agriculture, evaluate how well management goals were met. Modify management plan if necessary using the results from the first year's trial to inform this decision. Evaluating the response of areas managed with precision agriculture may require a check strip (not managed with precision agriculture) for comparison.

- Repeat the above steps as many times as necessary to achieve desired site-specific results. Remember that throughout this process equipment suppliers and researchers are available to provide decision support.

## Research on Site-Specific N Management

### *Importance of Site-Specific N Management*

Nitrogen is typically the most limiting nutrient in crop production. **Nitrogen supply** and demand are affected by soil chemical, physical, and biological processes. Nitrogen requirements are affected by crop N need and the amount of N supplied from soil and crop residues. Worldwide recovery of N in harvested cereal crops is estimated to be only 33% of total N applied (Raun and Johnson 1999). Poor N recovery is due to multiple factors that can include biological N **immobilization**, losses occurring from **leaching** and volatilization, and inefficient crop uptake and utilization. Improving the efficiency of N utilization is of concern because movement of N beyond agroecosystem boundaries contributes to degradation of air and water and because growers seek to reduce costs from wasteful inputs. (See Chapter 6: Soil Fertility Management.)

Management strategies that increase NUE can mitigate greenhouse gas emissions. (See Chapter 4: Crop Residue Management and Chapter 6: Soil Fertility Management.) The potential for site-specific N application to reduce nitrous oxide emissions has been experimentally demonstrated in the field (Sehy et al. 2003). The significance of reductions in applied N is controversial because several interacting factors influence N transformations in soil (Venterea et al. 2012). However, recent analyses and field work have suggested that emissions of nitrous oxide increase exponentially with N input (Hoben et al. 2011; Shcherbak et al. 2014) rather than linearly. For dryland farmers of the inland PNW, precision agriculture is an important strategy for climate change **mitigation**. Agricultural N management practices that reduce N fertilizer application rates without reducing crop yields could potentially reduce agricultural nitrous oxide emissions, generate greenhouse gas offsets, and enhance overall environmental quality.

Under current greenhouse gas offset programs, emission offset credits generated by agricultural N management actions are based on reducing annual N fertilizer application rates for a given crop without reducing yield. Because reductions in N fertilizer entail economic risk for producers due to possible yield depression from under-applied N, economic incentives are important. Programs that offer incentives for N emission reductions are a promising strategy for reducing regional emissions (Brown 2015; Ward 2015); however, in interviews of 33 growers from across inland PNW drylands, insufficient financial incentives and excessive paperwork were commonly cited as barriers to involvement in nutrient management plans (Ward 2015).

### ***Principles of Precision N Management***

Precision management of N fertilizer means synchronizing N application with variability in crop N demand. To do this, it is necessary to understand crop requirements for N (Fiez et al. 1995) and crop response to applied N (Huggins and Pan 1993). Fiez et al. (1995) concluded that recommended N application rates on north-facing backslopes at a study site in the Annual Crop AEC were excessive because of low fertilizer uptake and high losses of N. However, landscape position alone was not the best predictor of site-specific N fertilizer needs in this study. ●

Regional fertility guides (Koenig 2005; Mahler 2007) are not appropriate for developing site-specific N management prescriptions because they do not account for variability in crop **unit nitrogen requirement** and N supply (Pan et al. 1997). Some landscape positions have high soil N supply but low yield potential and low response to N fertilizers, while other areas have high yield potential, lower N supply, and good response to applied N. In addition to landscape position, yield and crop performance are influenced by interacting effects of soil, water, weather, nutrient availability, crop variety, and management (Mulla et al. 1992; Pan and Hopkins 1991). (See Chapter 6: Soil Fertility Management for a discussion of processes that affect N availability.)

### ***Patterns in Site-Specific Yield Responses to N Management***

In a 2007 on-farm study near Colfax, Washington, in the Annual Crop AEC, Huggins (2010) compared yield benefits from variable rate nitrogen

(VRN) applications to uniform N rates at different landscape positions. The farmer identified low- and high-yielding areas of the field, and uniform and variable urea fertilizer N inputs were compared at selected geo-referenced locations across the field. Positive yield response to VRN application tended to be most pronounced in the low-yielding areas, which was likely due to relatively shallow soils and low potential to store soil water (Figure 8-5). Reducing the N fertilizer rate by 40% in the lower yielding areas increased hard red spring wheat yield by 25% compared to uniform N application. Previous application of excessive N in such areas may have increased soil water consumption during vegetative growth and left less water available during grain filling. Conversely, increasing N rates in higher yielding areas by 63% increased hard red spring wheat yields by 12% compared to uniform N application. Areas with relatively high yields tended to occur on relatively flat uplands, which likely had deep soil and high water holding capacity (Huggins 2010). ●

In this example, two N application rates, one for low-yielding areas and one for high-yielding areas, were adequate to improve efficiency compared to a single application rate. On the basis of this study, reducing N rates leading to increasing yields on low-yielding locations would be expected to result in greater economic returns. The economic effects of increasing N inputs on higher yielding areas is less clear and would probably depend on additional factors such as wheat and N prices. The results of this on-farm research trial suggest that site-specific characteristics such as slope and soil type combined with grower knowledge have potential as decision aids for precision N applications, especially because the required data can be generated by growers with just a yield and protein monitor, GPS, and VRN technologies.

