Precision Agriculture Technology and Robotics for Good Agricultural Practices

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Abstract: There is a growing concern by governments, retailers and consumers about the safety and quality of food. Because products are resourced on a on a global scale it becomes important that the origin of the products as well as all the treatments during production can be traced and that the production methods can be verified as good agricultural practices (GAP). This also includes considerations for the environment and sustainability. The concepts and technologies developed in the framework of precision agriculture, including automation and robotics, make it possible to produce with a minimal environmental impact and at the same time all treatments and handling are recorded and can be uploaded in the different data bases that are used for tracing the product origin and for verifying compliance with GAP criteria. Gap criteria are also such that new developments in automation and robotics are stimulated to relief producers from excessive administrative work. As such these technologies can evolve as efficient instruments for food safety assurance.

Keywords: precision agriculture, food safety, good agriculture practice

1. INTRODUCTION

There have been major developments in the world related to food safety and traceability. Some of the initiatives come from governments to protect the health of the citizens, the other are private initiatives by growers and retailers in order to meet the expectations of their customers with respect to food safety and environmental sustainability. Everyone in the food chain assumes that these expectations can be satisfied if production is done in line with good agricultural practices (GAP). It appears also that the origin and destination of animal feed, materials and food in all stages of production and distribution must be known and as information available to the qualified authorities or to food safety departments at manufacturers or retailers. GlobalG.A.P. is an example of a standard for primary agricultural production (1). A partnership between retailers, food traders and growers administers and maintains this standard that is being used worldwide. The aim is to ensure integrity, transparency and harmonization of global agricultural standards since sourcing of food, either fresh produce or processed farm products, has become a global activity.

Precision agriculture technologies and robotics share the underlying ideas of GAP and may become important tools for complying with the regulations and for documentation of the production conditions as a proof of compliance.

2. PRINCIPLES OF GOOD AGRICULTURAL PRACTICES (G.A.P.)

The G.A.P. schemes principles are based on the following concepts (1):

- Food Safety: The standard is based on Food Safety criteria, derived from the application of generic HACCP principles.
- Reducing the inappropriate use of chemicals in general and especially the use of chemical plant protection products, or reduce the level of residues found on food crops
- Environment Protection: The standard consists of Environmental Protection Good Agricultural Practices, which are designed to minimize negative impacts of Agricultural Production on the Environment.
- Occupational Health, Safety and Welfare: The standard establishes a global level of occupational health and safety criteria on farms, as well as awareness and responsibility regarding socially related issues.
- Animal Welfare (where applicable): The standard establishes a global level of animal welfare criteria on farms.

The Scheme covers the whole agricultural production process of the certified product, from before the plant is in the ground (seed and nursery control points) to non-processed end products (Produce Handling control points). In response to the challenges posed by fast changing crop protection product legislation, the GlobalG.A.P. organisation developed guidance notes to help farmers and growers to become more fully aware of the maximum residue limits (MRLs) in operation in the markets where the product will be sold.

A general regulations document explains the structure of certification to GlobalG.A.P. Standard and the procedures that should be followed in order to obtain and maintain Certification. The requirements for G.A.P. certification are bundled in a document with control points and compliance criteria. Several other GAP schemes also have similar requirements although the emphasis may be different depending on the country where it was initiated or applied.

3. PRECISION AGRICULTURE, AUTOMATION AND ROBOTICS

The basic principles underlying precision agriculture can be be seen as a summary of good agricultural practices and they require:

- Correct information (soil, previous crops and treatment…)
- Correct observation
- Correct analysis
- Correct genotype
- Correct dose
- Correct chemical/biological compound
- Correct place
- Correct time
- Correct (climatic) conditions
- Correct equipment

