Digital technology and precision agriculture

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Abstract:
Precision agriculture, a concept that emerged in France at the turn of the 21st century, seeks to provide the “right dose, at the right place, at the right time”. The fundamental principle underlying this site-specific crop management system is still sound: a plot of farmland is a varied, living environment. For want of materials and agronomic advice adapted to specific plots, this heterogeneity has long been a drawback, since farmers could only adopt “average” practices for their farmland. Reinforced by the progress made in digital technology, precision agriculture is turning this disadvantage into an opportunity. The digital revolution is reaching out into all branches of economic activity, including agriculture, and opening new perspectives thanks to the coming generations of sensors and of computationally intense information systems.

People who talk talking about digital technology and precision agriculture have in mind the definitions related to their own experiences and mind-sets. The views expressed when these phrases are used are often narrower than they should be. For example, the idea of the “right dose at the right place” is often seen as the concept underlying precision agriculture. It refers to what agronomists call “site-specific crop management” for modulating inputs in a field. Under this system, the variability within each field (properties of the soil, characteristics of plant life) is diagnosed for the purpose of applying the right dose of an input in each part of the field. This idea is not false, but is probably too narrow.[1]

A broader definition

To this specification should be added the full range of decision-making tools (often electronic) that enable a farmer to manage crops in relation to a specific intrafield location. To be more exact: precision agriculture could be better defined by the formula “the right dose at the right place at the right time”. Likewise, the definition of digital technology should be broadened to refer to sensors, monitors, information systems, data bases, terminals (such as smartphones), robots, etc. This is important because agriculture has always relied on technical advances in the broad sense in order to improve not only working conditions but also its global performance (economically, etc.). For the farm world, digital technology is, among other things, a new approach toward a more precise way of farming.

[1] This article has been translated from French by Noal Mellott (Omaha Beach, France).

What is expected from precision agriculture?

What is the finality of precision agriculture? How is it a vector of progress? The answer has to do with the physical environment, which, in French agriculture at least, varies widely by space and time. On the scale of space, farmers have already experienced variable yields inside a single field; often by a coefficient ranging from one to two, even in a so-called "homogeneous" field.

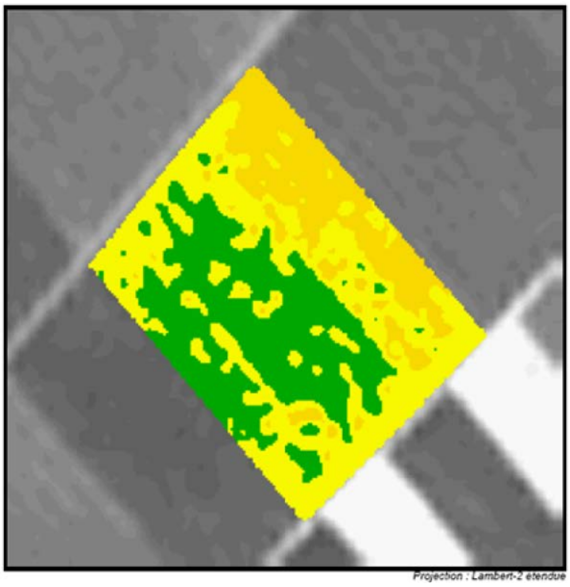

Figure 1: The intrafield variability of the biomass of wheat at the stage when the ear swells. The values range from 5.4 (yellow) to more than 7.8 (green) tonnes of dry matter per hectare.
(*Source*: Farmstar http://www.farmstar-conseil.fr/)

Figure 1 shows the variability of the biomass produced by wheat at the stage when the ear starts swelling, *i.e.*, a few days after the emergence of the flag (last) leaf. The same or even a higher degree of variability, occurs at the time of harvesting.

