The last stage in the Precision Agriculture (PA) cycle is implementing the decisions made in the fields or orchards. From the first Precision Ag Corner (New Ag International 64, in Nov-Dec 2016), we described the different stages, equipment, techniques and methodologies to make more informed management decisions. Whenever a non-uniform management strategy decision is made, site-specific management solutions are to be considered. In this issue, we review the different available options to put PA into practice either using conventional machinery or using hi-tech equipment, known as Variable Rate Technologies (VRT). Additionally, new trends are also depicted for future agricultural practices. New Ag International has partnered with the Research Group on AgroICT & Precision Agriculture (GRAP) of the University of Lleida-Agrotecno Center in Catalonia, Spain. In every issue of the magazine Alexandre Escola, Jaume Arnó and José A. Martínez-Casasnovas, with our Editorial Team, are putting together an editorial whose ambition is to help the various stakeholders bridge the gap between datanomics and commercial farming!

MAP-BASED vs REAL-TIME SENSOR-BASED PRECISION AGRICULTURE

Before getting into the last stage of the PA cycle, the operation in the field (Fig. 1), we need to recall the principal ways to implement PA. Map-based PA uses maps to display the spatial variability of the observed or sensed parameters (Stage 1). Once the different maps are created by using interpolation processes (Stage 2), they have to be combined to end with a prescription map (Stage 3) to be implemented in the field (Stage 4). A prescription map is a map of the field showing the dose rate or the intensity of a site-specific management (SSM) operation (seeding, fertilization, irrigation, tillage, crop protection, etc.). The time needed to complete the whole PA cycle may range from some days to some weeks, depending on the data acquisition and processing, allowing other data sources and ancillary data to be considered in the decision making process.

In real-time (RT) sensor-based PA, a sensor or a combination of them are used to take on-the-go continuous readings (Stage 1), extract information (Stage 2), make decisions (Stage 3) and implement them on a RT basis (Stage 4). The time it takes to go through the whole cycle is only some milliseconds! In such a short time, there is obviously no possibility to create maps or combine different data sources to make complex decisions.

Consider the application of plant protection products to an apple orchard. In a map-based PA approach, a system to monitor the canopy volume could be used to create canopy volume maps of the orchard (e.g. using a LiDAR-based mobile terrestrial laser scanner). From the canopy volume maps, management zones could be delineated according to different canopy volume classes. A decision on the flow rate to be sprayed in each management zone could be subsequently made to warrant the right dose rate (i.e. the amount of active ingredient to be applied). In a high-tech approach, a variable rate sprayer using a global navigation satellite system (GNSS)

Figure 1: Last stage of the PA cycle: operation in the field.
receiver would then be required to determine its position within the map, obtain the flow rate to be sprayed from it and self-adjust to deliver the desired dose rate using variable rate technologies (VRT).

On the other hand, in a RT sensor-based approach the sprayer would be equipped with a sensing system providing with RT continuous canopy volume measurements that would be subsequently translated into a flow rate to be sprayed by the self-adjusting variable rate sprayer. In this case there is no need to use a GNSS receiver since the operation is performed in the same place and at the same time the canopy is monitored.

There is still a third approach: the fusion of the previous two. Imagine you have a prescription map with different management zones with specific dose rates assigned to each one. Imagine you are spraying the dose rate assigned to a zone and, all of a sudden, a tree is missing. The variable rate sprayer would keep spraying the assigned flow rate resulting in a waste of money and higher contamination risks. The solution is equipping the sprayer with a canopy sensing system able to switch the sprayer off when there is no tree in front of the nozzles. In this situation, the prescription map provides a macro approach while the sensing system may refine it in a kind of a micro approach.

One of the pros of map-based PA is that the exact amount of the agricultural input can be determined a priori, as it can be derived from prescription maps. This allows the right amount of fertilizer or pesticide mixture to be prepared or bought to avoid having remnants at the end of the operation. As a negative aspect, map-based PA may require knowledge on GNSS, geostatistics and GIS. On the other hand, RT sensor-based PA does not require using maps and GNSS receivers to build them or to extract information. There is no need to use GIS or geostatistics, either. However, the amount of inputs to be applied is not known in advance and the farmer will probably have remnants at the end of the operation that they will have to get rid of.

