Good Agricultural Practices, Quality and Traceability

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1. INTRODUCTION[1]

Agricultural production is part of a long chain of activities that starts from the seeding (or even earlier) and stretches all the way to the consumer. They should meet consumer expectations in terms of quality, safety and also value or price. Many intermediate steps are involved and these often involve handling, storage and transportation across national borders or continents. Information should be transferred across this chain. The automation that will be a major part of the future agricultural and biological production systems also faces some challenges posed by the systems characteristics that will have to be dealt with.

When we look at the processes in agricultural production systems then we can say that they are *complex in nature*. Indeed, as we gain a better understanding of biological processes we also find that they have a great complexity and that in many cases this complexity remains difficult to formulate in exact terms.

Society has high expectations from these food production activities, but at the same time they are more and more subjected to international agreements on trade. This makes that competition between producers or regions of production becomes an important item in decision making. Nevertheless this competition should not impair food safety to consumers or long term food security for society. There are also needs for technology development because of the need to reduce land degradation or to optimize water use. The (bio)technological revolution, genetically modified crops or crops for green chemicals need different planting, tending, harvesting and handling equipment. 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.

Since agricultural products are stored and shipped over long distances and time periods, there can be a considerable change in quality. On the one hand, one would like to know how quality will evolve after harvest. This may affect the timing of the harvest, the required storage conditions for maintaining a certain level of quality, or the available time between harvest and consumption.

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

GlobalG.A.P. is an example of a standard for primary agricultural production (1). It is a partnership between retailers, food traders and growers that administers and maintains a standard that is being used worldwide. The aim is to ensure integrity, transparency and harmonization of global agricultural

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standards since sourcing of food, either fresh produce or processed farm products, has become a global activity.

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

a. Food Safety: The standard is based on Food Safety criteria, derived from the application of generic HACCP principles.
b. 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.
c. Environment Protection: The standard consists of Environmental Protection Good Agricultural Practices, which are designed to minimize negative impacts of Agricultural Production on the Environment.
d. 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.
e. 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, GAP AND 'LICENSE TO OPERATE'

Precision agriculture technologies 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.

Precision agriculture can be seen as a summary of good agricultural practices that rely on:

a. Correct information (soil, previous crops and treatment…).
b. Correct observation
c. Correct analysis
d. Correct genotype
e. Correct dose
f. Correct chemical/biological compound
g. Correct place
h. Correct time
i. Correct (climatic) conditions
j. 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. 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).

Changes in society and attitude of consumers are such that agricultural practices will be questioned more in the future. This will go further than 'say what you do' and 'do what you say' but also will imply that communities will give a 'license to operate' only when stringent production requirements are met and documented. The it is not only that consumers require GAP when buying products, but that consumer action groups will only allow production when certain conditions are met and documented.

4. MEETING 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.

a. Site history and site management

Planting the suitable crop (and variety) at the correct place implies that the farm manager is aware of the soil condition and 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. This means that there is also a need for a traceability system that is linked to a field and not just to a crop that is grown and commercialized.

b. Fertilizer application

Good agricultural practice implies that the correct dose of fertilizer is applied at the correct moment and in the correct way. The 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 (based on crop sensors, weather, soil history…) 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 and the equipment and timing of the treatment are such that it can be traced for GAP certification evident.

c. Crop protection and integrated pest management

Weed control

Core technologies (guidance, detection and identification, precision in-row weed control, and mapping) are required for the successful GAP system for weed control. 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. . 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 The subsequent treatment can be a mechanical or thermal action or an herbicide application. The precise herbicide treatment using micro-dosing nozzles on the most sensitive parts of the plant further reduces the chemical use. Place and time of weed populations and the applied treatments can be registered for the GAP database as well as for the field data base (in a field passport).

Pest and disease management

Good agriculture practices reduce the incidence an intensity of pests and diseases and also the use of chemical control methods. 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. Different tools have been developed for supporting decision-making in plant disease control and include warning services, on-site devices, and decision support systems (DSSs). These decision-support tools operate at different spatial and temporal scales, are provided to private sources, focus on different communication modes, and can support multiple options for delivering information to farmers (Rossi et al., 2012).

