PLANT RESEARCH INTERNATIONAL

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Programmatic essay prepared in the framework of the research program 'The societal component of genomics research' of the Netherlands Organisation for Scientific Research (NWO)

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Samenvatting

Genomics en duurzaamheid: verkenningen van een maatschappelijke norm

Duurzaamheid is een van de vier hoofdthema's van het Nederlandse genomics onderzoek. In dit essay wordt een overzicht gegeven van genomics en duurzaamheid in relatie tot landbouw en landbouwkundig onderzoek. Nadruk ligt op de mogelijke problemen en dilemma's met betrekking tot de wisselwerking tussen landbouwgenomics en duurzame landbouw. Huidig en toekomstig genomics onderzoek naar de aardappel wordt deels gebruikt als voorbeeld. Het doel van dit essay is om vragen te formuleren die richting kunnen geven aan toekomstig sociaal-wetenschappelijk en multi/interdisciplinair onderzoek op dit terrein. Door middel van literatuuronderzoek, interviews met negen belanghebbenden en een kleine publieksenquête zijn de volgende toekomstige onderzoeksvragen geïdentificeerd:

- Wat zijn de werkelijk onderscheidende kenmerken van respectievelijk landbouwgenomics, plantenveredeling, plantenbiotechnologie en genetische modificatie van planten? Wat wordt bij genomics precies bedoeld met 'op grote schaal'?
- Duurzaamheid heeft zich ontwikkeld tot een maatschappelijke norm. Is dit ondanks of dankzij vele definities en opvattingen? Wordt duurzaamheid als sociale norm gebruikt om genomics maatschappelijk te legitimeren? Of is genomics een optie om die sociale norm in te vullen?
- De relatie, zowel wetenschappelijk-inhoudelijk als sociaal-maatschappelijk, tussen genetische modificatie van planten en landbouwgenomics wordt als belangrijk en precair gezien. Welke terminologie over genomics wordt gebruikt door welke maatschappelijke groeperingen in welke context? Is de kennelijke vooronderstelling van vooral genomics onderzoekers gerechtvaardigd dat alle toepassingen van landbouwgenomics die NIET op genetische modificatie berusten automatisch maatschappelijke steun zullen krijgen?
- Is landbouwgenomics een volgende stap in de voortgaande industrialisering, economisering en mechanisatie van de landbouw? Zo ja, is dat dan in het belang van de maatschappij en wordt dit ook door de maatschappij gewenst?
- Zijn landbouwgenomics en duurzame landbouw twee benaderingen die elkaar volledig uitsluiten omdat genomics is verbonden met reductionisme en duurzame landbouw met holisme? Zo nee, op welke wijze kan landbouwgenomics dan bijdragen aan een duurzame landbouw?
- Op welke wijze komt de onderzoeksagenda van landbouwgenomics nationaal en internationaal tot stand? Onderzoek naar de mate van controle door het bedrijfsleven en de maatschappelijke diversiteit van opvattingen over dergelijke zaken, ontbreekt en lijkt wenselijk. Tegen deze achtergrond is het zinvol om te analyseren hoe de onderzoeksagenda van het Centrum voor BioSystems Genomics (CBSG) is bepaald en of en hoe er alternatieven moeten en kunnen worden geïdentificeerd en uitgewerkt.

Executive summary

Genomics and sustainability: exploring a societal norm

Sustainability is one of the four major themes in the Dutch genomics program. In this essay, an overview is given of the concepts of genomics and sustainability in relationship to agriculture and agricultural research. Emphasis is put on potential problems and dilemmas on the interface between agricultural genomics and sustainable agriculture. Current and future genomics research into the crop potato is used in part as example. Aim of this essay has been to identify and formulate questions that may direct future research in the social sciences as well as research of a multi/interdisciplinary character. With the help of literature, interviews with nine stakeholders and a small-scale survey of the public at large, the following questions for future research have been identified:

- What are the truly distinguishing characteristics of agricultural genomics, plant breeding, plant biotechnology and plant genetic modification? In the context of genomics, what is meant precisely with 'large scale'?
- Sustainability has developed into a societal norm. Is this thanks to or despite of many definitions and opinions? Is sustainability as social norm used to legitimize genomics in society? Alternatively, is genomics an option to implement that social norm?
- The relationship, both in science and in society, between genetic engineering of plants and agricultural genomics is seen as important and delicate. Which genomics terminology is used by which social groups in which context? Is the apparent assumption of notably genomics researchers justified that all applications of agricultural genomics that are NOT based on genetic modification will be automatically accepted by society?
- Should agricultural genomics be seen as a next step in the progressing industrialization, economization and mechanization of agriculture? If so, is that in the interest of society and is this desired by society?
- Are agricultural genomics and sustainable agriculture two approaches that exclude each other completely, because genomics is based on reductionism and sustainable agriculture with holism? If not, in what way can agricultural genomics contribute tot sustainable agriculture?
- How is the national and international research agenda of agricultural genomics established? Research into the extent of corporate control and the diversity in opinions about that control is missing and advisable. Against this background it is worthwhile to analyze how the research agenda of the Dutch Centre for BioSystems Genomics was established. A related interesting issue is whether, and if so, how, alternatives for that agenda must and can be identified and pursued.