### MYRIAD POSSIBILITIES WITH VRT

Whatever the approach, when the decision is non-uniform SSM, the equipment used must be able to adapt its performance to the variability in the field. When field variability is well structured and following clear and simple spatial patterns, conventional machinery could be used, adjusting the output rates manually according to the prescription map. Nevertheless, when field variability is high and no simple spatial patterns are found, hi-tech variable rate equipment able to self adjust to meet the desired rate needs to be used. VRT may be implemented in fertilizer spreaders, sprayers, seed drills or centre pivots. Such implementations need to be equipped with controllers, actuators and sensors. The controllers are responsible for the use of GNSS data to extract set points (output rates) from prescription maps, in a map-based approach, or to acquire and translate sensor readings into set points in a RT sensor-based approach. Besides, they generate control signals to be sent to the actuators to adjust the equipment to apply the desired output rate established in the set point. Actuators are usually valves, motors, cylinders, conveyors, pressure regulators, etc. Finally, the boarded sensors are responsible for monitoring the performance of the implementation and its accuracy in delivering the output rate in what is usually a closed-loop control. The aim of VRT is varying the output rate in agricultural equipment. However, the variation of output rates can be done in different ways and for different purposes. The different possibilities of VRT are listed in Figure 2. The simplest dose rate variation is called selective application and consists in ON/OFF applications. In selective applications, whenever an agricultural input is to be applied at a specific location according to SSM prescriptions, it is applied at full dose rate. Thus, possible rates are 100% or 0%, nothing in between. Selective application is also known as patch or spot application (e.g. patch or spot spraying) since the inputs are only applied at specific locations at full rate (ON) and are not applied in the rest of the field (OFF). Selective of patch applications may be derived from either map-based or RT sensor-based approaches.

Typical examples of RT sensor-based selective application are WeedSeeker (Trimble Ag) and WEEDit, used in site-specific weed control. The two systems are based on optical sensors emitting and receiving red and near infrared (NIR) light, so that their controllers can calculate the normalized difference vegetation index (NDVI=(NIR-RED)/(NIR+RED)) in a continuous way. Their use is intended for bare soil or stubble field situations, where no green plants are to be expected and NDVI values are to be very low (<0.3). Once a threshold is established, NDVI readings over the threshold mean presence of weeds and trigger a fast reacting solenoid valve allowing a full herbicide dose rate to be sprayed with a nozzle. These solutions are an alternative to the traditional blanket spraying method and drastically reduce the amount of chemicals sprayed. Their profitability depends on the cost of the systems (which is usually high), the cost of the herbicide and the savings, which are related to the presence of weeds, their spatial distribution and the area covered. WeedSeeker needs a sensor for each nozzle and its manufacturer claims driving speeds up to 16 km/h or even to 32 km/h and reductions of herbicide costs up to 80%. Alternatively, each WEEDit device controls 5 different nozzles and can reduce chemical costs up to

![Variable Rate Technology possibilities.](image)
90%, driving at speeds up to 25 km/h, according to the manufacturer. Both systems can be retrofitted onto existing sprayers. An equivalent map-based selective ON/OFF application would require a weed distribution map to be obtained before the herbicide application. Such maps can be created from data acquired by UAV equipped with RGB cameras, by scouting and visual georeferenced observations or by other means included in Stage 1 of the PA cycle (data acquisition). Once the map is created (Stage 2), a decision is to be made on where to apply and where not to apply herbicide on an ON/OFF basis in the form of a prescription map (Stage 3). The operation in the field requires the sprayer to be equipped with a GNSS receiver and a controller capable of extracting information on whether to spray or not according to its location in the field. Other map-based possibilities could be the other way round: that is, instead of spraying in the intended locations, preventing spraying in undesired locations. Moreover, the same would apply to other management operations: fertilizing, seeding, irrigating, etc. The size of the minimum management zone unit is related to the minimum controlled working width. For instance, a selective sprayer with non-independent sections would only be capable of switching ON and OFF the whole boom. Thus, the minimum width of management zones in the prescription map will be the sprayer working width. However, if a sprayer could control its different sections, the minimum zone width would be the length of a section. Moreover, if the spray were capable of switching ON and OFF individual nozzles, then the minimum zone width would be around 50 cm. In the case of a seed drill, an example of what is possible to achieve with a map-based ON/OFF precision single seed drill with individual seed units control is shown in Figure 3.