There are indications that automatic observation of diseases may be possible at an early stage, but 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.

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. 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 an 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 neighboring crops.

There is an increasing possibility in the use of smartphones in the field to take pictures of perceived diseases or pests and send these together with the GPS coordinates of the location in the field where the picture was taken to the cloud. After some computations in the cloud the system could provide information on the kind of disease and the potential or desirable treatment. This treatment advise would then be based on the crop information (type of crop, planting date, expected harvest date) that is stored in the cloud. The advice can also include the required dose depending on the biomass density or even the micro-climate variations in the field.

d. Microbial safety

Microbial contamination can occur during the field stage and at 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.

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. 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. This may alter the future concepts of harvesting handling, sorting and packing equipment. Cleaning actions are part of the traceability system.

5. CHAIN OF TRACEABILITY

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.
A crop goes through a number of operations, transactions or shipments in the chain from the field to the c. This is even more complicated when feed and animal production is part of the chain. At each step there should be a possibility to trace the crop either upstream or downstream. It is sometimes argued that tracing one step in either direction should be sufficient and that not all data should be centralized. This requires a good communication network between potential sites where the traceability data are stored as well as access control. Cloud computing may be a way to proceed. A benefit of accessibility of data can be that in the longer term field variability related to weather and soil conditions can be extracted from such database allowing farmers or their advisors to optimize the production strategies. It is also a way to increase the expert knowledge or models for predicting what can the outcome of a treatment this year can be, given that similar production conditions may have occurred in the past. In this way, the historical traceability information is not only valuable for consumers but also for produces or other operators in the chain.

6. CROP CONDITION SENSING

It is very important that the crop condition is known and also that the crop response to a treatment is observed so that this can be taken into account for subsequent actions. It is of interest that the acquired data can yield information on physiological processes through the use of underlying physiological models rather than just statistical correlation models. In this way control actions can be based on a better understanding of the physical and physiological processes. Mechanical and optical measurement methods are considered appropriate for observing crop conditions and will be briefly discussed here.
The term texture is related to the feel of food within the mouth and as such it includes a wide range of attributes that can be measured with instrumental methods or with sensory tests. Texture properties arise from structural elements and the way they respond to forces or deformations (in the mouth), eventually resulting in breakdown of the structure and the flow of the material.
The macroscopic texture properties of fruit are determined by its cellular and histological properties such as cell wall elasticity, cell turgor pressure, and pectin content. The mechanical properties of the fruit are an important basic element to texture and the interaction of a person with the fruit in the mouth causes rupture and failure of the fruit tissue. Often, texture measurements are based on a mechanical failure test of the fruit or of a fruit tissue sample.
A number of different techniques are available commercially or in the literature to measure mechanical texture attributes. Non-destructive tests have been developed in order to monitor fruit firmness changes during storage or to be able to grade fruit according to firmness. Some methods can be considered as based on the elastic contact theory. In dynamic contact force measurements with hard spherical indenters under well-defined loading conditions, the fruit firmness is derived from the peak force, the contact duration or a combination of these. Another method is based on whole fruit vibrations. Fruits are excited either by impact a some electromagnetic excitation device. The resulting fruit vibrations are detected and the resonance frequencies determined. The latter are closely related to the elastic properties of fruits. The method yields a kind of overall measure of fruit firmness rather than a local indication.
Photonics offers many opportunities because photons are ultrafast, and extremely focusable and function contactless which opens a number of usages for agricultural diagnostics. Photonics can be the basis for measurement systems to observe plant responses at different spatial and temporal scales. Indeed, growers also can visually recognize when a problem arises or when there is a large variation in crop condition in the field. Human observation is mostly limited to a qualitative interpretation. In search for a more quantitative approach, numerous articles and reviews have been published on optical properties of crops and image analysis in relation to fertilizer use, crop stress, disease or weed detection and product quality. In most of these cases, correlations have been established between a spectrum or an image and the particular crop characteristic that one wants to evaluate. These are then mainly empirical studies that have resulted in some practical implementations.

