3° Simpósio Internacional de Agricultura de Precisão

PRECISION AGRICULTURE IN ARGENTINA

R. Bongiovanni [(1)] and J. Lowenberg-DeBoer [(2)]

ABSTRACT:

Argentine farm managers see precision agriculture as a means to reduce costs in grain production, to increase productivity and make input use more efficient. Yield monitors, Global Positioning Systems (GPS) guidance and satellite images are increasingly used in large operations, while Variable Rate Application (VRA) is rare. Factors that encourage its adoption include: large farm operations with relatively high capital per worker, highly educated farm management, technology available from abroad, need for yield information, and ease of pooling data. Factors discouraging precision agriculture adoption are: high investment cost, high risk, low management-induced soil variability, and the widespread use of custom operators. The objective of this article is to present Argentina as a case study in the adoption of precision agriculture.

KEY WORDS: precision agriculture, adoption, GPS, VRA, Argentina

[(1)] Director, Research Project BID 1201/OC-AR PICTO 8-12931, National Institute for Agricultural Technology (INTA), 5988 Manfredi, Córdoba, Argentina. Phone and Fax +54 (3572) 493039. Email: <rbongiovanni@correo.inta.gov.ar>

[(2)] Professor, Department of Agricultural Economics, Purdue University, 1145 Krannert Building, West Lafayette, IN 47907-1145. Phone: (765) 494-4230. Fax: (765) 494-9176. Email: <lowenbej@purdue.edu>

I. INTRODUCTION:

Precision agriculture does nothing to improve commodity prices, transportation infrastructure or credit availability in their country, but some Argentinean farm managers look for precision technology to help them maintain their position as low cost producers of grain. Like producers in North America, they ask themselves what parts of this technology will prove practical and profitable for their conditions. These observations are based on information gathered from various sources and by several trips to the Argentine Pampas by the second author, who visited farms and met farm managers, crop consultants, custom operators and agribusiness people in the provinces of Buenos Aires, Santa Fe and Córdoba. These visits are part of a long-term collaboration of Purdue University in Argentina, especially with the precision farming program at the National Institute for Agricultural Technology (INTA), Manfredi Experimental Station, Province of Córdoba; and with the *Foundation Producir Conservando* (FPC).

Overall, the potential of precision farming in Argentina's agriculture is to reduce costs in grain production, to increase productivity and make input use more efficient. A broader perspective on precision agriculture includes the use of whole farm information systems for input management over time and space, to optimize field operation logistics, to supervise employees in the field, to manage production risk, to market differentiated products, to provide traceability for food safety, and to document environmental compliance. Yield monitors may also be used as a tool to diagnose weed, pests, diseases, drainage, fertility problems and differences in tillage systems, and therefore as a decision-making aid tool for choices of hybrids, varieties or pesticides to be used.

The objective of this article is to present Argentina as a case study in the adoption of precision agriculture, because the country is growing the same crops, with the same technology and with similar climate as the areas in North America where precision agriculture has become widespread, although with very different economic and institutional situations.

This article is organized as follows: the first section outlines some background information on Argentine agriculture, the second section describes the current status of precision agriculture, the third section explains the research efforts currently underway, the fourth section details the factors that affect adoption, and the fifth and last section summarizes the prospects for the future.

The Argentine Agriculture. Characteristics of the agricultural sector. Argentina is the second-largest country in South America (after Brazil), with a total continental area of 2,791,810 sq km, about three-tenths the size of the U.S.A. Nine percent of the area is arable land, located mainly in the fertile plains of the Pampas, in central Argentina. Grain production in Argentina is about 70 millions tons per year. Agriculture and the agricultural food industry represent 14.2% of Gross Domestic Product (GDP). Primary agricultural production represents 6.5% of GDP (IICA, 2004), or about 60% of exports by value, and the food industry represents another 7.7% of GDP (Llach et al, 2004). Main annual crops are soybeans (14,226,000 hectares), wheat (6,036,000 hectares), corn (2,807,000 hectares), sunflower (1,835,000 hectares), sorghum (545,000 hectares), cotton (158,209 hectares), and peanuts (157,326 hectares) planted during the 2003/2004 crop season (SAGPyA, 2004; IICA, 2004). About 40% of the current planted area is under no-tillage systems (AAPRESID, 2004).