### ***Refining Predictions of Site-Specific Responses to N Management***

Although insight into these landscape patterns in response to N application are useful, producers need tools with a higher degree of site-specificity for predicting responses to VRN. Developing grower-oriented, field-scale decision support tools to evaluate spatial variability in crop performance and assess site-specific management strategies is an emerging focus of research in the inland PNW. Brown (2015), Huggins et al. (2010), and

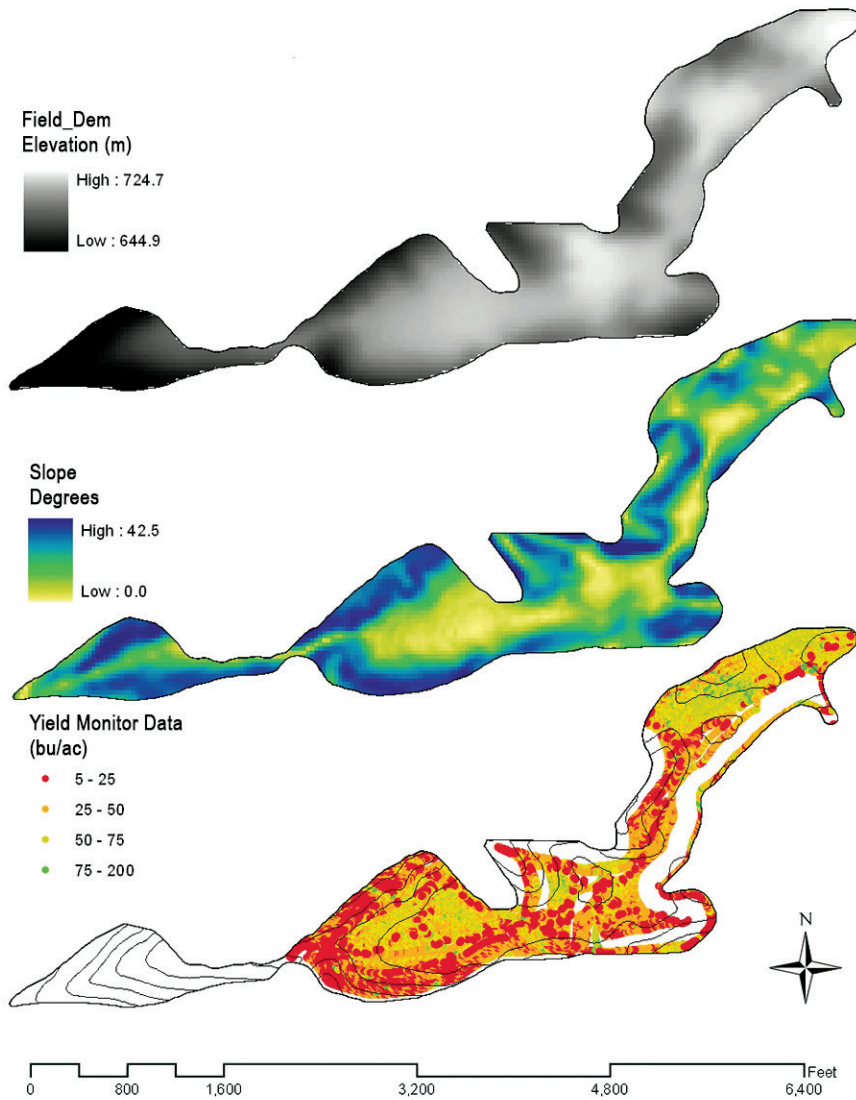


Figure 8-5. Field elevation, slope, and combine yield monitor data for hard red spring wheat at a farm near Colfax, Washington. (Dem = digital elevation model; Source: Huggins 2010.)

Taylor (2016) have developed tools for identifying crop performance with regard to increasing productivity as well as NUE (Table 8-2).

