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PRECISION AGRICULTURE: A PRIMER

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Abstract. Precision agriculture is an emerging high-technology agricultural management system. Congressional interest centers on federal support for research on precision agricultural and its enabling technologies. This report includes a description and background overview of the current status and development trends of precision agriculture in the United States. It also contains a glossary of related terms to assist readers unfamiliar with this topic, which is of growing importance in production agriculture.

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Precision Agriculture: A Primer

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Summary

Precision Agriculture is an emerging high-technology agricultural management system. Congressional interest centers on federal support for research on Precision Agricultural and its enabling technologies. This report includes a brief description and background overview of the current status and development trends of precision agriculture in the United States. It also contains a glossary of related terms to assist readers unfamiliar with this topic, which is of growing importance in production agriculture. This report is designed to provide basic information on this method of production and is not expected to be updated regularly.[2]

Background

Description

Rapid technological change is a central characteristic of U.S. agriculture and a major force in the industrialization of contemporary commercial agriculture. The pace of that change is partially dependent on public policies and society's institutions. Growing competitive pressures stemming from globalizing agricultural markets, improving yields, and new environmental concerns contribute to the reliance of farmers on technological innovation. Increased acceptance and reliance on emerging information technologies are becoming part of U.S. agricultural production. Precision Agriculture (PA) (also called site-specific crop production, prescription farming, and soil-specific crop management) refers to a suite of technologies that use sensing and geo-referencing innovations to apply more precise inputs based on a field's biophysical variability. Producers first determine the variability within their fields by relating crop production and/or soil attribute data to geographic coordinates using a Global Positioning System receiver. These data become the basis for digital soil fertility and variability mapping. The objective of PA is to quantify

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[1] Prepared under supervision of Jeffery Zinn, Senior Analyst in Natural Resources Policy

[2] Material for this report was drawn from agribusiness publications, academic reviews, and from *Precision Agriculture in the 21st Century: Geospatial and Information Technologies in Crop Management*. National Research Council. National Academy of Science Press. Washington, D.C., April, 1997.

and manage spatial and temporal variability that exists in virtually every field. Rather than applying fertilizer, seed, pesticides, or water at a uniform rate across an entire field, growers use computer technologies to continually adjust their input applications as they operate their equipment based on the biophysical variability of their land. Best estimates suggest that less than 4% of U.S. farmers are using PA technologies. The twin goals of PA are increased yields and reduced costs. PA is foremost a management system that may do for agriculture essentially what just-in-time production has done for manufacturing.

Costs Associated with Precision Agriculture

Farmers face significant but not prohibitive start-up costs before they achieve potential long-term efficiencies. These costs include yield monitoring, crop scouting, and soil testing over multiple growing seasons and learning how to use remote sensing, GIS, and variable rate application technologies (VRT). Individuals may either buy this technology directly or contract for various services with vendors, including crop consultants and input suppliers. A yield monitor for corn, wheat, or soybeans could cost $4000-$7000; soil sampling has been estimated at $3-$7 per acre, considerably more if samples are deeper and taken on a sampling basis of 1-2 acres. A truck-mounted computer system and GIS software could add an additional $3000. Service costs including soil sampling, yield monitoring, crop scouting, GPS receiver and, depending on the region of the country, a satellite signal subscription, and VRT controllers and fertilizer application (additional cost over uniform application rates) have been variously estimated at $13-$26 for a grower and $2.50-$14.50 for a dealer on a per acre basis.[3] Soil grid sampling could become an annual expense but, spread over sufficient acreage, this cost has been acceptable to adopters. Other sensor-based applications, sometimes referred to as "on-the-go" sensing, are evolving technologies. Although development research is underway, few such commercial sensors have been developed to date; this barrier could limit PA's development.