There is more and more a need to link the measurable optical characteristics to physical and physiological processes in the crop to increase the understanding of what is happening and then better pinpoint potential actions. One approach is the use of biophysics based mathematical models that link physiological processes to observed radiation and then apply model inversion. This model inversion may not always yield sufficient sensitivity to the different physiological components that can affect radiative transfer. Models at different spatial scales are used and sometimes they are integrated which increases the computational complexity.

Plant growth or vegetation development involves several processes that each occur on a different spatial as well as temporal scale. Example of these different scales are disease symptoms on a leaf, growth or the vegetative biomass in a field or a larger area. At those different scales information is required for correct identification or classification of quality characteristics, of diseases or of plants or crops. In many cases this identification can rely on optical information taken at a high spatial resolution, but it can just as well happen that this identification is only possible through the use of high temporal frequency information. Also, in case one wants to use information for statistical process control in order to detect abnormal deviations, then it is required to have high temporal frequency information. Then there is usually a trade-off to be made between fine (or coarse) spatial resolution and low (or high) temporal frequency information since it may be impossible to have a high spatial and temporal resolution. It is a challenge to combine the data obtained at different temporal scales and different spatial scales such that useful information is obtained (Robin et al., 2005).

Variation over time of crop characteristics can be due to normal development or also due to emerging stress conditions. Again here, there may be different scales at which these changes occur. Patterns in spectra or hyperspectral images changes can be observed using time-lapse acquisition. Obtaining the information from subtle changes may require advanced image processing. Hao-Yu Wu et al. (2013) describe a method to reveal temporal variations in videos that are difficult or impossible to see with the naked eye and display them in an indicative manner.

The method, which they call Eulerian Video Magnification, takes a standard video sequence as input, and applies spatial decomposition, followed by temporal filtering to the frames. The resulting signal is then amplified to reveal hidden information.

7. VARIABILITY MODELLING AND TRACEABILITY

The advantages of having a non-destructive sensor reaches far beyond the fact that it is just non-destructive. Indeed, they offer the possibility towards monitoring individual products during the experimental period, which on its turn allows for modeling the change of quality attributes or other characteristics.

By definition, such a model will be based on a simplification of the food product and, therefore, will never be ‘true’ as the only true model is the product itself. The aim of modelling food quality attributes is, however, not to develop true models but to develop valid models; that is, models that are consistent with the current knowledge level and that contain no known or detectable flaws of logic (Tijskens et al., 2001). Also, models should be detailed enough for the intended purpose but at the same time simplified enough to give robust manageable models. The basic strategy to develop a suitable model is to apply a systematic process of problem decomposition, dissecting the problem into its basic building blocks and then reassembling them leaving out the unnecessary detail. What is essential and what is redundant depends largely on the intended application of the model. In the end, the models are to be used to provide an appreciation of the quality of the logistic handling chain and to translate this into the impact the logistic conditions have on product quality attributes (Hertog et al., 2014).

The major challenge is to develop predictive models that assess the uncertainty of the predicted result. Given a simulation model, this problem reduces to the propagation of errors from the simulation input to the simulated result. With an increasing number of random factors it becomes practically impossible to establish the correct model response. Generally some reduction is required by identifying the most important (combinations of) input parameters that capture most of the variability.

With the availability of non-destructive techniques, quality of individual product items can be monitored over time, fully characterizing biological variance within a given batch. To properly analyze such data, biological variance needs to be explicitly included into the (statistical) data analysis. A novel statistical approach ('mixed models') to model such repeated quality measures was proposed using a practical example in which the firmness change of different tomato cultivars is considered. Another novel approach based on mechanistic models further improves the interpretation of postharvest behavior, as illustrated using the color of tomato. Both types of data analyses allow quantifying different sources of variance such as variance within a tomato cultivar and within a tomato and how those sources of variance change during storage. The approaches open the door to an improved measurement, understanding and prediction of postharvest batch behavior. These approaches enable postharvest management to optimize logistics, taking into account the full range of product variation that will be encountered.

If biological variance is included in (statistical) models describing postharvest quality change, propagation of the initial biological variance at harvest throughout the whole postharvest chain can be predicted taking into all relevant aspects affecting postharvest fruit behavior.