Characteristics of farms and farm structure. There are 333,000 farms in all Argentina, about two thirds of them in the Humid Pampas, which includes the Provinces of Buenos Aires, Santa Fe and Córdoba, down from 421,000 in 1988. Average farm size in this region is 533 hectares, up from 400 hectares in 1988 (INDEC, 2002). About 35% of the farms are specialized in crop production, 20% are beef ranches and 45% are mixed production, although these proportions vary with grains and beef price cycles. According to AAPRESID (2004), about 30% of the farms produce 70% of the total agricultural production. In the last few years, there has been an increasing number of large professionally managed operations that plant more than 5,000 hectares, paying rental rates ranging from 750 kg of soybean/hectare/year to 1500 kg of soybean/hectare/year of good cropland (i.e., approximately from 150 to 300 USD/hectare/year). Average purchase price for the best cropland ranges from 8,000 USD/hectare in the inner ring of the Pampas to 4,000 USD/hectare in the outer ring of the Pampas. The average rate of return for the average farm is 15%, while some large farms obtain average rates of returns as high as 90% due to economies of scale and to adoption of technology (no-till, biotechnology, irrigation and precision agriculture). Some farm managers plant more than 50,000 hectares of corn and soybeans per year in owned and rented land.

It is important to note that many crop decisions in Argentina are made by farm managers. Unlike much of the rest of the world where farms are typically operated by farmers who manage the farm business as well as doing some of the physical work (e.g., driving tractors and combines), many farms in the Argentine Pampas are owned by absentee landlords, who hire a manager to run the farm business. The farm manager usually hires employees or custom operators that do the physical work of production.

In Argentina there is a high taxation of the agricultural sector, in contrast to subsidization of agriculture elsewhere. This is done directly through export taxes and indirectly through the protection

of nonagriculture and other restrictions to trade. Currently, export taxes on grains are as high as 23.5% in soybeans. On the other hand, macro policies in the 1990's that caused the real exchange rate to decline (overvaluing the peso) have also had a negative effect on agriculture, which is more tradable than nonagriculture. And, a large deficit financed by borrowing had a more negative effect on agriculture, because it is more capital intensive than nonagriculture (Mundlak et al, 1989). Economic policies implemented in Argentina caused agricultural growth to lag behind if compared to other countries with similar potential. Strong changes took place during the 1990's in Argentina's agriculture: opening to free trade, strengthening of the South American Common Market (MERCOSUR), and internal reforms (deregulation, privatization and tax reform) that caused Argentine agricultural exports to almost double (Casaburi et al., 2001). In 2002, the Argentine peso – that had been attached 1:1 to the USD- was devalued to the current relationship of 3:1, following the 2001 socio-economic and political crisis. This helped boost agricultural production and exports, despite high export taxes. According to The Economist (2004), the Argentine Peso is 49% undervalued against the dollar.

Public agricultural research in Argentina is carried out mainly by the National Institute for Agricultural Technology (INTA), an autonomous organism of the Secretary of Agriculture that operates three research centers in the capital city area, fifteen regional centers for research and extension, and 40 experimental stations throughout the country. New research developments from these stations are provided to farm managers through a network of 233 extension agencies. About 1,300 staff members are actively involved in the provision of research and extension services. Universities also do research in agriculture, although they are more focused on education. There are other public research agencies that provide funding and grants for research, such as the Secretary of State of Science and Technology (SECyT), Agencia Córdoba Ciencia, etc. It is worth to note that Argentina invests only 0.35% of its GDP in science and technology, five times less than Brazil, for example (The Economist, 2001).

II. CURRENT STATUS:

Adoption of precision agriculture in Argentina began in early 1996 with the launching of the Precision Agriculture Project at the Manfredi Experiment Station of INTA. This program was extended to the national level in 1999, and it currently includes five experimental stations in five provinces (Buenos Aires, Córdoba, Santa Fe, Tucumán and Entre Ríos), with headquarters at Manfredi. Current adoption and evolution of precision agriculture technologies is shown in Table 1.

Updating the statistics provided by Griffin et al. (2004), with 1200 yield monitors, Argentina is the second country in number of yield monitors (after the U.S.A.), and with 51 yield monitors per million hectares, the fifth country in number in yield monitor density (after the U.S.A., Denmark, Sweden and Great Britain)

Table 1. Current adoption and evolution of precision agriculture technologies in Argentina.