Individual farm returns on PA investment will vary by the managment skills of operators, by the biophysical properties of each field, and by the interactive effects of altering various inputs. The limited data on economic returns to date show mixed results, which is not unexpected given the difficulty of maintaining any consistency of the system between comparative sites. Potential profitability of PA is highly correlated with the biophysical variability of the setting to which it is applied. No research has examined the economics of PA for an agro-ecological region, type of production system, or across all dimensions of a production system. The limited economic research available is based largely on relatively low-valued crops and inexpensive inputs, variables that are less conducive to producing significant profit advantages under a PA system. Changes that might give less wealthy growers incentives to invest in PA include cooperative arrangements to share technology, equipment leasing, and standardization of PA technology. PA is likely to attract farmers who are comfortable with computers and the information intensity of PA. As the technology matures, however, more growers may be likely to consider at least some of the PA technologies either through direct purchase or through contracting for PA services.

[3] *Precision Agriculture in the 21st Century: Geospatial and Information Technologies in Crop Management*. National Research Council. National Academy of Science Press. Washington, D.C., April, 1997.

Use of Precision Agriculture

Information on the adoption of PA is fragmentary and unsystematic. Adoption rates also are difficult to determine because PA is a cluster of different techniques that may be adopted in different combinations and at different times rather than a single farming system. Published USDA data indicate that about 64,000 farms (about 3.2% of total farms) used computer-aided chemical application or GPS technologies in 1995. More recent USDA data (1998) indicate little growth in acquisition of these technologies. Larger farms seem to be among early adopters although there is no hard evidence of a consistent size bias for PA techniques.

The rate of adoption does not appear to be uniform among crops either. Farm press articles and various regional agricultural meetings suggest that many adopters of yield monitors have been corn and soybean growers. Case-studies in the farm press and anecdotal information reveal that some Florida tomato growers, California vegetable and grape growers, Arkansas cotton growers, and Northwestern foresters have also adopted PA techniques. Based on experience to date, PA seems to offer the greatest potential benefits where input costs are high, field variability is high, high-valued crops are grown, and environmental effects, especially affecting water resources, must be reduced.

Environmental Aspects of Precision Agriculture

Proponents of PA have emphasized its potential to reduce environmental effects of production agriculture. Field-level studies suggest that more accurate calibration of inputs can reduce over-fertilization or excess use of pesticides. The lack of experience with PA as well as more extensive experience with other technologies, such as irrigation, however, suggest that PA might produce less environmental improvement in commercial-scale agriculture than individual field tests at this time indicate. Growers who find they can reduce certain inputs could be offset by other growers who learn they are under-fertilizing or using sub-optimal levels of pesticides and opt to increase their inputs.

Current Status of PA at the Federal and State Levels

Although the technologies undergirding PA are being developed and promoted largely by private companies, there has been a public presence in PA development. The 104^{th} and 105^{th} Congresses considered several bills to promote agricultural research and extension targeting precision agriculture and precision agriculture technologies. Three bills were introduced in the 104^{th} Congress to amend the Competitive, Special, and Facilities Research Grant Act and one to amend the research categories in the Fund for Rural America. Although none of these bills was enacted, interest in the Congress continued.

Three additional bills were introduced or re-introduced in the 105^{th} Congress. An original bill (S. 1150) to address high priority national agricultural concerns and to reform, extend and eliminate certain agricultural research programs was enacted as P.L.105-185, The Agricultural Research, Extension, and Education Reform Act of 1998. Section 402 sets research priorities and authorizes grants to study and promote components of PA technologies and to integrate research, education and extension efforts in PA. Section 401 further addresses PA in the context of natural resource managment. To implement Section 401, the Cooperative State Research, Education, and Extension Service (CSREES) has recently announced a new program entitled the Initiative for Future Agriculture and Food Systems (IFAFS) which was authorized by Congress in 1998. About $113 million is available for research grants through this initiative in 2000. Section 401 also gives priority to the concerns of small and mid-sized producers especially in natural resource management and farm efficiency. Congressional appropriators, however, decided in 1999 to prohibit USDA from using any CSREES funds to pay salaries and expenses of personnel to carry out the provisions of Section 401. The Secretary then tried to use funds from FY1999 to fund staffing for the initiative in FY2000. Funding this initiative is currently an issue in the FY2000 House Appropriations Committee's supplemental appropriation bill.

