Chapter 2. Inventions for future sustainable development in agriculture

Evert Jacobsen[1], Pieter J. Beers[2] and Arnout R. H. Fischer[3]

[1]Evert.Jacobsen@wur.nl; TransForum and Plant Breeding, Wageningen University, Wageningen, The Netherlands

[2]PJ.Beers@wur.nl; TransForum and Education and Competence Studies, Wageningen University, The Netherlands

[3]Arnout.Fischer@wur.nl; TransForum and Marketing and Consumer Behaviour, Wageningen University, Wageningen, The Netherlands

Abstract This chapter is directed to the importance of different inventions as driver for sustainable development of agriculture. Inventions are defined as radical new ideas, perspectives and technologies that hold the potential to trigger a change in sustainable agriculture. Innovation is based on one or more inventions that can bring a major breakthrough or have a smaller impact. Inventions can be science driven or society driven. They have been crucial in history of the existing agricultural knowledge infrastructure and will remain important in the future as driver for sustainable development. The main difference with the past is that inventions and their implementation will not always follow the old linear process of fundamental – (university), strategic – (research institute) and applied research with extension – (applied institutes) but that these processes are often non-linear and more complex, including society. For inventions to become successful innovations and to prevent negative side effects not only technical hardware elements of an invention are important but also software and orgware elements. Another important prerequisite for innovation through inventions is value capturing through entrepreneurship. Nowadays in agricultural life sciences patent rights are introduced which have to co-exist with, for example, plant breeders' rights in plant varieties with its principle of breeders exemption in order to preserve open innovation. Lessons learned show that new solutions aiming at sustainable development can be organized by intersectional inventions, directional inventions or open innovations sometimes followed by a switch between them.

2.1. Inventions – an introduction

An invention is the result of a highly creative process with outcomes beyond what is currently known. Inventions are initial ideas that may either require further elaboration, development or analysis to assess their true potential. After this, they

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can become the input around which innovations for sustainable agriculture are organized. In this chapter we define inventions as radical new ideas, perspectives and technologies that hold the potential to trigger a change. In this context, an invention is 'creating something that did not exist before' leading to new ideas for products and processes and an innovation is 'thinking creatively about something that already exists' (Branscomb and Auerswald 2002). An invention becomes an innovation when it is widely implemented and used in society. Recent inventions that have led to innovations are the Internet, e-mail, mobile telephone, nano-technology, biotechnology, and the concept of energy producing greenhouses.

Inventions play an important role in all sectors of our society, including in the agricultural sector. As they have played an important role in the development of our agricultural system in the past, inventions can and should be of importance as a driver for innovations towards a sustainable development of agriculture in the future (Leeuwis et al. 2006). However, as already addressed in Chapter 1, society has become an important stakeholder in development processes. Nowadays inventions are much easier debated in society than in the past (Smits 2002). Such discussions in society have focused on the benefits of the inventions, but can also constrain the use of a new invention, therewith limiting its potential to become an innovation. The main reason for this change is the increased awareness of society for all kinds of potential negative side effects of inventions and their implemented innovations for environment and health.

For innovation towards the sustainable development of the agricultural sector, it is important to know what positively or negatively influences inventions and how inventions can be positively directed in the future. Thus the questions are: What aspects are of importance to turn inventions into successful innovations? Is it possible to select inventions directly, including an understanding of their limiting conditions, in such a way that they improve sustainability?

This chapter aims to describe and discuss the most important elements of inventions for innovations in agriculture, and how the development and use of future inventions could be steered in such a way that they have a higher potential to turn into innovations. The chapter first discusses roles, types and aspects of past and modern inventions that influenced their success in Section 2.2. It proceeds in Section 2.3 with ways of stimulating inventions into an innovation using various examples of success. The chapter concludes in Section 2.4 with a short discussion on lessons learned and the expected future role of inventions for sustainability in the agro innovation system.

2.2. Inventions in agricultural infrastructure

In 1798 Thomas Malthus predicted that the world could not feed an exponentially increasing population. His prediction did not materialize. New inventions have been tremendously important to support sufficient agricultural production (see

Figure 1.2 in Chapter 1 for yield increase due to the green revolution). At this moment we stand for another major challenge. The world should be able to feed a doubled population by 2050 and at the same time do this in a more sustainable way. It is without any doubt that new inventions will be crucial to stimulate and enable a sustainable development in today's and future agricultural production. Inventions have helped before to allow for the required productivity increase and should now be aimed simultaneously at people, planet, and profit aspects.