It is clear that when such principles are adhered to, the requirements of GlobalG.A.P. can be met. However, a record is needed of all the steps and treatments carried out during the production. This is where automation and robotics can contribute to make the correct treatments and to document it. The principles of precision agriculture can also become a major tool for adhering to the "Lead Principle" that states: 'Environmental information communicated along the food chain, including to consumers, shall be scientifically reliable and consistent, understandable and not misleading, so as to support informed choice'(2). In the following we will look at the convergence between GAP and precision agriculture

4. GPS AND GAP: THE TRACEABILITY REQUIREMENT

Precision Farming and the use of Global Positioning Systems (GPS) on agricultural machinery, provide location and time information of all treatments. This is of course very important for automation like navigation during the different treatments or the collection of data on crop status, diseases and yields.
After harvest, the GPS data may be added to the shipping documents such that the origin of the product (the region, the farmer, the field) can be traced and the consumer can be assured about the origin claims. It is also possible in mixed final products to state where the different component of such a mixture originated. For retailers or stores that claim to sell locally produced food and for their clients, it offers the possibility to trace the product and verify the claims as long as the system is fool proof.

5. SITE HISTORY AND SITE MANAGEMENT

Not all soils (types or location) are suitable for all crops. A soil map can be the prime basis for assessment of soil suitability and variability. There are a number of measurement techniques that can help quantify within-field spatial variability of soils for precision agriculture The continuous in-field direct measurement of soil strength can be based on sensing the force when a tine is pulled through the soil (Sirjacobs et al., 2002). In an indirect method based on VIS-NIR optical reflectance the soil organic matter and moisture content can be estimated (Mouazen et al., 2006).
Measurement of bulk soil electrical conductivity (ECa) can provide an indirect indicator of soil properties like soil salinity, clay content and cation exchange capacity (CEC), clay mineralogy, soil pore size and distribution, soil moisture content, and temperature
(Sudduth et al., 2001).
Planting the crop at the correct place implies that the farm manager is aware of what crops were grown in the previous seasons and what treatments were given. In a number of cases residues from fertilizers, herbicides or pesticides from treatments in a previous season may still be high because of environmental conditions that were less favorable for their degradation or break-down. It is then handy that one can retrieve the data (dose, time and location) about these earlier treatment to make informed decisions. The risk of chemical leaching in the soil may vary by location and soil types and can be taken into consideration for crop production decisions. In other cases a sequence of crop rotations should be respected to avoid the effect or the spreading of soil borne diseases. Soil disinfection may be applied, preferably using environmentally friendly physical methods, and only there where needed on the basis of a risk assessment.

6. SOIL MANAGEMENT

GAP requirements state that farmers should have a soil map prepared for the farm and that they should also use techniques to maintain or improve the soil structure and avoid soil compaction. A soil map can be a good basis for applying these techniques in an efficient and automated way. Automation can then be effective, for example, for the orientation of rows, the soil cultivation techniques and the use of strips to reduce soil erosion.
Precision in seeding must also take the soil condition into account. Inappropriate seeding depth or seeding density can be a major cause of variability in growth and yield of individual plants. This is especially a point of attention for (no tillage) direct seeding.

There are also indications that the choice of cultivars or varieties should be based on the soil type and location. It may be difficult to continuously change the cultivars within a field, but subdividing the field in zones may be a solution. Of course it also depends on the subsequent use of the harvested crop or of the long term planning and harvest scheduling.

7. FERTILIZER APPLICATION

Good agricultural practice implies that the correct dose of fertilizer is applied at the correct moment and in the correct way. The correct dose depends on the soil condition or the crop condition. Numerous efforts have been done for automation of the measurement of nutrient availability in the soils. They include automation of soil sampling for laboratory chemical analysis. The time delay for getting the results can be reduced by using near field chemical analysis using optical VIS/NIR techniques or electrochemical sensors on prepared samples or even on. The latter can be direct measurement ion-selective field effect transistors (ISFETs) with flow injection analysis or the measurement of ion activity using ion-selective electrodes. At this moment they are only for pH reliable. Although the electrochemical measurements can be geo-referenced, the time lag between sample collection and sensor output precludes on-the-go control of variable rate lime and fertilizer applications (Adamchuk et al., 2004). If sufficient near field data are available then application requirement maps can be constructed for use in automated fertilizer spreaders. One step further is the online measurement of soil nutrient composition using similar optical or electronic sensors with immediate use of the information for adjustment of the spreaders (Mouazen et al., 2006).

