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How to Assure That Farmers Apply New Technology According to Good Agricultural Practice: Lessons From Dutch Initiatives

Lambertus A. P. Lotz, Clemens C. M. van de Wiel and Marinus J. M. Smulders*

Wageningen University and Research, Wageningen, Netherlands

The application of Good Agricultural Practice (GAP) contributes to many aspects of sustainable farming, including integrated control of weeds, diseases, and pests, and optimization of fertilization and irrigation. It is a relatively neglected issue in debates regarding the application of new technology, such as genetic modification (GM), which often revolve around the intrinsic properties of a GM crop allegedly leading to unsatisfactory performance. However, the performance largely depends on the agronomic and institutional embedding of applying new technology, which generally applies to all crops, whether conventional or GM. We describe and discuss four cases in which the government or private partners in the production chain regulate this, using legal measures, incentives, or mutual agreements, or a combination thereof. These cases serve as a starting point for a discussion on how GAP can be stimulated, organized, and guaranteed. We argue that next to the government, also seed suppliers, NGOs, and buyers, as well as farmers can be drivers for the application of GAP when tools are available that enable farmers to make optimal farming choices.

Keywords: technology adoption, conditional subsidies, legal requirements, licenses to produce, licenses to deliver, farm management information systems

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****Correspondence:***
Lambertus A. P. Lotz
bert.lotz@wur.nl

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INTRODUCTION

The debate regarding the cultivation of GM (transgenic) crops has triggered a number of studies on the sustainability of agricultural production. The reports (Franke et al., 2011; Lotz et al., 2014; National Academies of Sciences, Engineering, and Medicine (NASEM), 2016) clearly indicate that the sustainability of GM crop cultivation depends not only on the GM trait, the crop, where in the world it is cultivated, and socioeconomic and institutional characteristics of that region, but also strongly on whether the cultivation is performed according to Good Agricultural Practice (GAP). This is true for all agricultural innovations, and, in fact, it was already known for a long time (Luning et al., 2006).

One example is the use of herbicide-tolerant maize, soybean, and oilseed rape varieties, most of which are GM. Whether or not weed control using such varieties is more sustainable than without them depends strongly on whether GAP is followed (Franke et al., 2011; Mortensen et al., 2012; National Academies of Sciences, Engineering, and Medicine (NASEM), 2016). GAP requires the effective use of modern agroecological knowledge and measures of prevention, and also the alternate use of different mechanisms or mode of actions of weed control.

The most used type of GM herbicide tolerance provides tolerance to glyphosate. Overly heavy reliance on the exclusive use of glyphosate in weed control, year after year since the introduction of the crops in 1996, has led to the development of glyphosate-resistant weeds. To combat these, farmers have started to use more glyphosate or to combine it with other herbicides (Mortensen et al., 2012). This is contrary to GAP. Notably, based on insights from weed science and agronomy, rotations have been proposed, in which the use of a glyphosate-tolerant crop, for example, once every 4 years, could be environmentally advantageous (Lotz et al., 1999). This would, be a good supplementary measure to mechanical weed control, as it tends to select higher densities of perennial weeds over the course of time. The targeted use of herbicide-tolerant crops would also conform to new management systems that employ automated GPS-based weeding machines and other advanced technologies (e.g., Young et al., 2017). However, this idea has not been adopted until now, neither in the Americas where many farmers still rely only on glyphosate, nor in Europe where farmers do use rotations, but did not have the opportunity to include GM herbicide-tolerant crops in the rotation.

With regard to the control of weeds, pests, and diseases, GAP measures are identical to those of Integrated Pest Management (IPM) (Barzman et al., 2015). In insect-resistant crop varieties based on transgenic Bt, implementing IPM is essential to maintain the sustainability of the Bt resistance over the years and, thus, to maintain the advantage of lower insecticide usage. This means that resistance development in the pest insects needs to be mitigated, which is generally done using the so-called high-dose/refuge strategy (Kos et al., 2009). Alternatively, new transgenic varieties using other Bt variants with different modes of action (targets) can be developed (Carrière et al., 2016).