To get a grasp of how inventions and their subsequent innovations are influenced, we discuss two main contextual factors that must be considered on how inventions can be implemented towards innovation for sustainable development. The first factor deals with the ownership of inventions and the different modes of how to handle that. The second factor deals with the conditions necessary to transform inventions into innovations. These factors are illustrated by inventions from the agricultural sciences.

2.2.1. Ownership issues: Inventions, innovations and IPR

2.2.1.1. Ownership and agricultural inventions of the past

The green revolution inventions were characterized by an open innovation structure. Inventions were not protected by Intellectual Property Rights (IPR) and, therefore, available for everybody. This improved food security in many countries significantly. New varieties with a higher yield could be used by everybody. Two major inventions of the green revolution are discussed here are (1) breeding of short straw cereal varieties and (2) hybrid varieties with modern plant production techniques transforming agriculture by using more fertilizers and pesticides[1] (Borlaugh 2000a, 2000b). Both are typical ways of a linear innovation where a scientific finding is transferred onto the market by a process of fundamental – (university), strategic – (research institute) and applied research with extension – (applied institutes) and limited societal influence.

The first successful examples of an open invention are 'dwarf mutants' of wheat and other cereals. Those new varieties have much shorter stalks because of a dwarf mutation (Salamini 2003; Fig 2.1). This invention enabled the development of modern agricultural technology in cereals. It had a major impact on global scale, mainly because a system of plant breeders' rights (PBR) protected the ownership of the new invented variety, without limiting others to use the new variety as breeding parent and improve on it. The foundation for these rights was drawn up by the International Union for the Protection of New Varieties of Plants (UPOV). The Convention was adopted in Paris in 1961 and revised in 1972, 1978

[1] Besides its major advantages, the green revolution has afterwards also been criticized as one of the first examples of being not sustainable and partly reducing agro biodiversity because of less use of locally adapted varieties.

and 1991 (for a more elaborate discussion on the reasoning behind the PBR as a 'sui generis' system being distinct from patent rights see Rimmer 2003 and Dubois 2001).

The system of plant breeders' rights allowed breeders to use UPOV protected varieties as crossing parent in breeding programs of competitors to create new varieties (breeders exemption). This means that all traits in the protected varieties can be used for free in any new variety. UPOV protects the genotype of the plant, but not the new trait or its genetic background. In this way, a new variety with a new trait can be replaced quickly by a newly improved variety of a competitor. As a result, short straw varieties could also directly be developed in developing countries using locally adapted plant material. This invention tripled cereal production since the 1960s, changing India into a wheat exporting country (Borlaugh 2000a, 2000b).

Fig. 2.1. The benefits of being short. A: Varieties from early 1900s were as tall as a normal person. B. modern short straw varieties have much shorter stalks because of a dwarf mutation (Salamini 2003).

A second important example is the concept of hybrid varieties. The concept of hybrid varieties was practiced, more than 90 years ago, in the USA in maize, vegetables and other (cereal) crops (Crow 1998), and was introduced in Europe more than 60 years ago (Marton et al. 2003). Hybrid varieties are based on crosses between two inbred lines with optimal combination ability for yield. Because of hybrid vigor, hybrid varieties increased yield up to six fold.

Integrated into the 'hybrid invention' is the natural breeders' seed protection. Due to the impossibility to multiply the same hybrid seeds on the hybrid plant itself the seed is intrinsically protected. This way of seed protection has triggered hybrid breeding and seed trading of many (vegetable) crops, also in countries with absence or weak implementation of UPOV breeders' rights, resulting in the establishment of a number of strong seed companies worldwide (Anonymous 2009a).

These two examples from past inventions show that plant breeders' rights have been a successful factor to stimulate new inventions. It is a way in which open innovation is ensured, while still protecting new varieties. In general it can be said that this open system of plant breeding added a yearly yield increase of 2–3%.