Equipment (units)	1997	1998	1999	2000	2001	2002	2003	2004
Yield monitors with GPS	25	75	155	270	400	420	600	850
Yield monitors without GPS	25	125	145	180	160	180	250	350
Yield monitors TOTAL	50	200	300	450	560	600	850	1200
VRT planters	1	2	3	4	5	6	7	8
VRT fertilizer applicators (Terra-Gator trucks)	2	2	2	2	6	6	6	6
VRT fertilizer applicators (urea, knifed)	0	0	0	0	0	0	4	4
VRT fertilizer applicators (urea, spreaders)	0	0	0	0	0	0	0	10
VRT fertilizer applicators (UAN, knifed)	0	0	0	0	1	2	3	3
VRT self-propelled fertilizer applicators (UAN)	0	0	0	0	0	0	5	9
VRT fertilization, TOTAL	3	4	5	6	12	14	25	40
GPS guidance systems in airplanes	35	60	100	160	200	230	300	450
GPS guidance systems in applicators	0	10	70	200	400	500	2000	2600
GPS Auto guidance	0	0	0	0	0	0	0	3
GPS guidance systems, TOTAL	35	70	170	360	600	730	2300	3053
N sensor	0	0	2	2	4	5	6	7

According to Bragachini (2005), Coordinator of the Precision Agriculture Project of INTA, the 850 combines with yield monitor and GPS are potentially able to harvest up to five percent of the total annual harvest of the major crops, due to their large capacity, and because they are owned by large farm managers (40%) or custom harvestors (60%). The major North American combine manufacturers are marketing equipment in Argentina that either has a yield monitor as standard equipment or is prewired for yield monitor installation. The Argentine market leader combine manufacturer, Don Roque™, also pre-wires combines for yield monitoring. AgLeader®, a U.S.A. yield monitor manufacturer, has been willing to work with Argentinean dealers and farm managers to modify their yield monitor for Argentine conditions. Because there is no killing frost before harvest in Argentina, the stalks and straws are usually more humid than in the U.S.A., and this has created some problems for U.S.A.-built yield monitors (Amuchástegui, 2005). Thus, technical adoption requires some adaptations.

Differential Global Positioning System (DGPS) is available from a private company, D&E, who provides amplitude-modulated (AM) signal for USD 300 (plus tax) per year or for USD 900 per a lifetime. They broadcast from three antennas that cover twelve central and northern provinces of Argentina, located at San Carlos Sur (Province of Santa Fe), at Bolívar (Province of Buenos Aires) and Las Lajitas (Province of Salta). D&E is also the dealer and representative in Argentina for several North American and European brands of precision agriculture hardware and software. Satellite DGPS is also available from Omnistar® and from Racal™ since January 1998, at a cost of USD 2,000 (plus tax) per year. DGPS signal from John Deere (Starfire™) is expected to be provided soon.

Guidance systems for agricultural chemical applicators are the fastest growing precision agriculture technology, because they are easy to use and because of their immediate benefits. Several brands are available in the Argentine market. Relatively few applicators use foam markers. Most use flaggers in both ends of the fields, i.e., two employees that indicate to the machine or to the airplane

the width of the application. Guidance systems allow applicators to reduce employee health risks and to decrease labor costs.

In Argentina, only 50% of cropland is tested periodically for nutrient levels, 25% is tested annually before planting, and only about one-percent of the total crop area undergoes intensive soil testing (García, 2001). Only a small number of Variable Rate Technology (VRT) machines for planting or fertilizer spreading have been sold. Local manufacturers of agricultural machinery, such as Agrometal™ and VHB™ (planters and fertilizer spreaders) have become associated with local manufacturers of variable rate equipment (Verion™ and DiRocco™) for planters and for fertilizers, especially nitrogen. Some big agricultural input suppliers such as Agroservicios Pampeanos, a subsidiary of the Canadian company Agrium, offer VRT fertilizer custom services in the northeast of the province of Buenos Aires, using applicator trucks equipped with Falcon™ VRT technology (Amuchástegui, 2005). The chemical company PASA Petrosur also offers Variable Rate Application (VRA) with high-volume spreader trucks in the southeast of the Province of Buenos Aires, and VRA of urea-ammonium nitrate solution (UAN) in Córdoba Province (PASA, 2004), but so far,its use in commercial farms is limited, due to lack of soils information. The local dealer of the Norwegian company Norsk Hydro™ also offers the Hydro Precise™ fertilizer system, a scanning system for tractors that uses a variable-rate fertilizer equipped with Dickey-John™ controllers to vary the rate of nitrogen on-the-go. There are seven of these greenness sensors currently available in Argentina, and they are marketed through D&E. TecnoCampo, an agricultural input supplier of Córdoba, and A&T, a crop consultant and service provider company, also report that some farm managers of the provinces of Córdoba and Santa Fe are using manual VRT by topography (Amuchástegui, 2005).

