Although many people have sometimes heard about it, not everyone exactly knows what PA is and what it is not. Talking to farmers, one realizes that there is still confusion about PA, resulting in important misconceptions. That would explain why many farmers still consider it too risky, complicated and expensive, and are reluctant to the adoption of new technologies and to change the way they manage their farms. In some cases it may also not be advisable to move to PA. But in many other cases, farms could benefit from a more efficient use of productive inputs if PA techniques were adopted.

**MAIN PURPOSE: THE RATIONAL USE OF AGRICULTURAL INPUTS**

As the practice of PA largely refers to the rational use of agricultural inputs, it is interesting to start with a simple example about fertilizing. In a technified and modern agriculture, fertilizers are applied uniformly by distributing identical rates regardless of the location within the field. Moreover, advanced farmers perform the operation avoiding unnecessary overlays, for example, using satellite-based guidance systems (Global Navigation Satellite Systems) for controlled traffic farming. However, contrary to what one might think, this way of distributing fertilizers is not exactly PA. Here is the reason. Those same farmers are aware that often yield is not uniform throughout the field or in different seasons despite the even distribution of inputs, and spatial and temporal variation is to be expected. In other words, they are not surprised by the discordance between the uniform and ‘precise’ application of fertilizers and the variable spatial and temporal pattern of crop yields within the plots. Two consequences are immediate, i) fertilizer use is inefficient both from the agronomical and economical points of view, and ii) adverse effects can be produced on the environment by over-fertilizing low productive areas.

**Figure 1: Evolution of scientific documents indexed in Scopus containing any combination of Precision or Smart with Agriculture or Farming.**

Scopus is a database indexing most of the peer-reviewed scientific literature published in scientific journals, books and conference proceedings. The combination harvesting more records is, by far, Precision Agriculture (fivefold). That, together with the name of the International Society of Precision Agriculture, makes us opt for referring to all these techniques and methodologies as Precision Agriculture.

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**THE PRECISION AG CORNER**

In recent years, the term Precision Agriculture (PA) has been referred and discussed many times in agricultural exhibitions and conferences, professional meetings, magazines and cafes. Other forms are also used either by specifying the crop where it is applied, e.g. Precision Viticulture, or by using fancy names such as Smart Agriculture, Smart Farming or Digital Agriculture. In the academia, the evolution in the publication of scientific documents containing the terms ‘Precision Agriculture or Farming’ or ‘Smart Agriculture or Farming’ has been astonishing, starting with 0 documents in 1995 to more than 2,250 in 2015! The practice of PA largely refers to the rational use of agricultural inputs. To help us run our PA section in the magazine, New Ag International has partnered with one of the leaders in Europe: The Research Group on AgroICT & Precision Agriculture (GRAP) of the University of Lleida-Agrotecnio Center in Catalonia, Spain. In every issue of the magazine, Alexandre Escolà, Jose Antonio Martínez and Jaume Arnó with our Editorial Team will put together an editorial whose ambition is to help the various stakeholders bridge the gap between datanomics and commercial farming!

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The authors, from left to right: Dr Alexandre Escola, Dr Jose Antonio Martínez and Dr Jaume Arnó, University of Lleida.
potential areas. Therefore some farmers are applying different rates according to the expected yield in the different areas within the field to make fertilization more efficient and prevent fertilizer waste. That is really PA! Modern spreaders with positioning systems and electronic rate control may certainly help implementing this type of actions. Nevertheless, machinery alone will not solve the problem. It will be necessary to collect data on the crop and/or the soil, convert it into useful information and then make the proper decision on the best fertilizing plan. This way of farming can also be extended to sowing, application of pest protection products or irrigation, among other operations. In short, PA begins to make sense when crops are affected by a spatial and temporal variability that occurs within the fields, and actions of farmers are intended to correct or adapt to such differences.

DETERM INING SOIL VARIABILITY

Farmers are aware that soil may vary within the same plot. Depending on the terrain and/or the parent material, soils can be deeper or shallower, clay or sandy, or be affected by higher or lower salinity. Yield is mainly influenced by these soil variations, given the soil-plant interaction. Those variations can be found at different spatial scales and crop yields may reflect them within single plots, even if those plots are small in size.