2.2.1.2. Ownership and modern inventions in agricultural sciences

One of the emerging fields in agricultural life sciences is (green) biotechnology like 'omics', including genomics, proteomics and metabolomics, and genetic modification of organisms (GMO). Gene technology related to agricultural sciences, such as gene transformation or genetic modification (GM), is of importance for plant breeding (Bevan 1984). It can for example increase resistance of crop plants to (a)biotic stress caused by climate change, or reduce chemical use in crop protection. This field is also called the 'gene revolution'. In contrast to the green revolution, the gene revolution is much less open and increasingly subjected to industrial patent system. One of the main differences between PBR and patent rights (PR) is breeders' exemption which is allowed within PBR but not within PR and also not when a variety has been protected by both PBR and PR, at the same time. This double protection is valid, for example, when single PR protected traits have been inserted into the plant or protected methods have been used. Originating from the chemical and pharmaceutical industry, PR has been extended to cloned genes (Cohen and Boyer 1980) and biotechnological procedures (Bevan 1984) in the last few decades.

This development in ownership has allowed private companies to license inventions. In the USA, the Bayh-Dole Act[2] gave universities and institutes ownership of discoveries by PR rather than making them freely available in the public domain (Zilberman et al. 2001). This possibility of licensing of PR has greatly improved the transfer and application of technologies from universities to the private sector, but there are some serious drawbacks. Exclusive licensing PR of an invention to a single private (breeding) company has the potential to limit the usage of the invention to the larger benefit of society by other companies during the protection period.

In the future inventions can play an important role in relation to sustainable development. To feed the world and to replace petrol-based chemicals and fossil fuels, the maximum potential yield of crops has to increase. Inventions can open doors for new developments. For example, in nature, several pathways for photosynthesis, like C3 and C4, are found. Their photosynthesis efficiency is different as, for example, observed in C3- and C4-crops (Monson and Moore 1989). Developing plant varieties with the most efficient photosynthesis mechanism would increase the energy production by the plant to the benefit of the yield. An invention that may support this is to increase efficiency of photosynthesis by molecular biotechnology.

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[2] P.L. 96-517; The Bayh-Dole Act, 1980.

However, exclusive rights and use of those inventions is not desirable, because a broad and quick implementation of inventions that can serve sustainability is required. The common interest of society may be better served in other ways, such as non-voluntary or compulsory licensing of patents (Reichman and Hasenzahl 2003).

2.2.1.3. Open innovation under attack

The earlier described examples of yield increase by the introduction of dwarf mutants and hybrid varieties show how open innovation in plant breeding can benefit agricultural production and the agricultural sector as a whole (Borlaugh 2000a, 2000b). This open competition model ensures that none of the involved companies can block progress of societal importance. It also ensures that new traits become available worldwide quickly. Still, the competition model is very clear: only the variety is protected, not their traits or genes. Breeders know how they can earn money.

Although the introduction of PR in agricultural life sciences is considered to be very important, in plant breeding, it affects the open competition model ensured by the UPOV system when more varieties are introduced with GM traits, protected by PR (Jacobsen and Schouten 2009). The present interpretation of using PR in life sciences does not allow breeders' exemption. The result will be that breeders have free availability of new traits from normally bred varieties but no availability during the protection period of GM-traits from varieties with patent protected traits. Increasing reliance on patented GM-traits will frustrate the existing open breeding system. This PBR system has so far been ensuring a rapid and widespread availability of successful traits in a sufficient number of different genetic backgrounds worldwide and in the existence of a financially well performing private breeding sector.

An additional complication in the co-existence of PR and PBR in the near future is the expectation that the same traits will be available in classical PBR protected varieties and in PR protected GM-varieties. For example, it is expected that certain (resistance) genes will become available in classical varieties, and that the same trait with the same gene will be present in GM-varieties which are not freely available for breeding. The only, if any, difference between these varieties might be the location of the resistance gene in the plant genome. This will make the resulting PR discussion highly complex, because it is not clear whether the gene can be used as being the outcome of classical breeding, or whether it is protected by GM patents. This can result in increasing numbers of genes coding for important traits which are not freely available for variety breeding, causing a slow down of yield gain worldwide.

In sum, the co-existence of both PR (representing more closed innovations by patents rights) and PBR (representing more open innovation by plant breeders' rights) in one variety demonstrate that the rules and regulations related to:

1. PR will result in a slowdown of the rapidity of optimal variety development, because of the lack of free availability of important GM-based genetic variation, and;
2. PBR is not stimulating expensive investments that are needed for quick progress with important cloned traits because of aspects like breeders exemption and farmers privilege.