According to Bragachini (2005), there are more than twenty companies that provide integral precision agriculture consultant services to farm managers. Service packages include soil survey with GPS, including digital elevation maps, soil compaction measurement, georeferenced soil sampling, soil testing in U.S.A. laboratories, georeferenced crop scouting, satellite images, creation of soil management zones, fertilization recommendations, soil mapping, etc. (AgroSat, 2005)

Remote sensing for agriculture in Argentina is also becoming popular, motivated by four key drivers, in descending order of importance: First, satellite images are required by law (in the province of Buenos Aires) to obtain emergency tax exemptions for flooding (Testa, 2001). Second, some banks also use satellite images before granting loans for production or for land purchase. Third, large farm managers use remote sensing to determine the quality of the land and the risk of flooding, before buying or renting. Lastly, remote sensing is used by agronomists / crop consultants to determine aptitude areas, green indexes, topography, etc.

The reception of satellite information (LandSat 5 and 7) in Argentina has been done since early 1997 by the federal government through an antenna of the National Commission on Space Activities (CONAE), located at 30 km west of the city of Córdoba. LandSat 5 images have been relatively inexpensive, compared to costs in the U.S.A., which has allowed public institutions and private companies to profit from this technology. Currently, Landsat 7 images are offered at USD 150 per full image with a resolution of 30 meters by 30 meters. Farm managers can obtain digitized images of their farms, ranging from USD 20 for the basic image up to USD 100 for images with a digitized map, area of the fields, and a written report with an interpretation from INTA-Castelar (Mercuri, 2005).

The program "Harvest Forecast" of the Department of Climate and Water of INTA Castelar (province of Buenos Aires) has been using remote sensing and GIS since 1991 to determine the planted area for each crop. This information, combined with crop simulation models (e.g., CERES wheat, etc.), has allowed INTA-Castelar to predict grain production. The importance of this tool has been proven during the large scale flooding that took place in the last few years. Currently, it is possible to obtain LandSat satellite images for any given location every sixteen days, corresponding to the satellite recurrence cycle (Mercuri, 2005).

Many farm managers and agronomists also use this information, in combination with the available soil maps, to determine the productive aptitude of soils, before buying or renting land. Some of them have also used this information for restructuring field divisions.

It is important to highlight that the greatest advantage of the use of satellite images in Argentina is due to three main factors: the first is the lack of detailed cartographic information. The available soil maps are only at a scale of 1:50,000, and there are no digital elevation models, such as the ones which are used in the U.S.A. to analyze spatial variability in agricultural areas. Second, the images from multi-spectral cameras are very expensive, because they are offered by foreign companies. INTA Castelar has recently purchased the required instrumental, and they expect to begin offering the service soon at a lower price. Other local private companies are also entering the market. The third factor that leads to an increased use of satellite images is that the panchromatic aerial photographs currently available are outdated, because they are the same ones taken for the development of the soil maps, in the late 1960's and early 1970's. Therefore, satellite images are an important resource when it comes to time series images and to up-to-date information.

Regarding GIS software, FarmWorks™ is by far the most used among farm managers. D&E is the representative in Argentina. Using a push marketing strategy, they have been offering training courses for farm managers and agronomists in the use this software, in order to provide incentives for the sale of this and their other precision agriculture products. This software has the advantage of being available in Spanish and it has a relatively low price.

Most researchers use ArcView™ (from ESRI®) GIS software, but its cost in Argentina is a disadvantage: USD 2,300 for the basic software, as compared to USD 1,250 in the U.S.A. The company Centro GIS (http://www.cursogis.com.ar), which is related to the Department of Architecture of the University of Buenos Aires, offers training workshops for professionals of different disciplines on a regular basis, on ArcView™, Envi™, remote sensing and aerial photography. There are also some crop consultants who use SSToolbox®, a GIS software built on ArcView™, especially designed for agriculture by SST Development Group, Stillwater, OK, U.S.A. (http://www.sstdevgroup.com/). The representative of ESRI® in Argentina is Aeroterra (http://www.aeroterra.com.ar/), a firm which also offers training courses and remote sensing images from different satellite companies, such as Ikonos™ and Radarsat™. The price of the high definition Ikonos™ images (USD 6,000) in Argentina also reflects a big markup, as compared to the prices in the U.S.A. (USD 3,000).