For example, using the key developed by Brown (2015) winter wheat can be separated into five performance classes (Figure 8-6). This classification



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Table 8-2. Performance criteria for assessing wheat responses to variable application of nitrogen in the Annual Crop agroecological class. ●

Criteria	Crop	Location
GPC, N uptake efficiency, N retention efficiency	Hard red spring wheat	CAF, near Pullman
Yield, GPC, NUE	Soft white winter wheat	CAF, near Pullman
Protein, N balance index ( $N_g/N_f$ )	Soft white winter wheat	Near Walla Walla; CAF, near Pullman

GPC = grain protein concentration; NUE = nitrogen use efficiency;  $N_g$  = grain N;  $N_f$  = N fertilizer application rate; CAF = Cook Agronomy Farm. All locations are in Washington. Adapted from Brown 2015, Huggins et al. 2010, and Taylor 2016.

allows for post-harvest interpretation of crop performance that diagnoses limitations to N supply or crop uptake. In addition, the information can be used to guide future site-specific N management decisions for optimizing yield, yield quality, and efficient use of N supply.

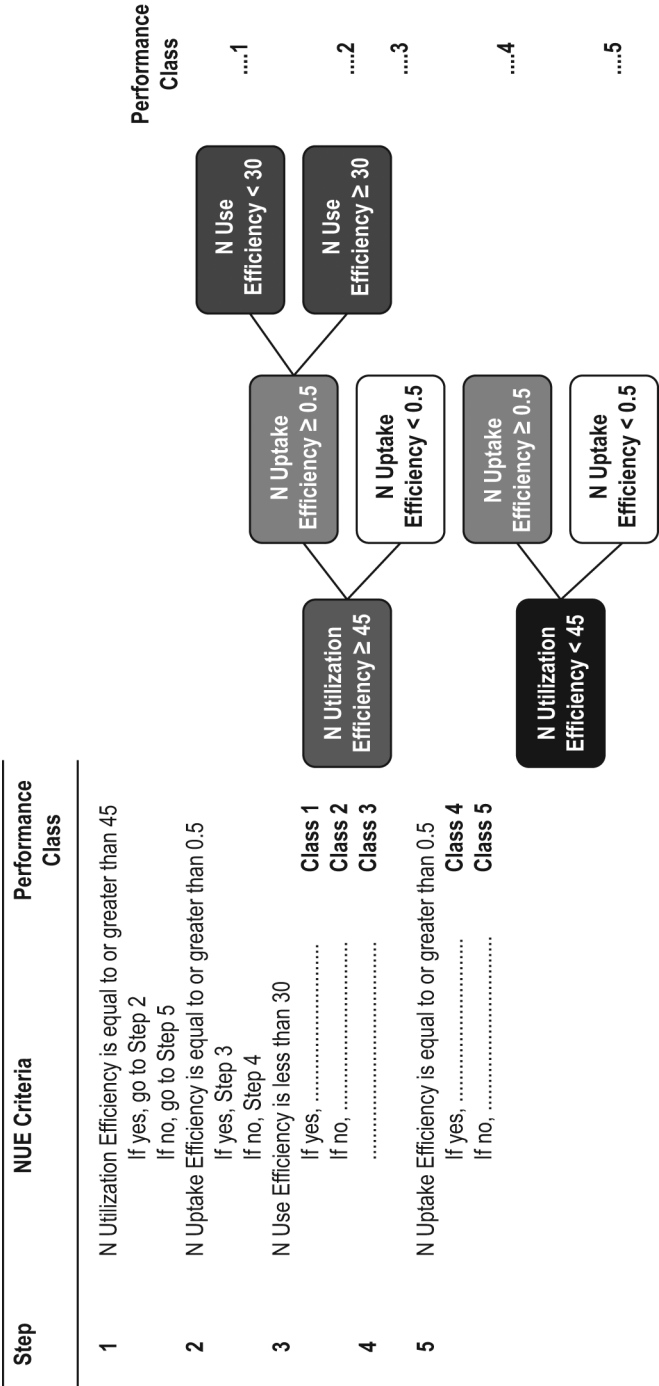
## Available Technology

### *Remote Sensing*

Remote sensors of soil or crop properties may be proximal (hand-held or tractor-mounted sensors), aerial (mounted on airplanes or unmanned aerial vehicles), or satellite-mounted. Remote sensing uses interactions between electromagnetic energy and soil or plant material. Applications of electromagnetic radiation in remote sensing involve non-contact measurement of reflected electromagnetic radiation. Precision agriculture systems use primarily visible, near infrared (NIR), infrared, and thermal sensor data (Figure 8-7A). Plant pigments absorb visible light of specific wavelengths and reflect radiation that is not absorbed. Measuring light absorption at different wavelengths enables detection of active crop growth (i.e., chlorophyll a and chlorophyll b activity).