Besides their individual advantages, consequences of the co-existence of PR and PBR are negative in relation to the sustainable development of agriculture and world food production. This problem should be solved in a satisfactory way, which allows the beneficial aspects of both systems. One compromise could be to continue with both protection systems under the condition of breeders' exemption (Jacobsen and Schouten 2009), which requires the owner of a patent to agree with free license to breeders' exemption of newly introduced GM-traits and the breeder of the new variety to pay a reasonable license fee afterwards.

2.2.2. Organization of inventions and innovation

The way inventions are organized can greatly influence their potential for implementation to become an innovation. Many inventors still try to innovate linearly. Nowadays, inventions for sustainable development have to be seen in a complex interaction between human creativity, technology and the market place. They can no longer be considered as driven strictly by technology and basic research (Smits and Boon 2008). The increasing influence and involvement of society on the actual innovation based on an invention is important to recognize. Hence, it is important to know how the implementation of inventions can be made more smooth and successful. Below we discuss some aspects that are of importance for realizing actual innovation.

2.2.2.1. 'Ware' elements of inventions and entrepreneurship

Innovation is a complex process that takes place at the level of specific products, business and sectors as well as at the level of (inter)national communities (Smits 2002). Successful innovation is a fruitful combination of different elements from technical, societal and economic point of view. Inventions and the innovations connected to them should nowadays take into account different 'ware' elements (Leeuwis et al. 2006; Anonymous 2003):

- *Hardware* which relates to the material innovation;
- *Software* referring to the new skills and knowledge to use and implement the invention (including tacit knowledge); and

- *Orgware* referring to new organizational and institutional conditions, influencing development and functioning of innovations (Smits 2002). This also includes regulatory frameworks, modes of operation with regard to IPR, role and influence of public opinion, etc.

In case of a lack of balance between the different 'ware' elements, the application of an invention may be limited or may even lead to a complete blockage by society. Failure to adequately address the food-specific concerns in society has influenced the success of 'green' biotechnology for GM crops, whereas the 'red' (health) and 'white' (industrial) biotechnology are more accepted in society (Lelyveld 2009). Similarly, society is reluctant or even negative towards modern, highly-productive animal production systems (Ten Napel et al. 2006).

Two different lines of reasoning explain the misfit between technological possibilities and societal acceptance. It is hypothesized by some that natural sciences have made larger progress in understanding natural processes than social scientists in understanding social processes and behavior (Norman 2005). From this point of view, it seems that social sciences are lagging behind to keep up with knowledge on societal acceptance of technological developments. Against this, it can also be argued that it is the late involvement of social sciences and public participation which has resulted in a lack of understanding of contemporary societal requirements for important innovations. This led to mistakes by important stakeholders in the initial introduction of for example GM products, which has created a lastingly hostile atmosphere in European society towards these inventions.

To overcome hostility towards inventions like GM crop development and highly productive animal production systems, the polarized debate must be turned into a dialogue to look ahead. Psycho-societal solutions among the stakeholders have to be found, which may take considerable time (Termeer 2009). Orgware elements are important to incorporate in order to overcome this challenge.

Nowadays, basic research programs allocate part of their budget to social and ethical research, to incorporate specific knowledge about societal implementation of inventions. In this way, soft – and orgware elements are set on a comparable level as hardware elements of research. However, to get the right balance between the ware elements, budgets should not only be set side-by-side. In our view, an integration of the ware elements is needed for the right balance, meaning that the ware elements should be naturally implemented together from the beginning and implementation of the development.