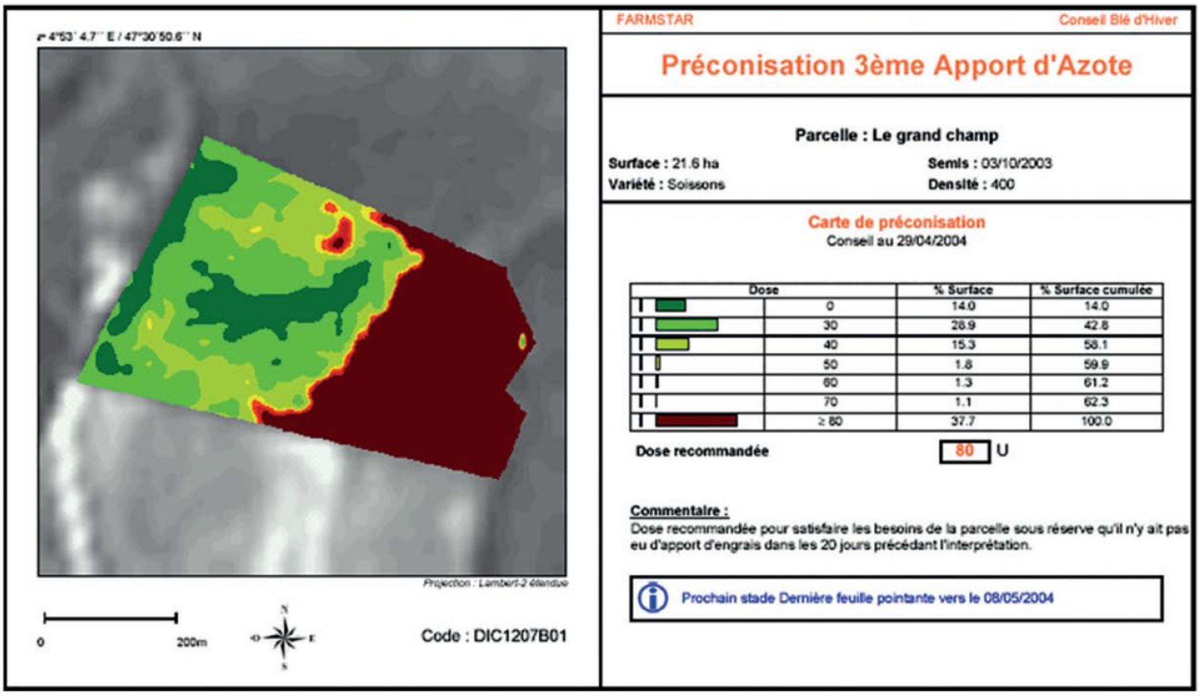

Figure 2: The need intrafield of nitrogen fertilizer for wheat at the stage when the ear swells. The values range from 0 kgN/ha (green) to more than 80 kgN/ha (deep red).
(*Source*: Farmstar http://www.farmstar-conseil.fr/)

As we see in Figure 2, the need of fertilizer also varies considerably inside a field. This example shows that it is worthwhile adjusting the dosage of fertilizer to the actual need at every "point" in the field. The benefits to be drawn from this are:

— savings on fertilizer (in sections of the field that need less fertilizer than the average of the whole field);

— not only a much better dosage for sections of the field that need more fertilizer but also, as a consequence, the expectation of a better yield and of ears with a higher protein content;

— a reduced risk of fertilizing too much sections of the field that need less and, as a consequence, a considerable reduction of risks for the environment.

Figure 3 presents the findings from tests that, conducted on location, compared applying fixed and adjusted doses of nitrogen fertilizer. This experiment, conducted by C. Desbourdes in wheat fields from 2005 to 2008, demonstrates both the higher yields (green points) and the savings on fertilizer (the difference between the red and blue bars).