A third example of the relevance to grow innovative crops according to GAP is the need for IPM to prevent pathogens from overcoming resistance genes in host plants. Late blight-resistant potatoes are based on the introduction of classical resistance genes, whether introduced by traditional introgression (e.g., Nuijten et al., 2017) or by transformation (cisgenesis, Haverkort et al., 2016), and their cultivation leads to lower fungicide usage. The causative pathogen, the oomycete *Phytophthora infestans*, has been shown to notoriously quickly overcome single gene-based resistance. Therefore, pyramiding of multiple resistance genes in a potato variety and careful monitoring of resistance development are necessary, supplemented with fungicide application whenever a resistance gene is in danger of being broken. A decision-support system has been developed for this purpose, using resistance monitoring and weather data to model and predict the development of the disease. This enables potato growers to sustain late blight resistance with as little use of fungicide as possible (Kessel et al., 2018).

This perspective paper poses the question as to how to organize such IPM—as GAP principle—in a commercially driven production chain, to keep farmers from choosing strategies that are only cost-effective in the short term, such as to only use glyphosate or varieties with a single disease resistance gene without additional measures.

Liebman et al. (2016) reviewed the literature extensively to find reasons as to why worldwide farming practices often deviate from GAP. Their focus was on weed control and they came up with the following impediments:

1. Inadequate policy instruments to selectively reward particular growing practices or discourage others.
2. Insufficient commercial incentives to encourage changes in cultivation practice.
3. A shortage of extension facilities for training farmers in GAP and enabling them to make informed decisions on cultivation measures.

Below we discuss four distinct cases in which GAP was or is organized and, where possible, certified, and assess in which way and to what extent the above-mentioned impediments were addressed. These concrete cases are derived from well-documented cultivation practices in The Netherlands and based on discussions with parties involved in the primary production chain and on the literature study. For each case, we assessed which elements and experiences could be helpful for guaranteeing that new technology in agriculture is used according to GAP principles.

CASE 1: WEED CONTROL IN MAIZE (AN EXAMPLE OF AN INCENTIVE BASED ON A CONDITIONAL SUBSIDY)

In the framework of a revision of the Common Agricultural Policy in the EU, the level of income support for farmers was connected to methods of weed control in The Netherlands. In order to receive a full premium, a farmer had to apply a maximum of 1 kg of active ingredient for weed control in maize in combination with a minimum of one full field application of mechanical weed control. Within a short period of time, this cultivation system was applied on around 80% of the Dutch maize acreage (Lotz et al., 2002). The reasons for this fast adoption were lying in a good basis from weed research, effective extension (e.g., Van der Weide et al., 2004), and a clear financial advantage to the farmer. In 2005, this "cross-compliance" arrangement was repealed. Van Zeeland et al. (2009) studied the effect of this repeal on weed control in maize, and they found, for the period after 2005, a decrease of about 70% in mechanical weed control, accompanied by an increase in herbicide load of surface and ground water.

One can conclude that the "cross-compliance" arrangement was effective in promoting adoption of integrated weed control in maize. The three impediments listed by Liebman et al. (2016) were effectively addressed: (1) there was an adequate policy instrument, that is, a conditional subsidy provided by the government; (2) there was sufficient financial benefit for the farmer to invest more in mechanical weed control and, in some cases, to incur a higher risk of insufficient weed control; and (3) there was effective support from research and extension. Simultaneously, there was no assurance for sustaining the practice in the longer term: as soon as the "cross-compliance" arrangement ended (2005), the maize growers, or the contractors, to a large extent, returned to a largely herbicides-based weed control.

CASE 2: POTATO VARIETY: AVITO (AN EXAMPLE OF AN AGREEMENT BETWEEN PRIVATE PARTNERS)

Averis Seeds B.V. is a subsidiary of cooperative Avebe, a company that produces starch and protein from potatoes. Averis is involved in the development, multiplication, and trade of starch potato varieties, and has plant breeders' rights on varieties that are grown in the starch potato cultivation areas in North East Netherlands and North West Germany. One of these varieties is Avito, which is a conventionally bred variety with one resistance gene against late blight. To prevent the pathogen *P. infestans* from overcoming the single resistance, Avito seed potatoes are supplied to growers under a contractual obligation to sustain resistance by applying fungicide as advised by a decision-support system. The seed potatoes of this variety are slightly more expensive than other potato starch varieties, but the grower is financially better off because far less fungicide spraying is necessary (on average 4 instead of 15 times per growing season). Avebe-Agro decides when spraying needs to be performed, an important criterion for successful compliance is the absence of *P. infestans* in the crop.[1]

In conclusion, there is a net financial benefit of applying GAP for farmers, and the seed suppliers provide a decision-support system for successful cultivation. Thus, impediments 2 and 3 listed by Liebman et al. (2016) have been targeted by the producer of the variety.