There is also an increasing number of users of IDRISI, a GIS software developed by Clark University. Main advantages are its low price (USD 600 for the academic version), raster oriented and extensive client support. IDRISI has expanded its popularity at many Argentine universities and most recently to other public and private institutions (INTA, SAGyP, etc.). There is an IDRISI Resource Center (IRC) (http://crean.org.ar/Idrisi/) located at the University of Córdoba, Department of

Agronomy (CREAN), which provides training courses for agronomists, biologists, geologists, etc. CREAN also provides consultant services on remote sensing and GIS application in agriculture, forestry and weather impact.

Insurance companies, such as the Cooperative "La Dulce", in the southeast of the Province of Buenos Aires, have also pushed precision agriculture in Argentina. They have organized the Agro Informática 2000, December 8-10, 2000, together with a crop consultant company, INTA, Potash and Phosphate Institute (PPI-INPOFOS), and Purdue University (http://www.expoinfoag.com.ar/). Agro Informática is the Argentine version of the InfoAg Conference (http://farmresearch.com/infoag/) that is organized every other year by the PPI in the U.S.A.

RESEARCH EFFORTS. THE PRECISION AGRICULTURE PROJECT:

The Manfredi experimental station of INTA, province of Córdoba, is the base for the Precision Agriculture Project. Main tasks of this project are extension and research. The project also includes researchers in other experimental stations, such as Marcos Juarez (Province of Córdoba), Castelar (Province of Buenos Aires), Paraná (Province of Entre Ríos), Famaillá (Province of Tucumán), Oliveros (Province of Santa Fe) and Venado Tuerto (Province of Santa Fe).

Extension activities include extension workshops for farm managers and agronomists in the use of GIS software and fertilization recommendations, as well as training courses for both farm managers / agronomists and operators of agricultural machinery. The Project is also working closely with other government research agencies from Chile (INIA), Brazil (Embrapa), Uruguay (INIA), and Paraguay (CRIA). All of these research institutions sponsor a Precision Agriculture Avenue in the Cooperative Program for the Technological Development of Food and Agribusiness of the Southern Cone of America (PROCISUR). Seven Meetings and Training Workshops have been carried out so far in Argentina, Chile, Brazil and Paraguay as part of this program.

In mid 2000, the Project launched a website: http://www.agriculturadeprecision.org/, with updated information about precision agriculture technologies and the research being carried out in Argentina. This web page currently has an average of 99 daily visits from Argentina and from other Latin American countries.

On-farm trials are currently being conducted in farms of the area of influence of INTA Manfredi, as part of a Precision Agriculture Project funded by SECyT, coordinated by the senior author, to study the contributions of site-specific management to sustainable agriculture. The model involves the estimation of the site-specific crop response to nitrogen, using spatial econometrics techniques. This study is a continuation of the Ph.D. dissertation carried out at Purdue University by the senior author (Bongiovanni, 2002). This study is significant because it is the first application of spatial econometrics to yield monitor data. From the standpoint of the Argentine farm manager, this analysis is important because it offers a way to estimate the profitability of one type of precision agriculture technology.

Several other on-farm trials involving precision agriculture techniques are being conducted in the Manfredi Experiment Station area by multidisciplinary teams, aiming to show the effects of different management practices on crop yields. On-farm trials are also being carried out in

collaboration with the Association of No-Till Farm Managers (AAPRESID) and with the Potash and Phosphate Institute of Argentina (INPOFOS).

Effort is also being undertaken at INTA Manfredi to improve techniques of analysis of satellite images, in order to detect crop stress in peanut, and to correlate it with the incidence of diseases, especially *Aflatoxins*. Their goal is to differentiate areas of low and high risk of diseases, so they can be harvested and stored separately.

III. FACTORS THAT FAVOR ADOPTION:

Several factors suggest that yield mapping and other information systems technologies will be adopted more rapidly in Argentina, than they have been in the U.S.A., at least on larger farms.

Large farm operations with relatively high capital per worker in the Pampas. Norton and Swinton (2001) hypothesize that precision agricultural technologies will be adopted first in regions with large farming area and high capital investment per hectare. Using FAO statistics, they show that when it comes to countries as whole, only the U.S.A., Canada and Australia fit those conditions, but they hypothesize that while small, subsistence farms pull down national average farm area, some regions within developing countries may have the necessary preconditions for profitable use of precision technology in the near future (e.g., the Argentinean Humid Pampas). Norton and Swinton (2001) suggest that the early adopters of precision agriculture technologies might be the countries where agricultural land and capital are abundant. Based upon the relative abundance of land and capital relative to labor, their work proposes that Canada, the U.S.A. and Australia would be the prime candidates for adoption, followed by West Europe and Argentina. Argentina has a higher ratio of land to labor than Eastern Europe, Brazil, Asia, and the rest of Latin America. Nevertheless, in Argentina the adoption patterns may differ substantially from those in the U.S.A. and Canada because of differences in agronomic and economic conditions.