Shelf life prediction is an important issue for fruit handling. As mentioned before, not only the average quality trajectory a batch follows needs to be estimated, but also how much the quality is dispersed around the batch average since we are generally interested in an estimation of the time at which, for example, 5 % of the fruits reach a pre-set lower bound for their quality.

The implementation and validation of such a stochastic quality change model was tested in a traceability system for tomato. Tomatoes were stored at dynamically changing temperature conditions to validate the quality change model. Belgian tomato chains were monitored from grower to retail using radio frequency (RFID) labels with integrated temperature sensors. The monitored temperature scenarios were simulated to further validate the quality change model. Experimental results showed the potential benefits of integrating quality change models with traceability systems to satisfy consumer expectations. As the temperature logging RFID labels are too expensive to put on individual boxes the alternative to use a single RFID label per pallet seems to be feasible given the limited effect of the temperature differences within the palletized fruit (Hertog et al., 2008). The model based traceability systems to monitor product quality throughout the chain can then assist in identifying the poor temperature control and temperature abuse at a given point in the logistic chain as the cause of unacceptable quality at the receiving point.

These approaches enable postharvest management to optimize logistics, taking into account the full range of product variation that will be encountered.

8. MODEL BASED STATISTICAL PROCESS CONTROL

Nowadays, agricultural production performance is usually assessed and monitored by comparing mean values of a recent measurement period (e.g. week or month) with past performances or predetermined performance standards. This is usually done without the interference of statistical analysis. But excessive variation interferes with the evaluation of performance. High variability makes performance outcome unpredictable and difficult to interpret. However, understanding variability is the diagnostic key for improving process performance (Reneau and Lukas, 2006). Two concepts which are especially interesting for performing process optimization through monitoring are Engineering Process Control (EPC) and Statistical Process Control (SPC). EPC is the whole of activities that focus on the mathematical modelling of (production) systems (del Castillo, 2002), and SPC is a collection of tools which aim at discerning between normal and abnormal process variation (Montgomery, 2005). An SPC tool which is widely used for the detection of abnormal variability is the quality control chart. The use of control charts in agricultural production, and especially in livestock production, is gaining considerable interest (de Vries and Conlin, 2003; Reneau and Lukas, 2006).

In a synergistic procedure for early problem detection, the concepts of Engineering Process Control (EPC) and Statistical Process Control (SPC) are combined. The EPC adjusted data, by means of a recursively estimated trend and ARMA model, are the input of the cusum control chart (SPC) which is able to detect registrations which result from an out-of-control situation as a result of an emerging problem or disease (Mertens et al., 2011). The signal of the control chart can be used by management for early detection of problems. A synergistic concept has been rarely applied to agricultural production. Since the data of most agricultural production processes are non-stationary and dependent, this procedure can form the basis for the development of an intelligent management support tool for agricultural production systems like diary production, pig production, crop production, etc. The synergistic concept is in most cases applied for processes changing with time, but it can also be applied for assessing spatial variability or the sensitivity of, for example, varieties or treatments to spatially variable soil conditions. It is clear that reliable sensor data must be available.

9. 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.

Novel crop sensing techniques during growth or after harvest give information o crop stress, quality, diseases, pest or weeds. Now information is available about variability of crop or product characteristics. The repeated non- destructive measurements allow for modelling of the process evolution or the evolution of quality over time (or may be also in space), thereby separating inherent biological variability from variations caused by external process conditions. These models and observations are then the basis for statistical process control and informed decision making for interventions.

The frequently asked question about the economic benefits of precision agriculture is also raised about the economic effects of food safety and safety risks along the chain. In this respect, Valeeva et al., (2004) state that acceptable levels of food safety hazards need further elaboration to clarify the process of food safety improvement for producers. They also note that it is furthermore important to gain more insight into cost-effective ways of food safety improvement throughout the entire chain and that valuation of producers' benefits along the chain and their distribution are urgently needed. Perhaps the combined economic benefits of precision agriculture and good agricultural practices for food safety and consumer confidence are underestimated at this moment.

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