A similar approach can be used for fertilizer application to the growing crop. Crop nutrient status is mainly assessed for nitrogen on the basis of chlorophyll content. Optical reflectance sensors can be used to measure light reflectance from leafy crop canopies, which can be used to estimate the nitrogen status of plants and ultimately estimate how much additional nitrogen needs to be applied. It started with portable sensors for measurement at several specific locations in the field. Tractor mounted spectrophotometers using chemometric tools or multispectral sensor to derive chlorophyll content and then the nitrogen requirement of the crop are now direct inputs to control the variable rate application. Some of the systems are passive and rely on solar radiation for the light source (Reyniers et al., 2006). Other systems use an onboard light source to reduce the effect of the changing illumination conditions in the course of a day. It is also possible to base the chlorophyll estimation on laser induced fluorescence.

Banded application of nutrients near the plant rows potentially leads to a higher nutrient efficiency and reduction of leaching losses. Automatic guidance of the injectors are of great help in an established crop.

Fertilizer application into the soil, before or after crop planting, can also be based on manure or other organic waste. In that case a continuous measurement of the manure composition as well as of the flow rate may be necessary.

Weather forecasts can also help in decision making since granular application is not effective if dry conditions make that the nutrients will not reach the plant roots.

The above overview illustrates that automation and control in fertilizer application can be of great value towards satisfying GAP requirements. Indeed, at each time and location the nutrient requirements are determined and accordingly the application rate is adjusted. Sensors should measure the fertilizer mass flow rate over a range of particle characteristics or liquid characteristics. Granular fertilizers come in a variety of shapes, sizes, and chemical composition. Properties of liquid fertilizers may also differ. This suggests that a flow meters may have to be calibrated for particular products. The automatic registration of the applied doses such that it can be traced for GAP certification evident.

8. CROP PROTECTION AND INTEGRATED PEST MANAGEMENT

8.1 Weed control

Four core technologies (guidance, detection and identification, precision in-row weed control, and mapping) are required for the successful development of a general-purpose robotic system for weed control. Of the four, detection and identification of weeds under the wide range of conditions common to agricultural fields remains the greatest challenge (Slaughter et al., 2008). Various methods have been developed for weed detection. They are all in some stage between research and commercial application. Most are based on spectral characteristics and/or image based shape recognition to discriminate between weeds and the crop. They will not be further discussed here. The subsequent treatment can be a mechanical or thermal action or an herbicide application. Herbicide equipment can be attached to a regular tractor and there is considerable scope for the use of small autonomous vehicles that can do the work day and night when conditions are favorable.A few complete robotic weed control systems have demonstrated the potential of the technology in the field. Additional research and development is needed to fully realize this potential (Slaughter et al. 2008). The precise herbicide treatment using micro-dosing nozzles on the most sensitive parts of the plant further reduces the chemical use. In case population dynamics models are sufficiently developed, then they can help to decide not to treat if the weeds pose no direct threat to crop production or quality. These models may become more accurate after each observation in time. Place and time of weed populations and the applied treatments can be registered for the GAP database.