Highly educated and professional farm management and crop consulting. Since total Argentine literacy rate is 96.2%, almost all farm employees are literate. Nearly all farm managers have at least a high school degree, and some farm managers have a University degree. Approximately 90% of farm managers in the Humid Pampas use cellular phones, which may be a proxy for technology adoption, given the long distances between farms and cities. About 10% of the agronomists / crop consultants speak English at a working level, although that percentage drops to about 1% for farm managers (Bragachini, 2005). Table 2 indicates the percentage of farm managers in the Humid Pampas that use computers and of farm managers that are connected to Internet. According to a recent survey, 18% of agribusiness companies have already developed a website, and 70% are planning to develop one in the near future (Campo21, 2001).

Table 2. Percentage of farm managers in the Humid Pampas that use computers and of farm managers that are connected to Internet.

Percentage of farm managers that:	2000	2001*	2002*	2003*
Use computers	14	16	33	39
Use computers and Internet	28	32	39	50

* projected

Technology available from North America. Due to the similarities in the agricultural production of the U.S.A. Corn Belt and the Argentine Humid Pampas, most of the mechanical, chemical and

biotechnological technology available in the United States can be imported with little modification to Argentina, except for no till planters, where there is a need for local developments or adaptations of imported machines, due to the particular conditions and to the double crop wheat / soybeans. Approximately 1,000 Argentinean farm managers, agronomists and manufacturers visit the Farm Progress Show in the U.S.A. every year, to gather the latest developments in technology. As an example, INTA Manfredi has been organizing technical tours of the U.S.A. for the past fifteen years, visiting manufacturers, universities, and the Farm Progress Show. Nevertheless, machinery and equipment are more expensive in Argentina due to transportation costs and tariffs.

Farm managers are hungry for better crop data. As farm size increases in Argentina, farm managers willing to expand their operations need more and better information to rent or to purchase land. At the same time, large farm managers need information about soils and yields to make fertilization and other management plans.

Yield maps, as-applied maps and other precision data are more valuable in Argentina because the manager of the farm often does not observe crop conditions and yield from the tractor or combine seat. In the U.S.A. where farmers usually operate their own equipment, yield maps often help to quantify variability that producers already know about. In Argentina the maps often reveal variability that managers had not observed directly. In addition, yield maps, as-applied maps and other precision data provide an important quality control on work being done by employees or custom operators.

Use of yield monitor and other spatial data in Argentina will be facilitated because they will have less need to pool data across farms. In the U.S.A., farmers will probably need to pool precision data to achieve the full benefit of the technology. Most Corn Belt farms are not big enough to provide the range of conditions needed to begin to identify patterns without designed experiments. On the many large farms in Argentina, the need to pool data is reduced. Many farms plant over 5,000 hectares. Depending on soil variability and management, 5,000 hectares may provide enough data to begin to identify patterns without specifically designed trials.

If data pooling is necessary, it may be easier in Argentina than it has been in the U.S.A. Argentine agriculture has a long history of data sharing. For example, the groups of the Argentine Association of Regional Experimental Consortia (AACREA) meet regularly to share agronomic and accounting information. In part this occurs because Argentinean growers have only recently started to compete for rental land. In the past, they usually focused on improving management on the acreage they already controlled. In the U.S.A. one of the reasons for reluctance to share data is that producers do not want yields and other information in the hands of those who will be competing with them to rent the farm down the road.

Yield monitors in Argentina are usually used over larger areas than in the U.S.A. Because of the long harvest season and custom harvesting, large combines often cover 3,500 to 5,000 hectares/year, more than twice as much as the area covered in the U.S.A. By spreading the cost of the yield monitor and GPS over more area, the per-hectare cost is lowered.

IV. FACTORS THAT DISCOURAGE ADOPTION:

For the adoption of precision agriculture in Argentina, there are at least four crucial differences from the U.S. situation: higher investment cost, more risk, less management-induced soil variability, and the widespread use of custom operators.