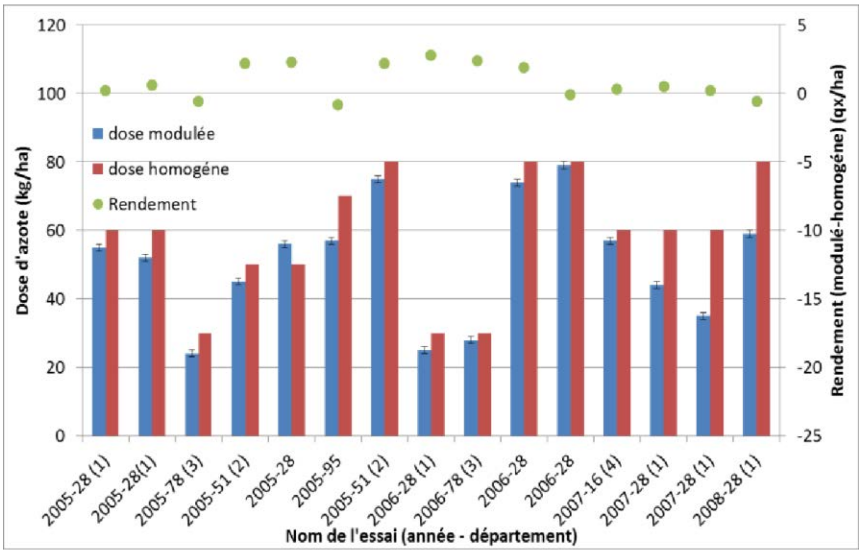

Figure 3: These results of tests run in a field show the interest of site-specific crop management for adjusting, intrafield, the last application of nitrogen fertilizer on wheat: higher yields (green points) and savings on fertilizer (the difference between the red and blue bars).
(*Source*: Caroline Desbourdes, ARVALIS Institut du Végétal)

As these examples show, it is worthwhile applying the "right dose at the right place". Let us now add to this phrase "at the right time".

In agriculture, the choice of the period for applying an input might prove decisive for yields and their quality. This has an obvious economic impact. Let us take the example of the conditions for applying herbicides. The weather strongly affects the effectiveness of spraying. It is now possible to inform farmers of the right time for spraying. As Figure 4 shows, the wind will be too strong during the coming three days (from Friday to Sunday).

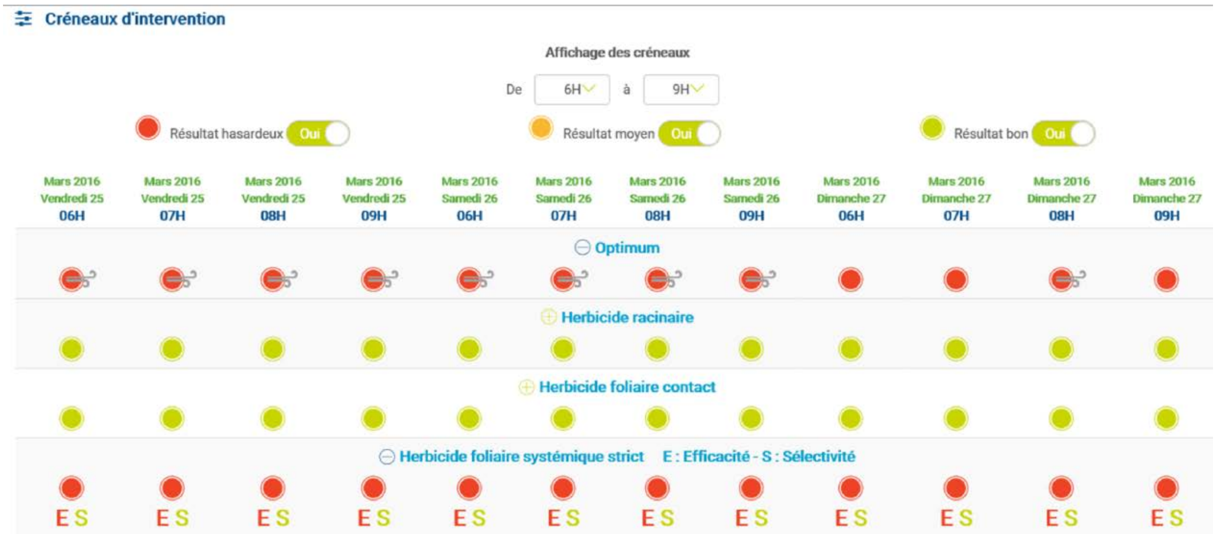

Figure 4: Conditions related to the effectiveness (E) and selectivity (S) of types of herbicides (absorption through the roots or leaves, by contact or systemic) as a function of the weather conditions (favorable in green and unfavorable in red) during a three-day period.
(*Source*: Advice from the software Taméo, Arvalis-Météo France.)