Entrepreneurship may be the key to effectively combine the needed hardware, software and orgware elements of inventions into a driver for innovation. An entrepreneur converts a new idea (invention) into a successful business (innovation) (Druckner 1993), turning ideas into cash. Entrepreneurship is crucial to provide prove of principle and drive stages towards the market, making an invention into an innovation. Besides the three ware elements of an invention, commercialization of the invention via entrepreneurship is equally important, (see Figure 2.2; MacGill and Outhred 2004). This, of course, requires a market demand for the new product and/or services of the invention.[3]

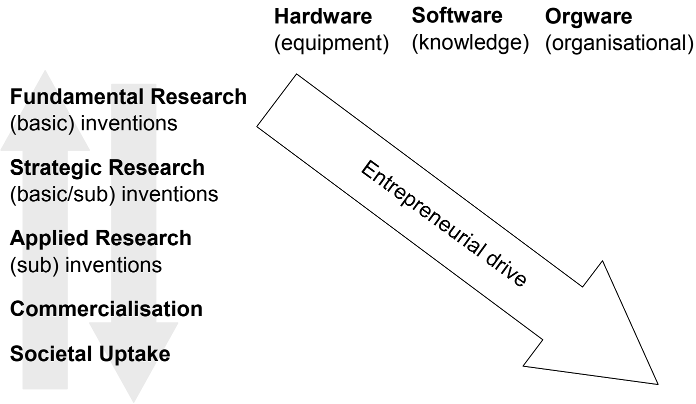

Fig. 2.2. 'Ware' elements of inventions obtained in research and their role in technical innovations and commercialization by entrepreneurship.

This section has described several aspects that are important for inventions and to turn an invention into an innovation. In sum, open innovation with protection of plant breeders' rights can boost new inventions that are needed for the sustainable development of the agricultural sector. Therefore, co-existence problems between PR and PBR must be solved. Additionally, to realize a successful innovation based on an invention, one should integrate hard,- soft- and orgware elements and ensure the commercialization of the invention.

2.3. Three ways to stimulate needed inventions

Since the need for a more sustainable development in agriculture calls for specific improvements on the performance of agriculture with respect to people, planet and profit aspects, it should be possible to stimulate inventions into those directions. So, instead of waiting for new inventions to occur as a result of serendipity, the question arises whether it is possible to select inventions directly, including an understanding of their limiting conditions, in such a way that they improve sustainability. Based on our experiences and recent publications on organizing innovations, we see three different ways of stimulating the needed inventions:

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[3] In this chapter we will not go further into this issue, see Chapter 5 for an in depth discussion on the organization of market demand in sustainable production chains.

1. Organize so-called 'intersections' that address the challenges
2. Stimulate directional inventions
3. Enhance the process of open innovation.

This section illustrates these three ways with examples.

2.3.1. Intersectional inventions

Intersectional inventions are inventions originating from an intersection between different fields of expertise (Johansson 2004). This can be between different cultures or between realms of knowledge. The intersection is where ideas from different cultures, disciplines and fields meet causing many different inventions. At present the most important factors involved in this process are convergence of sciences, the movement of people, and the explosion of computation. Recent examples of such creative mash ups of knowledge are high tech applications such as Google Maps and Google Earth, e-commerce, biotechnology, nanotechnology but also organic farming. An important aspect of intersectional inventions is that they often need new or adaption of existing legislation, which introduces societal debate into the new issue (Yanarella 1975).

2.3.1.1. Organic agriculture

The invention of organic agriculture started in a more general debate with many disciplines involved, within as well as outside the agricultural sciences (ecology, nature, human health, philosophy, ethics and religion). The development of organic agriculture is taking place in a multi-stakeholder setting and orgware elements were addressed from the start of the invention. As a result, sufficient flexibility in the regulatory system has been created by (provisional) derogations to overcome specific problematic hardware elements, such as the use of organic manure, residue issues of pesticides and availability of organic seeds. Derogation to certain aspects of the regulation were granted and accepted without negative reactions from society (Jacobsen and Schouten 2009). The organic agriculture trend is mainly driven by society and is based on a philosophy highlighting the intrinsic value of nature. Organic agriculture has created a niche market that provides a societal accepted and conceived form of sustainable agriculture.

Organic agriculture is a good example of an agricultural production system where an orgware and software driven approach has taken precedence, and where the strong position in relation to these wares contributed to solving hardware problems. The case of organic agriculture demonstrates that engagement of societal actors early in the process of innovation reduces the challenges and risks an invention meets on the way to wider adoption.

2.3.1.2. GM crops

The invention of GMO has had a very broad impact on all aspects of life sciences. The agricultural green biotechnology with GM plants and animals is still under critical discussion. Because of that, regulation for the release of GM plant varieties is highly complicated in Europe. Negotiations on GMO-regulations and the import of the first GM soybean (resistant to herbicide glyfosate) was the starting point for open disagreement between societal parties involved in the debate.