Higher investment cost. Currently, average real interest rates for production loans are in the range of 16% - 24% annually, and longer-term credit is not easily available. Argentina is having problems restructuring its external debt after the default of 2002, so interest rates are not expected to fall in the short term. Because most precision technology must be imported into Argentina, the cost is somewhat higher than the same technology in the U.S.A., due to import duties. For instance, a yield monitor with GPS costs twice as much in Argentina than in the U.S.A.

More risk. Grain prices in Argentina fluctuate a lot, which affects farm income. The Argentine government has no programs to stabilize grain prices or farm incomes. High interest rates, difficulty in obtaining credit, higher technology costs and risk discourage investment in all new technology, including precision agriculture. Access to insurance is limited: the Secretary of Agriculture (SAGPyA) indicates that only 9% of the agricultural production is insured, as opposed to 42% in the U.S.A., 52% in Canada, and 30% in Spain. In the crop season 2000/2001, insurance companies insured crops for a value of USD 52 million, which is considered low, because it is expensive, and because only large operations can afford it. Nevertheless, hail insurance is increasing, and some farm managers are hedging risks with futures and options contracts. At the same time, low public investment in infrastructure - transport, drainage, and research does not help to decrease production risks. It costs about twice as much to barge grain on Argentine rivers as what it does on the Mississippi (Tennessen, 1998). Most of the paved roads are two-lanes, two-ways, and access to farms usually include a large portion of unpaved roads, making it difficult for trucks to transport grains to the local elevators, especially in the rainy season. Large areas of the Humid Pampas have serious drainage problems, which cause seasonal flooding.

Less management-induced soil variability. Much of the Pampas is characterized by large fields that have only recently been converted from pasture rotations to continuous cropping. In most places management-induced variability is less than it would be in Europe or North America. There are few former fence rows, old lanes or feedlots. Fertilizer use is relatively new in Argentina. There has been little opportunity to create soil fertility patterns through the application or misapplication of fertilizer. INTA officials and crop consultants involved in precision agriculture argue that Argentina has more natural soil variability than the U.S. The natural soil variability in Argentina is substantial, even on the flat, apparently homogenous Pampas, where characteristics like salinity and small differences in topography can greatly influence yields.

Currently, many farms in Argentina use no fertilizer at all given the current relative prices. Even the well managed, highly capitalized farms use rates that are low by U.S. standards, on corn 35-65 kg per hectare of nitrogen (N) and 20-45 kg per hectare of P_2O_5 on soils of 1-3% organic matter and Bray Phosphorus (P) tests of 6-15 ppm. Normal values of Bray P tests should be 20-25 ppm (García, 2001). According to García (2001), farms are losing between 1.7 and 4 ppm every 3 years. This does not provide much opportunity to profit from cut backs or reallocation of fertilizer. Fertilizer consumption in Argentina has notably increased in the last ten years from 300,000 metric tons in 1991 to more than 1,800,000 metric tons in 2003. However, nutrient balance is still negative for soils of the

Pampas. Recent estimates show replenishment levels of 25-30% forN, 45-50% for P, 7-10% for Sulfur (S) and less than 1% for potassium (K), being almost nil for other essential nutrients (García, 2003).

Widespread use of custom operators. In Argentina farm management and equipment operation are often separate enterprises. Many farm operations, including planting, are done by custom operators. Many producers own almost no equipment. Harvesting is often done by crews similar to the custom cutters that operate in the U.S. Great Plains and paid with a percentage of the harvest, often 8% or 9%. For yield monitoring, custom harvesting can pose a problem. Combine operators are often employees of the custom harvesting business. They often have only a grade school education and have never used a computer. They are motivated to harvest as much grain as they can, as quickly as possible. They are not necessarily motivated to collect good data. A few custom harvestors have seen yield mapping as an extra service that they can provide their clients. Even if no added fee is charged for yield mapping, it cements long term relationships with clients. Custom operators also like having an estimate of harvest quantities from the yield monitor, which is independent of the farm scales or the grain dealer. Therefore, there are several incentives that are prompting its adoption. At some point in time data management will become a challenge for both, custom operators and farm managers, when it comes to transforming information into knowledge, and to transform that knowledge into management decisions. Effort is being made by INTA Manfredi and by local input suppliers to offer training courses for operators.

Training agronomists and farm managers to gather useful site-specific information. Site-specific agricultural technologies make possible the precision application of fertilizers and other inputs. However, a key information gap lies between the precision mapping of soil characteristics and the precision application of inputs. That gap is the fertilizer recommendation. Recommendations are typically based upon large-scale regional research that has been synthesized across many sites. By design, state- or regional-level agronomic recommendations omit local site characteristics, which undermines their suitability for guiding site-specific input applications (Swinton et al., 2001).