Farmers work with complex, diverse forms of life under conditions closely related to the weather and climate (and even stronger variations due to climate change), not to mention the business cycle's volatility. Since it is increasingly complicated to make the necessary decisions for managing a farm, farmers have adopted computer-assisted decision-making tools to help them make the right choices in line with their professional goals. These tools have been deployed on big farms for help with:

- — planting crops, in particular the choice of cultivars, dates and the density of sowing;
- — fertilizing crops (estimating fertilizer needs);
- — protecting crops (prediction models for pathologies, the fight against pests, etc.);
- — managing water (irrigation needs);
- — making environmental analyses;
- — assessing economic performance.

Table 1 presents the major decision-making tools distributed by Arvalis along with the percentage increase per year in use. Notice the sizes of the surface areas covered: the 70,000 hectares for Miléos represent 50% of the surface area in France devoted to growing potatoes. Even more remarkable is the strong growth rate of the areas covered.

Table 1
The principal decision-making tools in the Arvalis product line:
Surface areas (hectares) covered and annual growth rate (%)

Farmstar Expert	Service for managing nitrogen and the risks of diseases and of lodging (wheat and colza) using satellite imagery. This service comes out of cooperation between Arvalis and Airbus.	793,000 ha	+7%
Septo-LIS® Stadi-LIS® Prévi-LIS®	Services for predicting the stages of growth of cereals and the risk of foliar diseases (Septoria on wheat)	2,170,000 ha	+18%
Miélos®	Service for predicting mildew on potatoes	70,000 ha	70%
Irré-LIS®	Service for managing irrigation as a function of crop needs (wheat, barley, potatoes, corn, tobacco, etc.) and of the weather	21,000 ha	17%
FertiWeb®	Service for assessing fertilizer needs (all crops)	1,930,000 ha	—
Taméo®	Service for managing risks as a function of weather forecasts (on a 1 km2 grid). This service stems from cooperation between Arvalis and Météo-France.	—	—

From Farmstar to "digital farms"

The first operational step toward precision agriculture was, in 2002, the proposal on a large scale of a service using satellite images to provide advice to farmers for managing their wheat and colza crops at the infrafield level. Fifteen years later, Farmstar covers nearly 800.000 hectares in France. It has improved over the years by incorporating new applications and expanding to new crops (barley, corn and triticale). Beyond its actual interest for farmers (and thus for precision agriculture), this service's major innovation is to have coupled two, *a priori* separate, cognitive spheres: space and agronomy. Farmstar has combined satellite imagery and agronomic models from technical institutes in order to produce operational advice with a high added value for farmers.

While developing this new type of service, fundamental questions arose about digital technology, which is now gathering momentum in fields throughout France.