At least seven universities have established PA research institutes or laboratories: Purdue, University of Georgia, Oregon State, University of Minnesota, University of Arizona, Texan A&M, and North Carolina State. In 1996, about $9 million was reported as CSREES funding to PA-related research at land-grant universities. The Coastal Plain Experiment Station in Georgia received $3.4 million between 1991-1993 from CSREES to construct the National Environmentally Sound Production Agriculture Laboratory where PA is a major element of the research program. In addition, the Agricultural Research Service's (ARS) Subtropical Research Laboratory in Weslaco, Texas is the site of RESOURCE21, a project designed to launch four solar-powered satellites for remote sensing. This public-private venture is developing under a USDA Cooperative Research and Development Agreement (CRADA) involving six partners and the Agricultural Research Service. In 1995, the ARS invested $4.4 million in PA-related research in 15 locations. According to the ARS Budget Office, its spending on precision agriculture from 1996-1999 totaled $20.4 million. For 2000, it has allocated $7.7 million for PA related research. Other Federal agencies conducting research and development with PA applications include the Department of Energy (e.g., Idaho Engineering Laboratory) and the National Aeronautical and Space Administration (e.g., LandSat, Commercial Remote Sensing Program at Stennis Space Center).

GLOSSARY

Digital Soil Mapping: Fields are divided into grid cells of approximately 2-3 acres defined by a GPS receiver. Larger scale resolution is possible. Soil sample data from each cell are transferred to a digital map that is then used to manage precise input application.

Geographical Information Systems (GIS): A combination of computer hardware, software, and geographic data designed to capture, store, manipulate, analyze, and display data that is referenced to specific points on the Earth's surface. The capacity to perform many sophisticated spatial operations on these data differentiates GIS from simple mapping software.

Global Positioning System (GPS): Most PA will make use of the U.S. Department of Defense's 24 Earth-orbiting satellites to assign map coordinates. These satellites emit radio signals at precise intervals accurate to a billionth of a second. Through triangulation, a ground-based receiver translates the time lag between emission and reception of the signals into precise geographic coordinates on the targeted cropland.

Ground-based Sensors: Sensor-based application of inputs implies that sensors on the VRT can measure information in real-time and make the necessary precise adjustments. The technology is not as advanced as map-based applications at this time although research is underway in soil nutrient sensors, soil property sensors, and optical plant sensors.

Precision Agriculture (PA): An emerging set of farming techniques whose fundamental feature is assigning computer-based geographic coordinates to subfield variability of cropland for improving efficiency of inputs. PA's technology consists of four major components: a Global Positioning System (GPS) receiver, a yield monitor, a digital soil map, and variable rate application technologies (VRT). Data from these components are integrated through a geographical information system (GIS).

Remote Sensing: Data from light reflectance collected by instruments in airplanes or orbiting satellites. The data can estimate vegetation characteristics on small areas within a field. High resolution (e.g., 1-5 meters) satellite images are currently available to producers from private vendors (e.g., Space Imaging, Inc. is offering to sell high-resolution satellite images from IKONOS during the 2000 crop season)

Variable Rate Application Technologies (VRT): Computer-controlled equipment continually readjusts the application. Soil grid data provide the prescription for the particular fertilizers or pesticides to be applied to each grid. A GPS receiver in a truck enables the computer to recognize where it is in the field. Computer-controlled nozzles vary the types and amounts of inputs according to the soil fertility or pest population maps

Yield Monitoring Systems: Area-specific yields in the field are measured using combine-mounted sensors or volume meters. A GPS receiver mounted on the combine supplies the spatial coordinates so that estimates of yields can be assigned to small areas of a field to create a yield map.