1. Introduction

Sustainability is one of the four major themes in the Dutch genomics program and the focus of the Dutch Centre for BioSystems Genomics (CBSG). Genomics is a relatively new branch of research activities promising to contribute considerable to a future sustainable agroproduction. To realize this potential, agricultural genomics researchers have to translate their activities into what is sustainable, how can it be achieved by genomics, and how genomics compares to other attempts to create a more sustainable world. This essay will focus on the potential impact of genomics of (crop) plants on sustainability. In the context of this essay, this research activity of genomics will be referred to as 'agricultural genomics'. Although that would include genomics of livestock, this will not be explicitly covered. Based on a literature survey and interviews with stakeholders, the essay will give an overview of the future possibilities and risks concerning genomics in relation to sustainability. The potential implications are likely to be wide and may effect many stakeholders. The essay aims therefore to envision alternative paths of development for the relationship between genomics and societal issues. It identifies the problems and dilemmas, as well as suggests future directions of research and analysis. Given that sustainability is (becoming) a norm in current society, an issue is also whether it is used to legitimize genomics, or whether (and if so, how) genomics research and results will shape the norm sustainability. Potato, as important crop in the Netherlands, is used as a case study for parts of the analyses. Obviously, within the constraints of time and complexity of the issues discussed, our essay should be considered only a first, preliminary exploration of the potential social implications of genomics in general and in relation to sustainability. The points of view reported here should be seen as suggestive rather than definitive. However, we expect that the results of this essay will be largely supported by future investigations.

2. Conceptual framework of genomics and sustainability

2.1 Genomics

2.1.1 What is genomics?

In the Dutch research setting, genomics is defined as 'research by means of large-scale characterization of genes and gene products into the elucidation of the way genes, RNA, proteins and metabolites interact in the functioning of cells, tissues, organs and the complete organism and its environment, both in an individual or in populations of species, as well as between species' *[1]*. Interestingly, this definition does not imply or include any application of the research. In the scientific literature, several other connotations can be found for genomics or its sub-areas. These are either more compact or limited variants of the Dutch version *[2]*, or more broad *[3]*. The most distinguishing issue in the Dutch definition is 'by means of large-scale characterization'. A large-scale characterization, implicitly combined with a high or reasonable speed, generates the notion of 'high-throughput technologies' being at the heart of genomics research. The large-scale approach also motivates the further development of bioinformatics as a means to store, analyze and interpret the large amounts of data generated. By this combination with information science, genomics may and will help to move biology from *in vivo* to *in silico*.

It is currently not very well defined, however, what 'large scale' means. It is therefore unclear where genomics stops to be considered genomics. For example, is an analysis of how two genes interact *[4]* still 'genomics'? Current interpretation of large-scale seems to be largely determined by available technology. With ongoing technological developments, 'large-scale' is likely to be translated into 'all'. The ultimate and highly ambitious goal of genomics is then knowledge and use of 'all': the identification and structure of 'all' genes, 'all' gene products and 'all' molecules and 'all' their interactions in 'all' parts of 'all' organisms during 'all' lifespans in 'all' environments *[5]*.

The above broad, umbrella-like definition of genomics has prompted an explosion of different terms and concepts to specify and distinguish activities to claim or indicate a given sub-area of genomics research. This can apply to the level of analysis (structural genomics, functional genomics, biosystems genomics), to the molecule or phenotype of interest (transcriptomics, proteomics, metabolomics, phenomics), to auxiliary scientific concepts (ecological genomics, genetical genomics) or to others. The common denominator of many of these novel terms and classifications is the suffix 'omics'. Future historians of biological science may therefore well describe the beginning of the 21^{st} century as 'The era of omics'.

From a positivistic perspective, high-throughput technology-based genomics could be considered the ultimate culmination of the reductionist approach to biology: explanation of life solely in terms of interactions of genes and molecules *[6]*. The explanation of biological processes in molecular terms, which are in turn reducible to chemistry and physics, would be the ultimate reduction. It is interesting, therefore, that in the view of some, genomics will allow reconstituting and focusing on the whole of an organism (and population and ecosystem) and bring 'holism' back into biology. Reductionism can be considered a characteristic of biotechnology in general *[6,7]*. It would seem an interesting topic for further study to evaluate if genomics can really be considered an attempt to close the circle and move away from the basic assumptions of reductionism. This issue will be discussed in more detail below.

2.1.2 Biotechnology, genetic engineering and genomics.

We will first analyze in more detail the often-confusing relationships between the fields of plant breeding, (agricultural) genomics, (agricultural) biotechnology and genetic engineering. Biotechnology can be defined as 'the science and technology aimed at understanding and using living organisms or parts thereof to improve the organism for specific human uses or to make or modify a product' *[2]*. In this setting, many human activities should be considered part of the realm of biotechnology. For example, 'plant breeding' would be one of the important components of biotechnology. However, plant breeding is generally not considered part of biotechnology. The reasons for this deserve more analyses.