The combined invention of gene cloning and genetic modification of micro-organisms, plants, animals and for human health was originally science driven but has adopted many intersectional aspects. GM crop production has become the main example of limited application of an invention in important global markets due to its lack of acceptance within society. The history of this invention distinctly differs from organic agriculture, yet has one interesting similarity. One of the main differences is the starting point. In organic agriculture the starting point was focused on a philosophical idea on how to go forward with more sustainable agricultural processes. The starting point of the GMO invention became more focused on the approach and due to misalignment with societal drivers focused almost exclusively on rules concerning the risks of the technology rather than the benefits and solution of sustainability issues (Anonymous 1998).

An important other difference is the outcome of discussions about GMO compared to organic agriculture with the involved stakeholders and the prevalence of safety issues. Interestingly, these discussions on safety regulation development involved the same type of actors as those involved in the discussion on organic regulations: government, science, branch organizations and non-governmental organizations (NGOs). What caused a different outcome of discussion? First of all, the GM invention was a science driven invention, rather than society driven. At the start, the actors that were involved in the discussion had different backgrounds and starting points about the desirability and need for the application of GMO and, therefore, were not involved in the underlying philosophy of the invention. Also, opposite to the organic agriculture debate, large industries were involved in the discussion from the early days, introducing a different power balance. This all caused disagreement and lack of harmony in the discussion, eventually resulting in a societal drive towards detailed description and application of rules in the different fields of GMO application, especially in the European Union.

The outcome today is that the invention of GM-crop production is very successful outside Europe. In most cases only multinational companies are able to develop GM-varieties, due to the strict regulations. These companies can spend enough money to fulfill the highly demanding requirements that are needed to allow release of a GM variety onto the market. This makes GM-varieties very expensive. The estimated cost of getting a single GM-variety to the market is 6 to 7 million euro (Schenkelaars 2008). This is much higher than conventionally bred varieties, where expensive safety regulations are not playing a role, and makes

GM technology mainly applicable to big field crops, such as maize, cotton and soybean. The protests of the NGOs against GM crops did improve the position of multinationals in this field and weaken that of smaller, private breeding companies. In 2009, worldwide, over 140 million hectares of GM crop plants were grown, mainly consisting of maize, soybean and cotton.

2.3.2. Directional inventions

Directional inventions originate within a specific area of expertise (Johansson 2004). Directional ideas are operating within a specific field and are mostly based on specific expertise within that field, which is extended. A field relates to a discipline, culture or domain such as music, (molecular) biology or software industry in which one can specialize in a mono-disciplinary way. Directional inventions can, for example, help to simplify regulations based on reconstructed and/or extended knowledge.

2.3.2.1. Cisgenesis

In the field of genetic modification, cisgenesis is a recent development and considered as a directional invention. Central to the philosophy of cisgenesis is that it takes the grounds of opponents of GM crops as a starting point, and uses the opponents' suggestions where applicable.[4] In cisgenesis, natural genes (cisgenes) from either the plant itself or from a crossable species are used. Hence these genes are not new and belong to the existing breeders' gene pool with a history of safe use. Based on NGOs' and societal opponents' arguments against GM crops, cisgenesis applies marker free transformation with only cisgenes (Schouten et al. 2006a, 2006b).

Transgenes are genes coding for traits which are (partly) based on genetic information found in non-crossable species like bacteria and viruses. They are thus alien to the plant they are imported into. Therefore, transgenes are perceived as being 'unnatural'. For many, the use of transgenes is not acceptable rather than the technique of transformation.

Transformation of plants with transgenes or cisgenes is done by the bacterium *Agrobacterium tumefaciens*. In nature this soil bacterium transfers a few own genes, present on transfer-DNA (TDNA), into individual cells of the plant to induce a crown gall with production of amino acids for pathogens' own use. Normally these genes are not inserted into cells involved in sexual reproduction. However, during evolution of 15 different tobacco species up to 4 genes of this

[4] It is revealing that the idea of cisgenesis was invented through discussions within a Dutch Christian political party (Jochemsen 2000), while in general genetic modification of organisms is rejected by religious movements.

TDNA were introduced into the plants' sexual reproduction system (Intrieri and Buiatti 2001).