Spectral indices use ratios of plant reflectance in the visible and NIR regions to assess characteristics of plant canopies and soils. For example, in a study near Adams, Oregon, of the effects of the number of yellow flowers per unit area and leaf area index (LAI) on canopy spectral reflectance of

Figure 8-6. Dichotomous key to classification of soft white winter wheat performance on the basis of components of N utilization. (Adapted from Brown 2016.)



spring canola, the ratio of NIR and blue light was suitable for estimating LAI during flowering (Sulik and Long 2015). (For information on the use of spectral indices to predict crop residue cover and density, see Chapter 4: Crop Residue Management.)

Green vegetation absorbs most colors of visible light (except green) and reflects a large portion of incoming NIR wavelengths. Consequently, senesced, diseased, or sparse vegetation reflects more visible light and less NIR radiation (Figure 8-7B). The normalized difference vegetation index

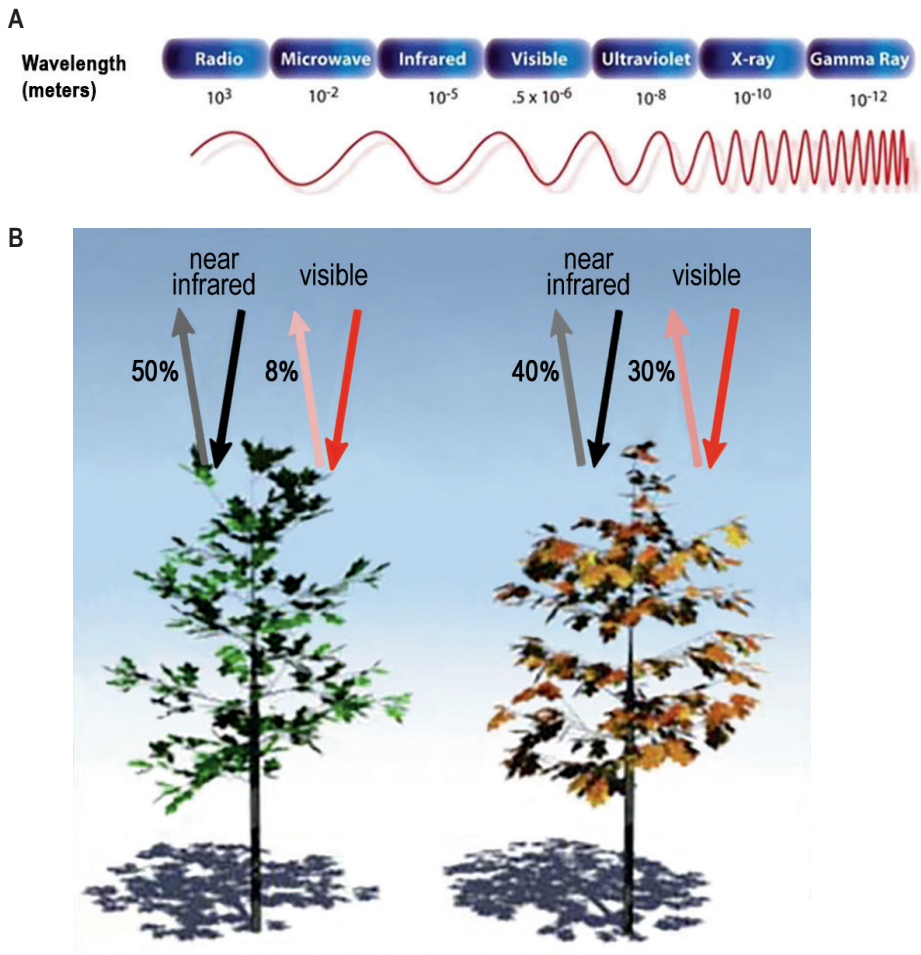


Figure 8-7. (A) The electromagnetic spectrum. (B) Differences in reflectance of near infrared and visible light by green and unhealthy or senesced vegetation. Note that the green foliage reflects less visible light than the yellowish-brown leaves. (Sources: NASA 2016a; 2016b. Illustration by Robert Simmon.)

(NDVI) uses a ratio of red and NIR spectral absorption to assess spatial and temporal variability patterns in photosynthetic activity. The NDVI and other spectral indices are used to study crop density, development, and reproductive capacity during the growing season.

Hyperspectral remote sensing collects reflectance data over a wide spectral range at small increments. Because hyperspectral imaging can be collected across a large range of wavelengths and at fine spatial resolution, it is useful for understanding spatial and spectral variability in reflectance for bare or vegetated ground (Mulla 2013).