To know what is the variability attributed to the soil, soil sampling and mapping is required. There are many strategies to sample soils. Besides systematic grid soil sampling, targeted sampling is a good practice, and it is performed according to areas that could have been previously defined with the aid of yield maps. A balance is to be found between a representative number of samples and its cost. An alternative gaining acceptance is the use of on-the-go soil sensors. As they are continuously sampling the soil, the result is an increase of the spatial sampling resolution. Electric conductivity (EC) is the more commonly measured soil property. Its interest lies in that EC is usually well correlated with soil properties such as texture (clay), moisture content or salinity. Since these properties affect yield potential, information provided by soil sensors can then be displayed in the form of suitable EC maps to delineate areas requiring different management practices. Moreover, overlapping yield and EC maps provide with a better under-

Figure 2: The cycle of Precision Agriculture. PA can be reduced to 4 stages. The first one consists in gathering as much data as possible about the crop, soil, terrain and all their environment. The output at this stage is data to be processed during the information extraction stage. Once data is converted into information, it is time to make management decisions. The output at this stage are prescriptions to be implemented at the last stage. The arrows around the cycle are possible inputs required at each stage. When information and prescriptions are displayed as maps and the cycle takes several days to be completed, that is the case of the so-called map-based Precision Agriculture. When information is not mapped and the cycle is completed in some milliseconds, it is the case of real-time sensor-based Precision Agriculture.

Figure 3: Potential management classes within a plot based on the analysis of acquired data from proximal and remote sensors. Top (left to right): Grain yield map derived from a yield monitor (Ceres 8000, RDS Precision Farming System); Soil apparent electrical conductivity map from data acquired with a resistivity sensor (Veris 3100, Veris Technologies); Normalized Difference Vegetation Index derived from a Sentinel-2A multispectral image. Bottom (left to right): Digital elevation model.
An Interview with...

Nicolas Tremblay, president of the International Society of Precision Agriculture (ISPA)

Dr. Nicolas Tremblay, agronomist, has a PhD in Plant Biology from Laval University in Quebec City, Quebec, Canada. He conducts research on crop nutrition and management at the Agriculture and Agri-Food Canada Saint-Jean-sur-Richelieu Research and Development Centre. His program includes studies on the variable rate management of nitrogen applications involving remote sensing, geomatics, geostatistics and meta-analyses. Dr. Tremblay is the current President of the International Society for Precision Agriculture (ISPA).

have proven more difficult to live up to expectations. Variable rate applications and zone sampling are among those. The difference in adoption rate is related to their effective impact on farm operations. In general, the PA technologies that have been successfully implemented are the ones solving pure “technology” problems, like driving unattended on predefined lines (auto-steering). However, as soon as the outcome of the technology has to deal with the functioning of the complex soil (including microbes)-plant-atmosphere (changing weather) continuum, it is much more difficult to obtain the desired impacts. Take variable nitrogen rate application for example. The amount of N you need to decide upon is a function of the amount of air and water that the soil contains in various horizons, the mineralization performance of the microbes naturally releasing N from organic matter, the future amount and spread in time of rainfall that will happen in the coming weeks and the previous crop, just to mention a few. Facing such complicated systems, there is a need to aim for the factors that are truly limiting our ability to achieve the desired impacts. It may be relatively easy to measure vegetation status at high spatial resolution for example. But if this is only a little piece of the jigsaw puzzle we need to make up, we need to understand other components that may be less easy to assess but more critical to the desired outcome. Otherwise our ability to effectively reconstruct the picture will never emerge to an acceptable level.

There are important gaps between academia, industry and farmers. What is the ISPA role in bridging those gaps? All these folks have their jobs to do. But the real way to achieve global success is when the three groups work together in mutual understanding. I would dare to say that scientists have the key to future PA adoption and impact subject to their ability to acknowledge the limits of their own studies and consider the components that will allow the producer to adapt the conclusions to his own reality. In other words, scientists should pay more attention in the future on understanding the contextual factors that determine the success or failure of what they propose. The current problem is that too much reward is being given to scientific publications and not enough to effective adoption of research results by the end users. ISPA is the perfect network for scientists to share their results and experiences. ISPA has been the first to establish itself in what is now a booming area and it is our responsibility to play a leadership role.