8.2 Pest and disease management

Good agriculture practices of pest and disease management imply production practices that reduce the incidence an intensity of pests and diseases. It also implies that observation and monitoring practices are established and that non-chemical approaches must be considered. Where possible, biological control and the use of predators should be favored. Specific chemical control should only be considered when the economic value of the crop would be affected. In-field hyper-spectral reflectance images were taken and Winter wheat infected with Yellow Rust was successfully recognised from nutrient stressed and healthy plants (Moshou et al., 2006). Following hyper-spectral imaging spectral vegetation indices (SVIs) related to physiological parameters were calculated and correlated to the severity of diseases in sugar beets. The SVIs differed in their sensitivity to the different diseases (Mahlein et al., 2010). Hence, there are indications that automatic observation of diseases may be possible at an early stage, but elaborate field trials are still required. At this moment a good visual and instrumental strategy must be used for scanning the crop for disease initiation and if possible combined with population dynamics models to make a treatment decision. The same is the case for pest control where traps are frequently used, but the read-out of the traps is still time consuming and requires a lot of field travel, since the traps must be spread out over a large area.

8.3 Application Equipment

It is clear that any chemical treatment must be registered. And correct application can only be done if the equipment is in good working condition. For assuring that proper maintenance is done in time, automatic performance monitoring for the different machine functions (mechanical, hydraulic, sensing) can be considered since on most equipment computer based controllers are already installed.

In further automation, one should consider systems such that the use of chemical compound is only possible according to the license as specified on the label: the site or crop, pest stage or crop stage, application rate depending on the pest or soil type, the timing of application according to season, application method and type of equipment, number of applications allowed per season. In addition one has to respect a pre-harvest interval in order not to exceed the maximum residue levels (MRL), which can be country specific. At the moment of a pesticide application, all the information about the crop is already up to date in the farm data base. The label information for a specific compound is also available or must be scanned before the active ingredient is put in the sprayer. In that case a alarm can be given if an erroneous treatment is planned, or maybe the equipment cannot be activated. Of course these must be reliable and fool proof systems. Measures should also be taken to avoid that some chemicals contaminate neighbouring crops.

9. MICROBIAL SAFETY

The major sources of microbial risks during field production seem to be contaminated irrigation water, manure application wild animals or birds or livestock that spread microbial diseases. The first two risks can be reduced by pretreatment analysis and incorporation in the soil as well as refraining from application at a given pre-harvest time.

Intrusion of animals in a field, especially in case of fruit and vegetable production, cannot always be prevented with fences. One should consider unmanned observation systems to warn the manager of such events in order that suitable inspection is done for potential contamination.

Microbial contamination can also occur during harvest and postharvest. Worker hygiene is very important here, and systems could be contemplated to enforce hygiene of workers and repeated cleaning of harvesting and transport equipment.

Sorting lines also pose risks, since one contaminated item that goes over a sorting line can spread the contamination over the whole line and subsequently over many products that follow.

The early detection and removal of an infected item, perhaps before it reaches the main parts of the grading line can help to avoid problems. This implies that design engineering must now also have a strong emphasis on design for food safety. This may alter the future concepts of handling, sorting and packing equipment. For example, modular design with suitable cleaning procedures and the use of non-contact sensing tools are one way for reducing risks. Eventually, additional microbial sensing technology should be installed to warn the user in case of a problem item.

6. CONCLUSIONS

In precision agriculture and automation a lot of measurements are carried out at different spatial scales (from single plants to entire fields) and at different moments during crop production. Precision Farming and the use of Global Positioning Systems (GPS) on agricultural machinery, provide location and time information of all treatments. It started with yield sensors, but at this moment tools are available for on the go measurement of the type and dose of treatments, for identification of the crop condition and possible infection with pests or diseases. Wireless communication can be used to transfer field data to record keeping software One can see that Control Points and Compliance Criteria of GlobalG.A.P. or of another GAP scheme can to a large part be automatically addressed using precision agriculture technology for the automatic record keeping.

Precision agriculture technology can be made smart such that the requirements for environmentally friendly and sustainable production are implemented in real time in crop treatment and fertilizer equipment. It includes then also the identification and registration of operations or treatments on the crop in the growing stage. At the moment of harvest the technology can help in the identification and if possible the measurement of the quality parameters depending on where in the field the crop was grown. Different batches can be made with labels linking to all the information. As such this technology can evolve as a great instrument for food safety and quality assurance

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