Few resources for local research to adapt technologies to Argentine conditions. Neither INTA nor the Universities have the necessary budget for research in precision agriculture. All the research carried out so far is possible through the collaboration of commercial companies, and of the top farm managers that are willing to do on-farm trials.

V. PROSPECTS:

Rapid adoption of yield monitoring. The most successful application of precision agriculture has been yield monitors. The monitors provide information on something that farm managers are passionately interested in: crop yields. From field testing of a few units in 1996, yield monitor use has grown rapidly (Lowenberg-DeBoer, 2000). New combines already come with a yield monitor installed or optional, which provides large farm managers who own 40% of the large combines, with a direct way to measure productivity of the fields they farm. Custom harvestors own 60% of the new large combines, and they see yield monitoring as a way to increase customer loyalty.

Rapid adoption of GPS guidance. Guidance systems for agricultural chemical applicators are the fastest growing precision agriculture technology, because they are easy to use and because the benefits are immediate.

Lag in VRT. We expect the use of VRT in Argentina to grow slowly because of the high cost of soil sampling, low management-induced variability and current low rates of fertilizer use. Crop consultants and farm managers cite soil laboratory analysis fees ranging from USD 20 to USD 40 per sample for a complete soil analysis, as compared to around USD 6 per sample in the U.S.A., which makes unfeasible the grid sampling approach. In the U.S.A. there is a large volume of samples and the labs can justify owning equipment for inductively coupled plasma-membrane analysis (ICP), which has a high initial cost (USD 125,000 in the U.S.A.), and high maintenance costs due to the price of consumables and the need for trained technicians. Laboratories using ICP enjoy economies of scale because they provide services nationwide (sometimes worldwide), and because in addition to soil tests, they use it for water analysis, detection of pollutants in the air, etc. In Argentina (and Australia as well), the volume of samples has been low and so they use more expensive manual lab testing methods. Those costs are prohibitive for grid sampling of the type used in the U.S.A. Even for a guided sampling plan with larger management zones, the cost would be quite high.

Challenges. Some key challenges for precision agriculture in Argentina include:

Training combine operators to collect high quality data. In response to this problem INTA Manfredi has already offered fifteen courses for combine operators so far, and is planning two more for 2005. Bragachini (2005) says that he hopes to convey the message that combines are harvesting data as well as grain, and that the data is valuable. The challenge is to build in a price incentive for the system to really work.

Training ag-economists and agronomists to carry out profitability analysis of VRA. Yield monitors have been in the market for almost 10 years, but everywhere it has proven difficult to link yields to crop conditions (e.g. soil tests, input application, topography). Profitability analysis often indicates that fertilizer VRA is not profitable. One hypothesis is that the whole field recommendations used to make VRA do not reflect site-specific response differences. Because the economics of precision agriculture are site-specific, analyses are needed in Argentina.

Interpreting data is a challenge everywhere precision agriculture is used. In Argentina there may be a special challenge in helping farm managers who do not spend hours in the tractor or combine seat to understand the variability of their fields. An additional challenge is adapting on-farm research designs. On-farm research methods developed in the U.S. may not transfer directly. For example, in the U.S. split planter designs work well for corn because many producers have corn heads that are exactly half the width of their planters. This is not the case in Argentina. On-farm research design need to be developed to fit Argentine equipment and the questions that producers there ask.

Adapting VRT to Argentine conditions will probably require finding ways to make use of low cost data, instead of heavy reliance on grid soil sampling. This low cost data might include: yield maps, topographical maps, satellite images, aerial photographs and eventually remote sensing and soil sensors.

Developing a local precision farming research base will probably be the most important challenge for Argentine agriculture. Precision farming technology developed in North America or elsewhere will need to be adapted to Argentine conditions. In the past Argentine agriculture has relied heavily on borrowing North American technology. For precision agriculture borrowing may not be entirely successful, because both the agronomics and economics of precision agriculture are site

specific. As in North America, a combination of private sector and public sector research will probably be necessary to help precision technology fulfill its potential in Argentina.

ACKNOWLEDGMENTS:

Authors would like to appreciate anonymous reviewers, as well as Cristiano Casini, Ph.D., Coordinator of the Department of Crop Production, INTA Manfredi, Argentina, for their contributions to the manuscript.

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