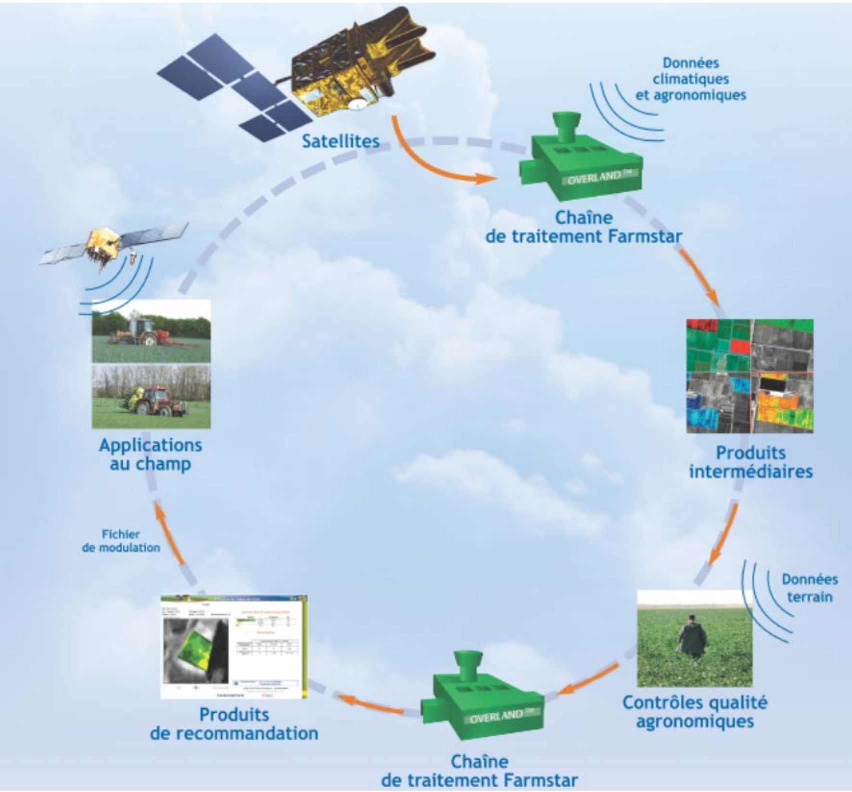

Figure 5: A technological loop for processing data for Farmstar

First of all, a question about information systems and the management of big data bases. In 2002, it was a challenge to be able to send the advice to farmers in short order — after, within a few hours, processing the data from images of nearly all of France (a pixel, the elementary unit, representing a square with a side of from ten to twenty meters), combining this information with the data on 80,000 fields and calculating farm climate models (using agronomic data bases about cultivars, the soil, decision charts, etc.). The advances made in digital technology, in particular the speed of calculations and data transmission, have considerably improved Farmstar's performance and reliability.

Another question soon cropped up: the ownership of the data being used. Who owns which data? This fundamental question led Farmstar to propose operational rules for protecting the anonymity of farmers and guaranteeing them full intellectual property rights over the data on their fields. This service has used the mass of data produced to generate new models and services. This signaled the start of the process of using data from individuals for a common interest. Intellectual property rights do not hold just for farmers and service-providers but also for the partners who have created services.

Farmstar encountered another fundamental problem, namely the interoperability of information systems and data bases. In France, the usual intermediaries between service-providers and farmers are farming cooperatives, traders and "chambers of agriculture". Not only do these organizations have their own information systems, but, it should not be forgotten, farmers also use several types of software to manage fields. The data from these sources must be made compatible so as to obtain a continuum of fluid, reliable information. This is indispensable to render a service of good quality.

In 2017, questions related to interoperability are being handled through application programming interfaces (APIs). The Internet is accessible at high enough connection speeds in rural areas; connections (GPS or RTK) are reliable; consoles on tractors adjust to several formats; and the connectors between tractors and digital tools are being standardized. Digital applications are proliferating, in farming as in other activities. Out of these experiments, the concept of the "digital farm" (in French: *digiferme*) has emerged.

Arvalis set up two "digifarms" — the one with big fields, the other with mixed farming (including livestock) — to study digital applications at the farm level, evaluate their advantages and develop new applications in collaboration with start-ups. This nonexhaustive list of the tests under way provides a glimpse of digital innovations in agriculture:

— robots for weeding that can replace herbicides or considerably decrease the quantities used;
— drones equipped with sensors for detecting weeds in fields;
— automatic steering systems for tractors and machines;
— RFID tags for automatically managing inputs;
— a whole range of decision-making tools for fertilizers, irrigation, crop protection, grain storage, etc.;
— connected sensors installed in fields for measuring the temperature, rainfall, soil humidity, etc.;
— connected traps for signaling pests;
— sensors installed in storage facilities (for grain or tubers);
— rapid assays of the soil and raw materials;
— probes for monitoring calving;
— systems for monitoring animal activities;
— electronic measurements of plant growth (to schedule silage and fodder);
— a connected dashboard for farms (for global management and alerts about everyday tasks).