As previously stated, VRT allow the output rate of equipment to be automatically and continuously adjusted. However, not all VRT solutions are to be strictly considered PA. Some sprayers, fertilizer spreaders and seed drills are capable of automatically switching off to avoid overdosing when overlapping an already treated area, on an ON/OFF basis. This technology is known as swath or section control. For this purpose, such implements use GNSS receivers and controllers to register the areas in the field being treated. Before applying any input at a certain location, the controllers make sure the area has not been treated yet. If so, the controllers send a control signal to the actuators to prevent spraying, fertilizing or even seeding the same area twice. While this is indeed a precise operation of the equipment, these technologies are not exactly PA although they really contribute to make agricultural operations more efficient and sustainable. The same applies to GNSS-based guidance and to ISOBUS. One of the most representative examples of these technologies is maize single seed drill with individual ON/OFF control of seeding units (Fig. 4). Apart from selective ON/OFF solutions, some sprayers, fertilizer spreaders and planters are capable of continuously varying their output rates in a continuous way according to forward speed variations in order to obtain a uniform dose rate in the field. Although output rates may continuously vary from 0 to 100% of the full rate, the purpose is not adapting the rates to the field variability but to achieve a constant blanket application throughout the field. Other VRT related to map-based or RT sensor-based PA are those varying the output rates in a continuous way to match the field variability. In this case, output rates can take literally any value ranging from 0% to 100% of the full rate, although certain commercial solutions are only capable of adjusting some discrete outputs such as 0%, 25%, 50%, 75% and 100%. Typical examples of RT sensor-based PA with continuously variable rate are nitrogen fertilizer spreaders equipped with optical sensors. The sensors measure the reflectance of the crop at specific wavelength for the controller to calculate different vegetation indices directly correlated with its fertilizing status or vigour. Then, the controller in the spreader translates the index value to the corresponding fertilizing rate according to a pre-programmed model or to an in situ calibration. The latter is usually done by asking the farmer to conventionally fertilize a field strip with the optimum dose rate. Before applying the fertilizer in the entire field, the VRT spreader scans the field strip and assigns the sensor readings the optimal crops status and, hence, the minimal nitrogen dose rate. Any area in the field with lower vigour readings will receive a proportionally higher fertilizer rate. Examples of commercial sensors and systems for RT sensor-based

![Figure 3: Example of what can be done with a map-based ON/OFF single seed drill (www.raderfamilyfarms.com/activities/corn-mazes).](image)

![Figure 4: Maize plants seeded without swath control (left) and with swath control for individual seeding units (right).](image)

continues on page 34
An interview with Brian Magnusson, Vice President, Technology & Innovation, Lindsay Corporation (USA)

Lindsay Corporation (NYSE: LNN) is a leading global manufacturer of irrigation and infrastructure equipment and technology. Lindsay manufactures agricultural irrigation systems and technologies covering 4.8 million hectares in over 90 countries, through its worldwide network of more than 350 dealers. Lindsay also offers irrigation consulting, design, pump and filtration solutions, advanced machine-to-machine communication, remote control and monitoring technology, and wireless networking solutions.

What is, in your opinion, the potential of Precision Irrigation (PI) in the framework of Precision Agriculture (PA)?

As the world marches towards a population of 10 billion people by 2050, a roughly 30% increase from today, Precision Irrigation will be a critical enabler helping producers around the world feed this growing population base. Water availability has the single biggest impact on crop yield potential, and ensuring the right amount of water is applied at the right time is where Precision Irrigation comes into play.

Precision Irrigation, as the name implies, is the precise application of the optimum amount of water at the ideal growth stages in the right locations throughout a growing season. Too little water or application of the water at an unideal growth stage will reduce yield potential; however, applying too much water can have the same yield-reducing impact and waste precious resources such as fresh water, nutrients and energy. Researchers around the world have spent 50-plus years studying the impact of various irrigation management practices and publishing reports describing how producers can apply these best practices. Until only recently, these practices were often difficult to understand, expensive to implement and/or too time consuming at a large commercial scale. With the relatively recent launch of Precision Irrigation tools such as FieldNET® Advisor™ by Lindsay Corporation, new technologies are being leveraged to automate use of these proven irrigation management best-practices – drastically reducing the cost and time required, while significantly simplifying application of these methods.