CASE 3: CERTIFICATION (AN EXAMPLE OF EXTRA-LEGAL DEMANDS BY THE BUYER)

For guaranteeing food and feed safety, several certification systems have been developed from the demand side in the agricultural production chain in The Netherlands in the last two decades. Van den Brink et al. (2012) gave an overview of certificates used in arable crops:

- VVAK (food and feed safety arable farming) for cereals, sugar beet, and potato
- VVCs (food safety certificates) for potato, sugar beet, vegetables, and grains for processing industry, seeds, and pulses
- GMP+ B6 for feed production (maize)
- GLOBALG.A.P.
- Qlip (dairy chain: maize and grass).

These certificates are mainly based on farmers' registration of cultivation measures. With VVAK and VVCs, farmers comply with EU Regulations on the hygiene of foodstuffs and feed, (EC) 852/2004, and feed (EC) 183/2005, respectively. GLOBALG.A.P. also uses registration of cultivation measures for certifying food safety, but additionally aims at promoting GAP by stipulating a number of actions according to IPM (Van den Brink et al., 2012).

A step further in the promotion of GAP is the certification scheme by Stichting Milieukeur ("Foundation Eco-label"), which comprises a comprehensive list of criteria for arable crops and field-grown vegetables.[2] This ecolabel initially met with little support in the market (impediment 2 in Liebman et al., 2016). Recently, there was a trend, incited by NGOs, of retailers (supermarket chains) declaring themselves in favor of purchasing only those products that comply with specific cultivation methods (described by Hees et al., 2016). Several Dutch retailers stated that, from 2019 onward, their mainstream vegetable and fruits should be produced according to this ecolabel. Another large Dutch retailer announced that, before 2019, products sold by them should have been cultivated without the use of 28 crop protection products with the highest environmental impact. Where these obligations for suppliers in the product-market chain extend beyond legal obligations for labels, etc., retailers refer to them as "extra-legal" practices.

CASE 4: LEGAL REQUIREMENTS (AN EXAMPLE OF BINDING RULES)

For the market introduction of a crop protection substance, a permit from registration authority Ctgb (Board for admittance of crop protection substances and biocides) is required in The Netherlands.[3] Admittance is accompanied by the user's instructions that need to be specified on the label of the substance. These legally binding instructions are enforced by the NVWA (Netherlands Food and Consumer Product Safety Authority) and, in fact, guarantee a basal level of GAP. Crop protection product labels also offer opportunities for additional instructions supporting GAP, for example, to follow a particular decision-support system to mitigate resistance development in the targeted pathogen or pest. Such instructions are not enforced by NVWA.

In the past, there was an additional system in The Netherlands for guaranteeing compliance with particular cultivation measures for GAP. Obligatory measures were drawn up and enforced according to disciplinary rules by the Commodity Board for Arable Farming. Dutch commodity boards represented entire production chains and had the authority to lay down rules that were binding all companies in their sector, to ensure that issues that concern the entire sector and society might be resolved without disrupting competitive conditions. An example of such public-law ruling is the obligation to control potato volunteers to avoid the spread of plant diseases (e.g. *P. infestans*) and pests (e.g. Colorado beetle). At the recent discontinuance of the commodity boards, most cultivation rules have been moved to the "Plantenziektenwet" (Plant diseases and law) and the "Wet Zaaizaad en Pootgoed" (Sowing seed and plant materials law) enacted by the Ministry of Agriculture, Nature and Food Quality, and these rules will now be enforced by NVWA.

[1] http://www.averis.nl/Rasseninformatie.aspx.

[2] http://www.milieukeur.nl/Public/Milieukeur_Agro_Food_Plantaardig_open_teelt_Schema/2017/MilieukeurOpenTeeltCertificatieschema2017-AKV.pdf.

[3] http://www.ctgb.nl.

The user's instructions on labels of crop protection substances and the afore-mentioned cultivation rules provide a minimum of guarantees to lift impediment 1 listed by Liebman et al. (2016). Further promotion of GAP along this path would entail taking up additional rules in the plant (disease) laws.

DISCUSSION

Measures that assure that farmers grow crops with specific IPM measures, or under GAP principles in general, while there are incentives to focus on cost-efficient agricultural practices in the short term, help to enhance the sustainability of farming. However, such practices are also relevant for societal discussions about the pros and cons of the use of new technology in primary production.