When small or medium farmers hear about PA some immediately say that it is not for them, that it is only useful in big farms in highly developed countries.

What would you tell them? Do you think that companies dealing with PA technology should explore the potential of PA in medium or small farms?

Precision agriculture is not just about getting the last expensive sensor, gizmo or piece of machinery. Yes, it is important to make adjustments in space but coarse resolutions may be good enough to bring about important improvements in management practices for producers who cannot afford to consider the latest technology. But there is also another essential component of precision agriculture that can help smallholders: the temporal one. Farming is a risk management business largely controlled by weather and climatic events. If “precision agriculture is a management strategy that uses a wide range of technology to gather and process data for the purpose of guiding targeted actions that improve the precision, efficiency and productivity of agricultural operations”, much of it can be funneled through smart phones that are already ubiquitous. I have been impressed by the work done in Africa by which computation methods are used to help support decisions through smart phones for improving integrated pest management interventions by local farmers. Farmers
from Nigeria, Ethiopia and Tanzania have their information processing done in Nairobi, Kenya. I am sure that we will see more and more such applications of precision agriculture wisdom influencing smallholders in improving their real time decision making. These will be based mostly on the retrieval and treatment of cumulative and forecast seasonal weather data overlaid on available digital soil maps in the background. Artificial intelligence or other suitable models will be used to propose the smartest decisions to farmers based on their own fields or seasonal features. Much productivity can be gained by targeting the many medium or small farms. Governments should pay attention to precision agriculture for smallholders as a way to quickly improve the productivity and profitability of their agricultural sectors.

We have recently seen an important increase of companies developing PA hi-tech products for machinery. What is the role of companies producing and distributing agricultural supplies such as pesticides, fertilizers, biostimulants, micronutrients, etc. in PA? Should they adapt their products and/or strategies to the PA needs? How? It is getting more and more difficult to put “silver bullets” on the market. Companies do a great job in developing new products that may (or may not) live up to their promise at the user level. Precision agriculture is about personalization. Hi-tech companies should consider using PA data sources to document the soil-seasonal conditions that are allowing their solutions to work effectively, and establish what is needed at the user’s level to guarantee success. This can be done at the product development level, but also at the on-farm trials stage. It is important to achieve testing in a diversity of conditions and to get not only the data (results) but also the metadata (soil-seasonal-management records). With sufficient data and metadata accumulated and processed, the conditions for proper use of the new products can be established and used for effective adoption and user satisfaction.

In addition to a certain amount of technology, PA requires new experts turning the huge amount of available data into information and information into useful decisions. However, PA education is still incipient. Are those experts already in the market? Is PA education and training properly addressed? Precision agriculture has a great future because it is the future of agriculture. The digital revolution is there in many sectors of our lives and there is no reason why agriculture should pass by this opportunity. There is a great demand for data management specialists in oceanography, astronomy, social sciences, just to name a few. The face of the world is changing fast - and the job marketplace with it. The ability of precision agriculture technologies to measure and document the performances of agricultural operations sometimes challenges traditional concepts. I like the idea that precision agriculture is about the proper management of the G x E x M (genetics x environment x management) interaction. Historically, each part was addressed as a silo. However, it is becoming clear that solutions for agriculture are more in the interactions than in each individual component of this relationship. The precision agriculture sector is badly in need of experts that have a strong background in agronomy, biology, data sciences and statistics who would be able to understand the big picture. The opportunities for universities are there to make the move. Some of them are heading in the right direction but the industry is evolving so fast that the whole adjustment process will take time.

What are the principal challenges of PA in the coming years? In the coming years, access to commercial farm datasets will become critical. Scientists can easily get data from the one or two experimental farms which they normally have at their disposal but, in a precision agriculture framework, this is not enough. As seasonal and soil considerations impact so much the outcomes of field studies, the only way to make quick and reliable progress is to access data from numerous places in a “big data” type of toolbox. This is the reason why we should encourage producers to make their data available to researchers through mutually beneficial agreements. That’s the only way they can help us to help them with this future where precision agriculture will become ubiquitous. Precision agriculture has the potential to change the performance of the crop and livestock sectors for the better. It is every stakeholder’s responsibility to make this happen.