PI is mostly related to technology and automation. However, agronomy and soil science play a crucial role in irrigation. How are you considering crop and soil variability? What are the products and services related to PI your company is offering to help in its implementation?

The three primary variables most impacting irrigation management decisions are 1) water usage traits of the specific crop and hybrid being grown, 2) characteristics of the soil, such as water-holding capacity, infiltration rate and residue cover, and 3) local environmental conditions in the field throughout the growing season. FieldNET Advisor is the only solution in the market that combines field-specific data on all three of these variables, and many other secondary variables, and integrates them into a remote irrigation monitoring and control platform that provides growers with the information they need to confidently apply optimum water amounts at the ideal time throughout the growing season, and have the ability to control their irrigation equipment and monitor its performance from their mobile phone, tablet or computer.

Knowing the key soil variables and tracking crop growth at every point throughout the field using field-specific historic and forecasted weather data, FieldNET Advisor can alert growers in advance when irrigation will be necessary and actually generates a variable rate irrigation (VRI) prescription for the field that is updated at least once a day to help ensure the optimum amount of water is applied at the right time and place as the crop(s) mature throughout the season.

What are the barriers in the implementation of PI?

Barriers to implementing PI have fallen significantly in recent years as more growers add technology to their operations to increase efficiency. However, as equipment becomes more advanced, the data generated by the equipment proliferates, which can be a challenge for growers to access and utilize. A barrier to harnessing the power this data holds is disparate data formats and lack of continuity across equipment platforms. To solve this data challenge for growers using irrigation, Lindsay’s FieldNET remote irrigation monitoring and control platform integrates multiple brands of electric pivots, and other irrigation components such as flow meters, pump stations and filters, and connects with other farming platforms such as the John Deere Operations Center and, coming in 2019, FarmCommand by Farmers Edge.

Cost-effective solutions are available to retrofit even the oldest and most outdated center pivots, so whether you have a brand new Zimmatic pivot or a 30-year-old pivot from a manufacturer that has long since gone out of business, taking advantage of this technology is as simple as calling your local Lindsay or Zimmatic representative.

From your point of view, what are the principal challenges in PI and PA in the coming years?

How is Lindsay positioned to address them? Where do you see the most important market growth for your products and services?

As we’ve seen over and over in the agricultural market over the last century, when new technologies emerge that demonstrate meaningful profitability improvement, time savings and simplification of a producer’s operation, adoption tends to happen fast. FieldNET Advisor was released in North America in May 2017, has been in continuous beta testing globally for additional crops over the past two years, and is expected to be released in many more countries by the end of 2018. This solution delivers these same key benefits and has seen rapid adoption. The key to spreading these technologies further lies in educating growers about the facts and science behind the solution, and testimonials from producers who have already seen these benefits in action.
N fertilizing are N-sensor and N-sensor ALS (Tara and Agricon), Crop Circle (Holland Scientific), GreenSeeker (Trimble), OptRx (AgLeader) and CropSpec (Topcon). All except the first are active sensors as they emit their own light. This makes them capable of working at night, too. When it comes to map-based PA, implements equipped with VRT would work in a similar way as those used for selective ON/OFF applications. The difference is that the designed prescription maps could prescribe virtually any dose rate. However, management zones should not be too small. Firstly, their width should be designed in accordance to the minimum controlled width of the equipment. Secondly, the management zones length should not be shorter than the length required for the equipment to change the dose rate. Changing the output rate requires mechanical adjustments and they take a certain amount of time to be implemented, depending on the technology used. As the time needed to change the output rate implies a distance in the field, the length of management zones should not be smaller than that distance to be effective. Continuously variable rates in a map-based approach could be used for plant protection products application, fertilizing, irrigation and other management operations.