One of the objectives (and not the least) of these digifarms is to assess the economic benefits of all these applications. A farm is, after all, a business that must, to survive, constantly look for ways to be more competitive. These two experimental installations will help us sort innovations so as to tell the difference between what is useful and those that are gadgets.

Figure 6: R&D axes in "digital farms" (DIGIFERMES® Arvalis).

Why do digital technology and precision agriculture go together?

Two waves of innovations are carrying the digital revolution in agriculture: *a)* the proliferation of low-cost, miniaturized sensors; and *b)* the processing of big data.

Technological progress in the design and manufacturing of sensors has not only led to their diversification but also considerably reduced production costs. NIR sensors the size of a matchbox claim to analyze plants with enough precision to enable farmers to make well-informed decisions without having to have costly tests run (often by a laboratory) and then waiting for the results (in the next few days at best). If confirmed by further testing, this type of innovation will thoroughly change farming practices. This example directly connects to precision agriculture: the implementation of a more accurate technique often entails an objective diagnosis of the situation with a rapid feedback of information. The coupling of sensors with software for interpreting the results can provide a service at a low cost. The performance of ever more measurements is no longer a limiting factor; instead, it offers the possibility of mapping the soil's properties and the crops' needs, of individualizing the feed for animals, etc. The weak link in the technological chain of precision agriculture used to be a "low-cost infrafield diagnosis". This link has been fully consolidated.

The other pillar of the digital revolution in agriculture is the processing of big data. The models for predicting disease outbreaks are the best illustration of this. Tools for predicting health risks are very useful to farmers; they can tell them when to start a treatment or, if it is not absolutely necessary, when to suspend it. These tools lead to gains in both these cases. To achieve this result, operational models for each type of pathological agent must be designed that use both climate data and information about the disease agent.

Figure 7: Yellow rust on winter wheat. If left untreated, the rust can cause up to 50% of the crop to be lost.

Yellow rust, for example, is a major pathology of cereal crops. If untreated or poorly treated, it can cause a crop loss of up to 50%. Since it spreads so fast, it is important to predict its onset so as to schedule treatments for optimal efficacity. Since this fungus, unfortunately, tends to mutate over time, a predictive model that used to prove its worth might become obsolete — as happened a few years ago. Since updating the model might take years of experimentation on location before recovering a satisfactory level of performance, a completely different choice was made. By processing hundreds of thousands of observations (reported by technicians and extension workers in a national biomonitoring network), the model was updated without needing to run a single test.

The incredible mobilization of farmers during the winter of 2015-2016 clearly illustrates the benefits of using data drawn from observations on location in fields. In two weeks time, farmers forwarded more than 2000 such observations. These were used to map the damage caused by the barley mild mosaic bymovirus, which aphids inject into barley during autumn and winter.

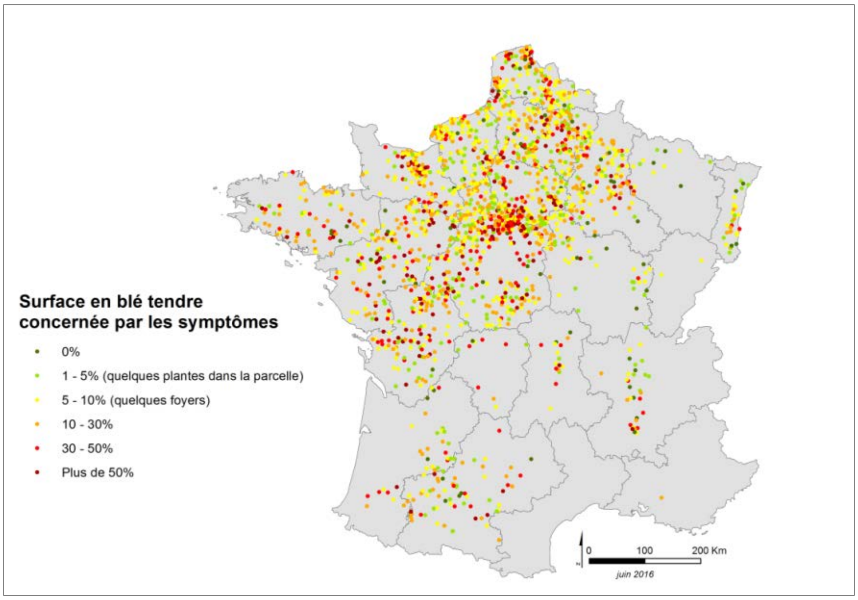

Figure 8: On-location information from farmers (2,036 messages) about the infestation of common (bread) wheat fields by the barley yellow dwarf virus.