**YIELD MAPS TO ANALYZE THE SPATIAL VARIABILITY**

One of the ways to start implementing PA is through yield maps. Yield mapping is now feasible for many crops i.e. cereals, forage crops, vineyards and some horticultural crops. Farmers can gather yield data at harvest and use it to create yield maps as a tool to analyse the spatial variability of their plots. There is a variety of software for the creation and visualization of maps, being Geographic Information Systems (GIS) or GIS-based programs an interesting option to store and process the acquired yield data. Once yield maps are obtained, farmers and advisors have to turn that information into management decisions to deal with the spatial and temporal variability of their crops. The yield variation pattern is critical at this stage. When this pattern is well structured, different areas can be defined within the plot for specific management strategies. However, it is necessary to know the causes of such variability to take the best management decision before conducting any action. Yield maps show the effect of a number of parameters affecting the crop yield together with the consequences of the farmer management.

**SENSING CROP VARIABILITY AND NUTRITIONAL STATUS**

Using remote sensing involves sensing and processing spectral information, e.g. the visible and near-infrared reflectance, from soil and crop canopies to obtain adequate vegetation indices (VI), such as the NDVI (Normalized Difference Vegetation Index). Both leaf crop development (biomass production) and chlorophyll con-
In PA there are two key aspects to consider before taking any decision: the magnitude of variability and its spatial pattern. When there is no or little yield, EC or NDVI variation throughout a plot it is unreasonable to implement PA solutions. Similarly, a situation with a poor spatial structure makes it very complicated delimiting homogeneous areas to be managed by agricultural machinery equipped with variable rate technologies (VRT). Farmers are then required to manage and interpret information reflected on the maps, individually or in an overlaying combination. Then, they should pay special attention to the two aforementioned components of spatial variability to assess the opportunity to implement PA. Once variability presents a reasonable magnitude and a structured spatial pattern, it is time to consider a site-specific crop management (SSCM).

Making the right decision is an important issue because productivity, economic benefit and sustainability in the leaves are indicators of the nutritional status of the crop and both can be detected using remote sensing. That is the reason why VI are especially useful in assessing within-field variability and check possible nutritional deficiencies or growth problems.

In a way, any agricultural practice based on crop properties expressed in VI is somehow also considering the soil spatial variation, given the soil-plant interaction discussed before. From soil, yield and crop data, farmers can retrieve very interesting information to share with advisors and suppliers of agricultural inputs to define a plan that suits the spatial and temporal variability of their fields. All these data (or some of them) are the starting point to begin implementing PA. From data to information and from information to knowledge. Last stage of PA is turning knowledge into better farm management decisions.

GOING FOR IT OR NOT DEPENDS ON THE MAGNITUDE OF VARIABILITY AND ITS SPATIAL PATTERN

In PA there are two key aspects to consider before taking any decision: the magnitude of variability and its spatial pattern. When there is no or little yield, EC or NDVI variation throughout a plot it is unreasonable to implement PA solutions. Similarly, a situation with a poor spatial structure makes it very complicated delimiting homogeneous areas to be managed by agricultural machinery equipped with variable rate technologies (VRT). Farmers are then required to manage and interpret information reflected on the maps, individually or in an overlaying combination. Then, they should pay special attention to the two aforementioned components of spatial variability to assess the opportunity to implement PA. Once variability presents a reasonable magnitude and a structured spatial pattern, it is time to consider a site-specific crop management (SSCM).

Making the right decision is an important issue because productivity, economic benefit and sustainability...
tainability are dependent on proper farm management. Let’s see how information derived from sensor data is of great interest to optimize the distribution of fertilizers or other productive input, for instance. Proved the spatial variation of yield (magnitude and pattern), and once different areas have been defined within the plot, the farmer is then faced with the difficult position of deciding what dose is to be applied in each zone. If targeted sampling has been conducted to understand the causes of yield variability, fertilization can be optimized depending on the sampling results. If yield variation is mainly explained by deficiency of certain nutrients in the soil, variable rate fertilization should aim to correct this imbalance, expecting similar yield to be obtained throughout the whole plot. It is reasonable that the farmer does not get uniform yield in a single season, but repeating this strategy medium or long-term returns may be reported. However, in plots where the soil is a limiting factor for the productive potential (e.g. due to soil depth differences or texture constraints), rates should be adapted to different expected yields for each area. In both cases, site-specific fertilizer application is set to a limited number of areas or classes within the plot, and we refer to this practice as class-specific crop management or map-based PA. Decision support systems (DSS) are very useful for the farmer at this point.