Initially, only transgenes were involved in the discussion on GMO regulations. For plant breeding, transgenes belong to a new gene pool, so that a demand for additional safety tests is logical. But, although society driven, cisgenesis is still being discussed in the societal debate. Based on the integration of societal concerns, Schouten et al. (2006a, 2006b) suggest that cisgenesis might be exempted from the GM regulation following the earlier rationale for induced mutations and protoplast fusion between crossable species.[5] Intermediate steps for application could consist of derogation for specific trait-crop combinations (Jacobsen and Schouten 2007, 2009).

By attempting to overcome the most important complaints of society against GM-plants with transgenes, the new technique of cisgenesis showed increased acceptance of the public (Duchateau 2008; Sameer et al. 2009).

It is clear that this invention is the result of public debate which requires an adequate balance between hardware, software and orgware. It is a directional invention with respect of type of genes used that potentially influences existing regulation. Both organic agriculture and cisgenesis supporters have realized a dynamic decision-making in the higher echelons of governments.[6] Regulators are continuously amending and adapting rules and regulations to cover new developments and insights in science, technology, practice and society (Yanarella 1975).

2.3.3. Open innovation

In agricultural life sciences, open innovation was the standard as described in earlier parts of this chapter. New scientific insights were published and freely available for everybody. However, in plant breeding, seed business developed a sui generis system called PBR to protect varieties but to keep them freely available as breeding parent for development of new varieties. The Bayh-Dole Act (1980) stimulated the introduction of patent rights which changed the open situation in agricultural life sciences. The recent experiences in modern plant breeding showed potential negative side effects of PR in this field. We believe that open innovation has the future, especially when it has to be related to sustainability because open innovation systems have the potential to lead to a quick succession of incremental innovations, which is needed in new fields. In addition, in certain fields communities of practice are frequently needed for solving problems in order to go quickly into the right direction. We are describing a few recent examples below.

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[5] Annex 1b of the EU Directive 2001/18/EC.

[6] Directive 2001/18/EC for GMOs and Council Regulation (EC) no. 834/2007 for organic production.

2.3.3.1. Care farming

Care farming is an upcoming activity in the agricultural sector (Hassink and Dijk 2006). Care farming is an unusual combination of disciplines like (organic) agriculture, psychiatry and transition sciences (see for more information on care farming action experiment Green Care in Appendix II). Care farming is a win-win initiative for clients, farmers and the community as a whole. The clients range from people with a mental disability to youth with behavioral problems, addicts and psychiatrically patients.

For the invention of care farming to become a fully fledged innovation, it has to solve a unique problem in agriculture as its clients, psychiatric patients, are not traditionally within the remit of agriculture. Support is therefore needed from the medical world. While both care farmers and their clients are very positive about the results (Elings and Hassink 2008), the relevance of combining the care of people with mental disorders with farming activities is still unclear. To make care farming even more attractive for, among others, health care insurers, interdisciplinary scientific research is highly needed to provide a scientific evidence base of the potential health effects of combining agriculture and care for psychiatric patients and specifically to gain insights into the health promoting elements of agriculture (Leerink 2009).

The lack of patents or other IPR systems on the basic invention makes care farming an open innovation with many characteristics of an intersectional invention. Care farms are a good example where an important innovation may be achieved without the need to develop too much specific (disciplinary) expertise.

2.3.3.2. Energy producing greenhouses

Currently, in the Netherlands, the greenhouse industry contributes to approximately 10% of the total natural gas consumption and up to 10% of the electricity use. However, greenhouses can reduce their fossil energy use considerably. The invention of an energy producing greenhouse came up in the early years of the 21st century. The energy producing greenhouse is a greenhouse that needs a small fraction of the energy needed by the most common greenhouses today and is even expected to be net producer of energy (Anonymous 2009b). Some recently developed energy efficient greenhouse concepts are based on durable energy sources such as solar energy, wind energy or geothermal energy: the solar greenhouse (Bot et al. 2005), the closed greenhouse (Opdam et al. 2005), the energy producing greenhouse (Bakker et al. 2006) and the Sunergy greenhouse (De Zwart 2009). A current example is a greenhouse system which converts natural energy sources such as solar energy into high-value energy such as electricity. Sonneveld et al. (2007) designed a system with a parabolic NIR (Near InfraRed) reflecting greenhouse cover. This cover reflects and focuses the NIR radiation on a specific PV (photo voltaic) cell to generate electricity (Electricity producing greenhouse).