Electrical conductivity (EC) sensors measure the electromagnetic energy of soil (the ability of soil to conduct an electrical current), which depends on total solute concentration (salinity) (Rhoades et al. 1989). EC is one of the measurements used most frequently in precision agriculture research to characterize spatial and temporal variation in properties that often affect crop yield. Sensors for continuous, real-time proximal sensing of soil EC have been used for mapping spatial patterns in soil clay content, salinity, soil moisture, and cation exchange capacity (Corwin and Lesch 2005). The EC of bulk soil, referred to as apparent soil electrical conductivity ( $EC_a$ ), has three components (Figure 8-8).

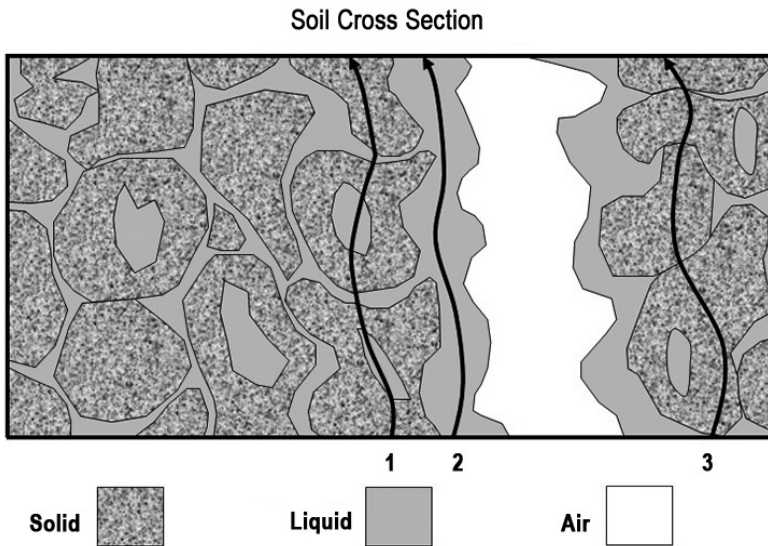


Figure 8-8. Three pathways for measuring apparent electrical conductivity of soil. (1) Solid-liquid phase, (2) liquid phase, and (3) solid phase. (Source: Corwin and Lesch 2005.)

Remote sensing of thermal radiation emitted by leaves and canopies has been used to estimate water stress (Cohen et al. 2005). This is done using canopy temperature as an indicator of water status.

### ***Geospatial Referencing***

A geographic information system (GIS) uses computer software and hardware to capture, store, manipulate, manage, and display geographically referenced information. When a GIS database is referenced to a base map or base data layer, geographic data can be projected onto a flat paper or screen. Data from many sources can be used, including soil or crop sampling, topographic surveys, digitized maps or photographs, and information from sensors.

Most GIS uses either vector or raster spatial data. Vector data uses coordinates to represent point, line, or polygon features on maps. Raster data are displayed as discrete picture elements termed pixels and can include any information displayed and stored as pixels, including aerial photography and scanned images.

The USDA Farm Service Agency provides growers with hard or soft copies of GIS imagery. Farmers can also obtain GIS data from some agricultural supply companies or build their own GIS project using software, such as Farm Works or SMS, and tractor or combine data collected during field operations. Some basic GIS software is free, but the cost of advanced GIS software may be substantial. Because of the technical complexity of some GIS applications, decision support personnel often play an important role in interpreting, displaying, and archiving of GIS data.

The Global Positioning System, or GPS, is a network (termed Navstar) of satellites put in orbit by the US Department of Defense. As of September, 2016, there were 31 active satellites (<http://www.gps.gov/systems/gps/space/>) transmitting one-way radio signals giving satellite position (latitude, longitude, and elevation) and time to users. GPS receiver equipment receives signals from the satellites and uses this information to calculate the user's three-dimensional position. The use of GPS in conjunction with GIS allows real-time data to be combined with accurate position information. This enables manipulation and analysis of large amounts of geospatial data.

## ***Models***

Models make it possible to analyze large data sets and make projections about outcomes if specific assumptions are met. It is important to keep in mind, however, that the projections of a model are not the same as experimentally demonstrated results. The more a model's assumptions are tested and supported by test results, the more robust we can consider the model.

## **Use of Precision Agriculture Technology in the Inland PNW**

### ***Precision Farm Equipment***

A variety of products that use precision agriculture technology are available to producers. Some of the most common types are listed below. For more information, see Yorgey et al. (2016).