**THE CHALLENGE: GETTING THE RIGHT ANALYTICAL TOOLS**

Supply companies may be required to fill this gap in terms of providing the farmer easy tools to manage productive resources according to the within-field variability. This is one of the current challenges to achieve a major adoption of PA. Another possibility is to opt for a map-based fertilization where only nutrients removed by the crop are returned to the soil. This site-specific fertilizer application results in what is called a site-specific maintenance application. Something similar may arise with micronutrients, and there are voices announcing the possibility that the removal of micronutrients by the crop can be satisfactorily recorded via yield mapping.

Distributing inputs based on prescription maps is easier with agricultural machines equipped with VRT. GNSS and variable rate systems are well advanced, and the industry keeps developing new concepts and equipment for this purpose. At the same time, the possibility of storing data on the equipment operation allows the farmer to control the quality and traceability of field actuations. The latter provides with very interesting feedback information for subsequent seasons. An important aspect is the need to build a prescription map of the input to be applied matching the specific needs of each location in the plot. This map is built prior the application, and completes a temporal cycle that began with the acquisition of data and continued with subsequent analysis and decision making stages. Depending on the input, the time taken to complete
the cycle may correspond to the crop cycle. However, real-time application of nitrogen and herbicide is another possibility to implement. In such cases, actual rates are decided ‘on-the-go’ while the application is been performed. In these systems, crop data is acquired by specific sensors and are immediately transferred to an electronic controller that decides the application rates without the need of using maps. Today, the time the whole cycle takes is only some milliseconds! A third option would be the fusion of both possibilities, operating in a macro approach according to prescription maps (base rates) and with real-time sensors in a micro approach to adjust the final application rates.

### Glossary of Terms

**Precision Agriculture (PA):** As PA is a very transversal discipline many different definitions can be found according to the different approaches. We list here some of them.

- Applying agricultural resources at the Right time, in the Right amount, at the Right place (Robert et al.), using the Right source (IPNI) and in the Right manner (Khosla).
- The use of new information technologies together with agronomic experience to site-specifically i) maximise production efficiency, ii) maximise quality iii) minimise environmental impact and iv) minimise risk (McBratney and Taylor).
- Observation, impact assessment and timely strategic response to fine-scale variation in causative components of an agricultural production process (McBratney and Whelan).
- The application of technologies and principles to manage spatial and temporal variability associated with all aspects of agricultural production for the purpose of improving crop performance and environmental quality (Pierce and Nowak).
- An integrated information- and production-based farming system that is designed to increase long-term, site specific and whole farm production efficiencies, productivity, and profitability while minimizing unintended impacts on wildlife and the environment (U.S. House of representatives)
- A systems approach to managing soils and crops to reduce decision uncertainty through better understanding and management of spatial and temporal variability (Dobermann et al.).
- A ‘whole-farm’ management strategy based on the use of data and information technologies with the aim of obtaining higher production efficiency and sustainable profitability while minimizing environmental impacts (the authors).

**Global Navigation Satellite Systems (GNSS):** Generic term used to describe global coverage systems to determine the location on the earth’s surface of a receiver (longitude, latitude and elevation) through the reception of radio signals from satellites.

**Decision Support System (DSS):** A computer-based system that integrates data with expert knowledge and feedback from previous seasons to assist in making management decisions.

**Site-specific crop management (SSCM):** A way to implement PA applying agricultural inputs according to the varying requirements of soil and crops within the field.

**Potential Management Classes (PMC):** The different areas within a field likely to receive different management practices or dose rates because they have different yield potential or environmental requirements. Two, three or four classes are generally defined, although the same class may be fragmented into several management zones throughout the field.

**Variable-Rate Application (VRA) using Variable-Rate Technologies (VRT):** The variable adjustment of inputs to match the needs within the plots (VRA) using farm machines equipped with variable automatic control devices (VRT). Although VRT may ease VRA from prescription maps, it is still possible to implement VRA with conventional machinery if management zones are properly designed.