One of the bottlenecks in applying this invention of an energy producing greenhouse concerns the physiological aspects of the plant. This new greenhouse has a completely different type of climate than conventional greenhouses. Air humidity has changed and new ways are needed to control crop performance. A new way of growing plants, called 'conditioned growth', manipulates the temperature of the different plant organs. This invention requires an iterative process of greenhouse technology and crop growth physiology (Bezemer et al. 2009). The action experiment SynErgie (see Appendix II) experimented with the application of an energy producing greenhouse. Hardware and software elements are of major importance to realize this conditioned growth. Free exchange of knowledge and entrepreneurship in this case is of crucial importance as it is the grower who needs to use this invention.

Modern greenhouse culture is changing more and more into sustainable vegetable production, serving great numbers of consumers with healthy food. In the near future, greenhouse horticulture will be more than just a supplier of high quality fruit, vegetables or flowers. They will also supply their excess solar energy to third parties in the form of heat or electricity.

Where the connection between care and agriculture was an open innovation between different sectors, connections between scientific fields can also be the result of directional innovations which improve a product in predictable steps along a well defined dimension (Johansson 2004). The inventive intersectional idea of the energy producing greenhouse is a nice representative of this, as it requires in specific fields directional improvements on greenhouse design, energy validation, and plant growth models.

Another major development is the increased influence of society on new developments, such as illustrated by the concept of energy producing glasshouses and the need of care farming. It illustrates that open innovation today in agriculture is still very important and often a guaranty for determining the right direction of new developments for sustainable agriculture as quickly as possible.

2.4. Conclusion

We started this chapter with two questions. What aspects are of importance to turn inventions into successful innovations and whether it is possible to select inventions, including an understanding of their limiting conditions, so that they can improve sustainability? We have addressed some past inventions in the agricultural sector and how they were applied into innovations by the linear process of fundamental, strategic and applied research. Sustainable development of the agricultural sector requires system innovation. Recently, inventions have been followed more frequently by non-linear innovation processes, they will play a crucial role to realize such system innovation, as is shown in this chapter. We have seen that inventions can be science driven, such as the invention of dwarf mutants, the hybrid growth concept and plant biotechnology. Inventions can also be society driven, if societal demands are the motivation for a change, which in turn requires inventions. Examples are energy producing greenhouses, care farming, and organic agriculture. The need for a more sustainable development of the agricultural sector is a societal demand for new inventions that stimulate the needed transition of the agro innovation system. In order to be more frequently successful such society driven inventions should take several aspects in consideration. Continued interaction with society is needed to direct these innovations towards acceptable designs. However, if relevant stakeholders in society, such as the immediate surrounding, are not adequately informed and/or involved from the beginning, obstruction against the final implementation of even society driven inventions and innovations may be possible.

In general we state that to realize inventions for a more sustainable agriculture, and turn these inventions into successful innovations, several aspects are of importance:

- The process of implementation of inventions into innovations will become increasingly non-linear. From the beginning of an innovation balancing of hardware, software and orgware elements of an invention through entrepreneurship are needed. This requires trans-disciplinary, rather than basic research.
- Intellectual property rights in agricultural life sciences can obstruct the necessary implementation and dispersal of an invention into an innovation, and therewith hinder the way towards a more sustainable agriculture. Sustainable development requires rapid sharing of new techniques and (re)combining existing inventions. The increasing use of IPRs in the agricultural sector can stimulate but also frustrate the innovation process. Non-voluntary licensing of patented inventions might be a theoretical but not practical solution to such problems from the beginning.
- When confronted with the challenge to find new solutions for sustainability and one doesn't know where one is looking for, organizing intersections between different disciplines can come up with new inventions that combine expertise from different fields. This approach could later be made more specific by organizing directional innovations.
- If the solution can be found in a specific field, such as a specification of an existing technique, organizing directional inventions enables a specific search for an invention.
- In case of highly complex problems of which the solution is unknown, new inventions can come up by using the collective intelligence of several actors with either specific or different disciplines in an open innovation context. The development of an energy producing greenhouse is an important example of such an approach.

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