- Combine monitors consist of sensors connected to GPS receivers. This equipment typically monitors yield at different locations within a field. With several years' data, the accumulated information can be used to generate prescription maps that divide fields into different zones for variable management. In addition to yield, combine sensors can monitor other variables, such as grain moisture content, protein content, and straw yield (Reyns et al. 2002).
- Aerial infrared crop images are another tool that can be used to develop prescription maps for fertilizer application. On infrared images, dense and vigorous vegetation is bright red, whereas less vigorous plants are lighter red or grey. Photos taken during crop growth can thus be used to delineate zones of higher and lower potential yield or plant biomass.
- Spatial soil mapping using measurements of soil  $EC_a$  can also be used to develop prescription maps. For example, ground conductivity meters developed by Geonics, Ltd. contain a transmitting coil and a receiving coil. The meter is placed directly on the ground where the transmitting coil generates small currents that are sensed by the receiver coil (McNeill 1980). A meter can



be coupled with GPS and with appropriate software to generate spatially specific data about  $EC_a$ .

- Variable rate fertilizer applicator systems use information corresponding to a sensed position to adjust fertilizer application rates as the applicator system moves across a field (Stombaugh and Shearer 2000). A variable rate applicator adjusts the rate of fertilizer that is delivered, using specifications from a zone map and a management plan. This technology is suited to fields with a wide range of yield potentials or fields with variation in residual levels of nutrients. Nitrogen is the nutrient most commonly applied at variable rates, but phosphorus, sulfur, and other nutrients can also be applied at variable rates.
- Auto-steer systems use the Differential Global Positioning System (DGPS), a highly accurate satellite system (<http://www.gps.gov/systems/augmentations/>) to detect the location of equipment and steer it across the field in a way that reduces overlap in passes across the field. Auto-steer systems can generally be retrofitted onto existing equipment.
- Section controllers improve the efficiency of input application by automatically shutting down operations (often a section of a piece of equipment) at locations (such as field edges and areas that overlap with previously covered ground) where additional application would be wasteful. Applications such as seed, fertilizer, and herbicide can be fine-tuned in this way. Section controllers can be retrofitted onto existing equipment.

### ***Adoption of Precision Agriculture Technology***

The benefits and risks associated with precision agriculture adoption depend on a variety of technical, geographic, economic, social, and cultural factors. Many growers use some precision agriculture technology but have not delineated SSMZs. For example, auto-steer was one of the first precision agriculture technologies to be adopted in the inland PNW and remains popular (Table 8-3). This technology has been shown to pay for itself rather quickly in dryland regions because it reduces overlap in input applications and requires little or no decision support or system component integration (McBratney et al. 2005).

Table 8-3. Responses to producer surveys in 2011 and 2012 about specific precision agriculture technologies.

Precision Agriculture Tools	Use		Have and do not use	Do not have	No response
	2011	2012	2012	2012	2012
GPS Guidance (vision-based)	46.8	65.6%	1.7%	29.3%	3.4%
Variable Fertilizer Applicator	N/A	39.4%	4.0%	53.1%	3.4%
Yield Monitor	N/A	34.3%	4.7%	57.6%	3.4%
Precision Agriculture Software	N/A	24.7%	3.8%	68.1%	3.4%
Aerial Crop Imagery	N/A	20.2%	2.6%	73.6%	2.4%
Variable Seeding Equipment	N/A	20.1%	3.2%	73.2%	3.4%
Spatial Soil Mapping	N/A	13.2%	3.4%	79.6%	3.8%
Auto-steer System (DGPS-based)	36.6%	N/A	N/A	N/A	N/A
Variable Rate N Application	20.4%	N/A	N/A	N/A	N/A
Section Controllers	25.5%	N/A	N/A	N/A	N/A

N/A = question not asked. See Bell (2000) for discussion of difference between vision-based guidance and DGPS-based auto-steer systems. Adapted from Mahler et al. 2014 and Gantia et al. 2015.

On the other hand, adoption of VRN technology requires a greater commitment. Since N fertilizer is the most expensive variable input cost for growers, a reduction in N application could increase gross returns. Ward (2015) estimated a 1.72 lb per acre reduction in N loss could be achieved under a precision N management plan based on a crop model simulation that compared variable and uniform N fertilizer application. Yet, other economic analyses of variable rate application of plant nutrients to small grains in inland PNW drylands have produced mixed results. Several studies reported that VRN increased profitability in some situations but not in others. In a hypothetical case analysis in the Annual Crop AEC near Farmington and Pullman, Washington (Fiez et al. 1994a), use of experimentally determined unit N requirements increased net returns from winter wheat by as much as \$14.80 per acre, but Taylor (2016) reported that at three sites in the Annual Crop AEC of eastern Washington the economic benefits of VRN management depended on yield potential. ● Reducing N rates in low-yielding field locations resulted in N fertilizer savings with VRN management, whereas increasing N rates in high-yielding zones resulted in no yield benefit but decreased NUE and economic returns. In addition to the cost of precision agriculture technology, the price of wheat and fertilizer as well as the likelihood of realizing a yield increase should be regularly evaluated to gain insight into how VRN might provide the least economic risk in high-yielding zones.