When either RT sensor-based or map-based approaches are used, it is advisable to record what is actually done in the fields in the form of what are called as-applied maps. For this purpose, sensors are needed to monitor the performance of the implement, GNSS receivers are required to obtain the coordinates and controllers are used to put everything together and record the data. As-applied maps are very useful to understand what is going on in the fields during the season, especially when problems persist. Additionally, they are very interesting for traceability purposes. Obviously, the more similar the as-applied map to the prescription map, the better.

**Prescription map:** Map of the field showing the dose rate or the intensity of a site-specific management operation (i.e. fertilization, irrigation, tillage, crop protection, etc.). It is the base information to implement map-based Precision Agriculture (PA).

**Variable rate technologies (VRT):** Technologies boarded in fertilizer spreaders, sprayers, seed drills, centre pivots and other agricultural machinery capable of self-adjusting to vary its output rate. VRT take advantage of controllers, actuators and sensors to extract set points (output rates) from prescription maps or to acquire and translate sensor readings into set points. Besides, they generate control signals to be sent to the actuators to adjust the equipment to apply the desired output rate.

**As-applied map:** Map of the field depicting what was actually done during the operation in the field. E.g. the actually sprayed plant protection products, the actual amount of fertilizer spread or the actual seeding rate.

**Hard PA:** Approach for the implementation of PA related to the use of high-tech equipment, automated processes, licensed software and few operators in large areas. Hard PA tends to be more plug&play and use software suites providing prescriptions with just pushing a button. That may be fine if everything works but it could be very dangerous, too.

**Soft PA:** Approach for the implementation of PA related to the use of conventional or low-cost equipment and sensors in smaller fields, more workforce and open source software. This approach usually requires more education on PA.

**Glossary of terms**

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**WHAT’S THE FUTURE? PA TRENDS**

Moving from uniform management to management zones is a big step forward. However, could we keep moving forward until management of individuals? That seems quite reasonable in Precision Livestock Farming or even in Precision Fructiculture, but what about arable or field crops? Then, what is the future in agriculture? From our point of view, the future of agriculture is PA together with data and Big Data analysis and interconnectivity, what is called Digital Agriculture or Agriculture 4.0.

Regarding management operations, the trend in recent years is the increase of working width in agricultural machinery. That translates into higher working capacities (ha/h), lower unit costs ($/ha) and less labour or workers. That may be fine for big farms with large regular fields. However, that means higher investments, little flexibility in scheduling tasks and limited reliability in case of maintenance and repair operations. Additionally, big implements are heavy and require powerful and heavy tractors which may cause compaction problems in certain situations. Another key aspect is that expensive equipment is expected to work larger areas and, hence, travel at higher working speeds. That makes “precise” management very difficult and forces shorter response times both in computer processing for decision making and in actuation. An alternative to that is the use of robot fleets or swarms. Although this may sound futuristic, some solutions for weeding (Naïo) and maintaining grass covers (Vitirover) are already commercial. Robots do not require operators and could work 24/7. This means they could take longer times in making decisions (e.g. deciding whether a plant is a crop or a weed) and performing management operations. Small robots are light and could make use of solar energy. If one of them fails, another could take charge of the job. On the negative side, small robots cannot take over heavy traction works and would need a network of workshops to be established to quickly react to repair and maintenance operations during the critical moments of the season. Investments may be high and the units are subject to robbery. This solution still seems to be far away from being implemented in the short term. However, some big agricultural machinery manufacturers already offer it in their portfolio (Project Xaver - AGCO). Let’s see what will happen in the coming years!!

**HARD vs SOFT PRECISION AGRICULTURE**

After eight Precision Ag Corners describing the different stages of the PA cycle, we can state there may be two overall approaches to implement PA: Hard PA and Soft PA. Hard PA means high-tech equipment, large areas, automated processes, licensed software and few operators involved. Soft PA uses conventional or low-cost equipment and sensors in smaller fields, more workforce and open source software. Hard PA is interesting when workforce is expensive or non-available. Nevertheless, when budgets are short for buying high-tech sensors but workforce is available and affordable, scouting with mobile phones is a feasible alternative, even in small fields. However, this approach usually requires more education on PA since the farmer or the advisors will have to run on-farm experiments to obtain specific solutions for their situations and will have to use several data sources and programmes to solve their problems. Hard PA tends to be more plug&play and uses software suites providing prescriptions with just pushing a button. That may be fine if everything works but it could be very dangerous, too.

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