Value is created from processing data

Despite the explosion of innovations (in particular sensors) in agriculture, the creation of economic value mainly comes from the interpretation of signals, as is, after all, often the case. For example, satellite imagery could already in the mid-1970s provide an astoundingly precise picture of plant cover, but no one was able to use this information until it was translated into indicators for producers. The models now in use did not yet exist. This information could not be coupled with a meaning till the turn of the century. We now face the same problem: sensor technology is advancing faster than data processing, and this innovative technology sometimes stalls for want of "decoding".

Let us take the example of sensors on board drones. As we know, this method for collecting data can deliver very detailed infrafield information, down to the scale of a centimeter. This ultra-precision cannot be processed, not now anyway, because the unit used for decision-making is calibrated on the width of farm machinery (usually ranging from a few meters to a few dozen meters). To continue with drones, I might mention the mapping of adventive plants in a field. The drone's sensors record the plant cover's reflectance, but interpreting these signals does not enable us, not yet, to tell the difference between adventive plants and cultivars except for crops (such as corn, sunflower or beets) planted in rows. It is not yet possible to identify the types of adventive plants, even though this would be useful to determine how to weed.

Figure 9: Adventive plants between two rows of corn. Drones equipped with sensors can detect this pattern, but it is still hard to identify the types of adventive plants.

In general, the current technological stickler is not the performance of sensors, which are still undergoing improvement, but the high-speed processing of data so as to give all this information a meaning for decision-makers and to quickly convey this interpretation in the form of advice to producers. In agriculture, the time spent waiting for feedback is decisive, since crops, the weather and parasites are constantly evolving. If the period between diagnosis and intervention is too long, the information loses much of its worth. This holds especially for crop protection, for which the reasonable waiting period ranges from one day to one week at the very most.

Conclusions

From these thoughts on digital technology and precision agriculture, a few remarks should be made; and a few trends, pointed out.

First of all, agriculture and farmers are open to the advances made in digital technology. For most farmers, this technology is an additional lever for managing the uncertainty of their work (the vagaries of weather and of the business cycle).

The agricultural firm is a complex place where, everyday, major decisions have to be made about quite different subjects: business, agronomy, animals, taxes, safety, etc. The possibilities offered by digital tools, responsive and simple to use, bolster the services that farmers need for helping them make decisions. Farmers are already familiar with site-specific farming practices; this precision is advantageous both economially and environmentally. Digital applications open new prospects in terms of site-specific crop management (the dosage of inputs, for example).

From a social viewpoint (on which this article has not dwelled), the use of digital technology is also a vector of progress. Automatic steering systems on farm machines, robots (already widely used) for milking cows, robots (still in the testing stage) for fieldwork… all these innovations are going to lighten the workload. This does not leave farmers indifferent.

This new technology in the broad sense is also a factor for attracting young people to agriculture. Owing to it, the farm world reflects toward society an image of modernity. This is a point of satisfaction.

The farm world itself is particularly concerned about two questions. The first has to do with the data and their use. Property rights to the data produced by farmers is still a sensitive topic. An aspect that keeps them on edge is the fear of controls; and this anxiety has grown since data bases containing their personal information are being interconnected. The second question concerns technical consultancy. Nowadays, this task is being done almost exclusively by the aforementioned chambers of agriculture, cooperatives and traders. Tomorrow, these players might come into competition with start-ups that will provide advice simply by processing big data bases compiled from information coming from the proliferation of sensors.