Mahler et al. (2014) summarized University of Idaho surveys of grower adoption of precision agriculture technology over three decades. The surveys, conducted in 1981, 1996, and 2011, showed that adoption increased markedly between 1996, when use of these technologies was estimated at 10%, and 2011. Mahler et al. (2014) concluded that variable rate systems were more popular in drier areas, and that younger farmers and farmers on relatively large farms were most likely to adopt new technologies. In 2012, the University of Idaho's Social Science Research Unit surveyed a representative sample of producers in dryland farming counties of northern Idaho, eastern Washington, and northeastern Oregon about their use of technology (Gantla et al. 2015). Responses from the 2011 and 2012 surveys are summarized in Table 8-3. The proportion of farmers using GPS guidance increased markedly between 2011 (47%) and 2012 (66%). In 2012, over one-third of respondents reported having and using variable fertilizer applicator and yield monitoring technology. Few producers (less than

5% for each of seven technologies) reported having precision agriculture technology and not using it, but more than two-thirds of respondents did not have technology for spatial soil mapping, aerial crop imagery, variable seeding equipment, and precision agriculture software. Among growers who said they did not have precision agriculture technology, the most commonly selected reasons cited were that equipment was “too expensive” (62%) and/or “not cost-effective for my operation” (59.9%). In addition, about one-quarter of respondents indicated the technologies were “not worth the investment of new capital” and that they were “difficult to learn to operate and maintain” (Gantla et al. 2015).

## **Things to Consider when Making Decisions about Precision Agriculture**

When making decisions about whether to add precision agriculture equipment and technology to a farming operation, it is important to consider several questions. This is true whether the producer is a novice or has already experimented with precision agriculture and is considering further changes. Most growers will want to give some thought to the following interacting issues:

**Impacts on your finances.** How much will the initial investment in precision agriculture technology cost? Will financial support be available? What are the projected maintenance costs? How long will it take for projected reductions in input costs to offset initial costs? Will there be costs associated with getting help from experts? How will fuel costs and other farm costs such as fertilizer inputs change when the new technology is implemented? Will improvements in grain yield and quality boost your farm's income?

**Impacts on your agroecosystem.** What specific factors limit productivity on your farm? Can the limiting factor(s) be measured accurately and treated effectively? Which factors can you control and which ones do you have to live with?

**Impacts on labor and time.** How much time will be required to install new equipment? How long will it take to gather the data needed for making management decisions? How long will it take to gain the expertise needed to use precision technology? Once the system is up and running,

will implementation save time? If you participate in a financial assistance program, will the associated paperwork be time-consuming?

**Impacts on grower knowledge.** How many people on your farm will need to gain the knowledge necessary to use precision agriculture? How difficult or time-consuming will it be to acquire this knowledge?

**Impacts on the environment.** How will site-specific management affect off-site flows of fertilizer, insecticides, herbicides, and/or water? How will precision agriculture adoption affect on-farm vehicular passes and related soil compaction and water movement? Will long-term, site-specific management improve the quality of your soil?

**Impacts on society.** What effects would widespread adoption of precision agriculture be likely to have on your community? What about the long-term stability of your farm? Will adoption of precision agriculture affect whether younger generations decide to stay on the family farm or leave home to look for work elsewhere?

Because precision agriculture is based on site-specific practices, field results at one locale may not apply to other sites, even within the same AEC. The same is true for growers: what works for one person won't necessarily work for another. Grower intuition, skills, and priorities are important for evaluating whether to adopt precision agriculture.

### **Conclusions: Challenges and Future Directions**

Precision agriculture technology and practices are rapidly developing. Spatial resolution, return frequency, and spectral resolution have improved dramatically in the past 25 years (Mulla 2013), as have data storage and analysis capabilities. But complex, highly precise technology does not always translate to appropriate management.

In the inland PNW, research on N dynamics has led to improved understanding of the effects of site-specific spatial and temporal variability on crop growth and development. This information has been used to develop criteria to rank wheat into performance classes that can be used to predict response to applied N (Figure 8-6). Research on regional hydrology has clarified vertical and horizontal movement of water, nutrients, and soil. Such information forms the basis for site-specific diagnosis and treatment

### Farmer-to-Farmer Case Study Series

**Ron Jirava**, farms near Ritzville, Washington, in the Grain-Fallow AEC where he receives about 11.5 inches of annual precipitation. Jirava prefers not to invest heavily in variable rate technology because he hasn't "been convinced that, in an area where moisture's the limiting factor," precise mapping would be worth the economic investment (Mallory et al. 2000; [https://www.youtube.com/watch?v=z2fdxvANWsA&list=UUO\\_J3MbC2\\_x772upBPM-CvQ&index=29](https://www.youtube.com/watch?v=z2fdxvANWsA&list=UUO_J3MbC2_x772upBPM-CvQ&index=29)). ■

**Eric Odberg**, who farms near Genesee, Idaho, in the Annual Crop AEC where annual precipitation is about 22 inches, has been using VRN for several years and is pleased with the results (Yorgey et al. 2016; <http://cru.cahe.wsu.edu/CEPublications/PNW691/PNW691.pdf>). With VRN, Odberg says, "You're applying less nitrogen out there, which is better for the environment. You're not putting on excess, which would just go into the groundwater and into our rivers and streams."