The four cases described above brought us from a government steering through conditional subsidies, along agreements between private parties from both supply and demand sides, back to a government enacting legally binding rules for GAP. Each case illustrated a particular approach to address the impediments to applying GAP as listed by Liebman et al. (2016), that is, inadequate policy instruments, insufficient commercial incentives, and/or a shortage in research and extension facilities.

As seen in two of the cases, governments have various instruments to provide incentives to apply GAP, including setting rules (e.g., seed law, labeling) and conditional subsidies for desirable cultivation methods. Both may be effective, but fine-meshed rules or subsidies may not be seen as the most efficient or desirable in the political debate. Whether or not to follow this route is in the end a political decision.

Likewise, the route of self-organization of a sector through product boards has recently been abandoned in The Netherlands because of perceived contradictions between the compulsory nature (enforced levies) of these organizations and the goal of full and open competition among enterprises. The sector is presently looking into developing alternatives for some of the collectively organized activities.

Which feasible alternatives exist as incentives to use GAP? We have seen an example of a seed provider ensuring the proper use of its proprietary plant materials through contracts with its growers. In this example of a "license to grow," the position of the seed provider was extra strong because it was also the primary user of the harvest (starch potatoes) for processing. Other examples of rules imposed by the seed supply side exist. The providers of GM crops also use contracts that include measures to promote so-called stewardship. This has encountered mixed success, for example, in Bt (refuge compliance) (e.g., National Academies of Sciences, Engineering, and Medicine (NASEM), 2016). In herbicide-tolerant crops, overreliance on a single herbicide in the crop rotations was often not prevented in the United States, leading to problems with resistant weeds (Mortensen et al., 2012; National Academies of Sciences, Engineering, and Medicine (NASEM), 2016).

For the cisgenic late blight-resistant potato in the DuRPh program (Haverkort et al., 2016), it was proposed to enforce proper resistance management through licenses on patents that would require application of GAP. Suppliers may also demand such practices while giving licenses for varieties for which they own plant breeders' rights. In the end, the efficiency will depend on the extent to which the seed provider is able to enforce obligations to follow GAP in the face of competition with other seed providers.

Likewise, from the demand side, there is a requirement (incited by NGOs) to also implement obligations beyond legally existing ones (as "license to deliver") for the way the products they buy are cultivated. Are these enforceable in a competitive environment? Large retailers may be expected to be influential in this regard and to be able to set up a reliable certification system. One of the risks is the multiplication of different labels, which may confuse consumers.

An intermediate situation exists in the form of an ecolabel. Such a label provides rules for farmers and gives a choice for consumers in shops, without the notion or ambition to modify all production at once. Their success depends on the willingness of the consumer to pay the price premium, and on the cogency of the label. The strongest label in shops is that of organic agriculture, but this is targeted to a particular view on GAP, and, for example, requires the *a priori* exclusion of some innovative breeding techniques (Nuijten et al., 2017).

We used Dutch examples that represent four different approaches to tempt (case 1) or oblige (cases 2–4) farmers to work according to GAP. We argue that these approaches are applicable worldwide. Often, farmers already express their desire to work in the most sustainable way, but lack the tools to do so or to make the optimal choices. This may at least partly be addressed by research enabling a commercially viable implementation of GAP by farmers. We have described decision-support systems (run by companies) that can bring down the use of pesticides without affecting yields for growers. The higher costs for resistant seeds are offset by higher revenues because of lower pesticide use while at the same time crop resistance is sustained. Such decision-support systems are currently also developed directly for farmers, to enable them to implement the optimal management and save money, and are made applicable in farm management information systems (Fountas et al., 2015). An example of such an improved extension in The Netherlands is the farm management system "Akkerweb," which uses GPS-based location information and includes, for instance, a "Phytophthora module"[4]

We foresee that further exploration of electronic tools and models will help ensure further development of more sustainable food systems, for farmers all over the world. The underlying science of agronomy provides insights into smart combinations of crops and measures. At the same time, new technological developments will continue to evolve, be it automated equipment for precision agriculture, better crop varieties, or crop varieties made with new plant breeding techniques that may have to be tailored for specific environments. The implementation of such technology into agriculture can be the starting point for a wide societal dialogue about how to

[4]https://akkerweb.eu/en-gb/Home/phytophthora-module.

organize and guarantee GAP now and in the future, to ensure an optimally sustainable food production for the twenty-first century.

AUTHOR CONTRIBUTIONS

LL initiated the article, selected examples, and was involved in writing, CW was involved in the literature study and writing, MS was involved in writing. All authors contributed to the discussion about the examples and approved the final version of the article.

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