Odberg had two things working in his favor as he transitioned to VRN technology. First, he was able to reduce some initial equipment costs by participating in cost-share programs such as USDA-NRCS's Environmental Quality Incentives Program and the Conservation Security Program. Using auto-steer with a 90 lb per acre application saved Odberg \$3.97 per acre, while varying his application rate saved an additional \$4.54 per acre. Second, Odberg sought help from experts. He cautions other growers against being intimidated by precision agriculture technology. On the other hand, because his system is complex and requires a skilled operator, Odberg feels he needs to be the one to operate the machinery. Thus, his benefits in precision and cost savings come with a cost in lost flexibility. ●

The Farmer-to-Farmer Case Study Series can be accessed at [https://www.reacchpna.org/case\\_studies](https://www.reacchpna.org/case_studies).

of constraints on crop yield and quality. This foundation sets the stage for further research on how to match inputs to crop needs.

In particular, additional research on the following agronomic issues has the potential to increase scientific understanding of precision agriculture in the inland PNW:

- Additional field testing of performance classes for wheat response to applied N.



- Site-specific approaches to addressing limiting factors other than N (such as P, S, pH, pests, and pathogens).
- Research on the challenges of using precision agriculture in the Annual Crop-Fallow Transition and Grain-Fallow AECs. ▲ ■

Currently agronomic research on precision agriculture in the inland PNW is ahead of evaluation. Additional research assessing the impacts of precision management on society and the environment is needed. For example, attention to these areas would increase our understanding of the wider context of precision agriculture:

- Additional economic analyses of specific conditions under which precision agriculture improves net returns to producers.
- Studies of the environmental effects of precision agriculture in the inland PNW (e.g., does nitrate loss to the environment decrease with precision agriculture management?).
- Studies of the interactions between agronomic, environmental, economic, and social effects of precision agriculture in the inland PNW (i.e., can precision agriculture result in win-win-win scenarios, and, if so, under what circumstances?).

Finally, programs that continue to promote communication among growers as well as between growers and support personnel are essential for promoting appropriate and effective precision agriculture in the inland PNW.

## Resources

### **AgBiz Logic: Farm Decision Tools for Changing Climates**

*[https://www.reacchpna.org/sites/default/files/tagged\\_docs/6b.2.pdf](https://www.reacchpna.org/sites/default/files/tagged_docs/6b.2.pdf)*

### **AgWeatherNet**

*<http://www.weather.wsu.edu>*

### **GeoCommunity Sources for GIS and Mapping Software**

*<http://software.geocomm.com/viewers/>*

*<http://spatialnews.geocomm.com/features/viewers2002/>*

**Geospatial Data Gateway**

*<https://gdg.sc.egov.usda.gov/>*

**National Coordination Office for Space-Based Positioning, Navigation, and Timing, 2016. The Global Positioning System.**

*<http://www.gps.gov/systems/gps/>*

**REACCH Precision Agriculture Resources for Farmers**

*[https://www.reacchpna.org/Precision\\_Agriculture\\_Resources\\_for\\_Farmers](https://www.reacchpna.org/Precision_Agriculture_Resources_for_Farmers)*

**REACCH Nitrogen Management Webinar Series**

*<https://www.reacchpna.org/seminars-nitrogen-series>*

**REACCH Farmer-to-Farmer Case Studies**

*[https://www.reacchpna.org/case\\_studies](https://www.reacchpna.org/case_studies)*

**US Global Positioning System Agriculture Applications**

*<http://www.gps.gov/applications/agriculture/>*

**USDA Aerial Photography Field Office**

*<http://www.apfo.usda.gov>*

**USDA Natural Resources and Conservation Service: Incentive Programs and Assistance for Producers**

*<http://www.nrcs.usda.gov/wps/portal/nrcs/detail/national/climatechange/resources/?cid=stelprdb1043608>*

**WSU Extension Learning Library**

*[http://extension.wsu.edu/learn/?keyword=precision+age&posts\\_per\\_page=6](http://extension.wsu.edu/learn/?keyword=precision+age&posts_per_page=6)*

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