Often, the distinction is made between 'traditional' biotechnology and 'modern' biotechnology, the latter being based on DNA technology. Plant breeding is than a form of 'traditional' biotechnology, if biotechnology at all. Traditionally, plant breeders have assimilated many technologies; some based on DNA technology. Therefore, molecular (plant) breeding is part of biotechnology or a component of 'modern' biotechnology. Molecular or marker-assisted breeding is the identification and evaluation of useful traits by the use of marker-assisted selection, markers being 'flags' on the genetic material. Genetic engineering (or genetic modification or genetic manipulation) is another component of 'modern' biotechnology. It refers to the technology to take DNA from one organism and insert that into the DNA of another organism.

Genomics is or will become an important component of 'modern' biotechnology. Some feel that it is particularly special and will lift biotechnology to a new level; others feel that it should perhaps not even be considered part of biotechnology. In a contribution titled 'Who controls and who will benefit from plant genomics?' the term genomics is used largely synonymous with genetic engineering *[8]*, whereas others present the generic term biotechnology as synonymous with genetic engineering *[9]*. Apparently, terminology is used highly interchangeably, which may be taken to indicate that genomics is still a relatively young field of science.

For many scientists, the concepts of genomics and genetic engineering are neither synonymous, nor mutually exclusive. Agricultural genomics will point to genes (and phenotypes) in crop plants that could be of use in the basic aim of biotechnology: to improve the organism or its associated agronomy for specific human uses. This improvement can be achieved through marker-assisted selection. It could also be put into action through genetic engineering. In genomics, genetic engineering is likely to be of help in answering research questions. The function of a plant gene may be easier studied in microbes or model plants in order to understand better what it does. However, application of such knowledge does not imply by definition the use of genetic engineering in plant improvement. In addition, the availability of funds for genomics research is a motivation to pursue the approaches thought to be specific for genomics. Genomics could, or is expected to, generate knowledge of plants that would allow obtaining desired improvements without the need for genetic engineering.

In the public perception, however, the relationship between agricultural genomics and plant genetic engineering seems much less clear. For this essay, an issue is how stakeholders in society view the relationship between genomics and genetic engineering. Genomics is a relatively new concept that may not yet have reached the vocabulary of the public. Notably in Europe, 'genetic engineering' seems to have lost the battle for public trust *[10]* and the controversy is awakening in the USA.

Our assessment is that genomics researchers are aware they may lose public trust. The genomics research world is attempting hard to not have genomics endowed with the public trust issue of genetic engineering. Therefore, they present genomics as 'something else' than genetic engineering. The other side of the coin is that the enthusiasm for genomics may be motivated by the possibility it opens to get out of the genetic engineering controversy, and do basically similar research as before, but call it differently. The practice of doing one thing and calling it something else is not unheard of in research *[6]*.

Alternatively, genomics will give priority to applications without genetic engineering. The positive interpretation could be that genomics has learned from the genetic engineering disaster and will not make similar errors. In this context, the deeper motivation of genomics researchers is an issue that merits more study.

The new Dutch Centre for BioSystems Genomics (CBSG) indicates: 'Our genomics program will yield new genetic markers that contribute to sustainable agroproduction. The further development of marker-assisted breeding will provide new opportunities for crop improvement without genetic engineering. The option of genetic engineering will be used for research purposes, but will not be commercially exploited without close consultation with relevant stakeholders in society' *[11]*. This demonstrates the sensitivity of Dutch agricultural genomics research and researchers to the apparent perils of genetic engineering. Moreover, it suggests that the Dutch research world in agricultural genomics assumes that all non-genetic-engineering applications of genomics will get societal consent without consultation. That is an assumption that urgently needs confirmation from societal research.

In genetic engineering, the research world has attempted to introduce 'genetic modification' to do away with the negative connotation of 'manipulation' or possibly 'engineering'. In societal discussions about genetic engineering, the use of either the word modification or manipulation already seems to stigmatize participants as proponents or adversaries. The already existing different connotations of genomics may result in a considerable confusion of tongues that a priori will hamper proper communication between experts, with other sciences and with the public. It may develop into a new tower of Babel or a Gordian knot. Some stakeholders may even have interest in creating such a situation. It would therefore seem a valuable exercise to analyze in more detail which societal groups are using which terminology of 'genomics' in which context and with which agenda.

2.1.3 The promises of genomics

Genomics researchers promise or claim to revolutionize biology and transform biological science from a largely descriptive activity into an information science *[5,11,12]*. In a combination of genetics and information technology, genomics will explore and exploit gene functions in living systems. The knowledge that stems from genomics is thought to be useful in addressing of what are seen as the problems of our time, such as pollution, disease and food supply. This knowledge will trigger further improvements in diagnosis, prevention and agronomic practice. In addition, it claims to allow better defining problems in the framework of genes and gene action. In this way, genomics promises to formulate and generate contributions to solutions to societal problems and desires *[13]*. It will also allow distinguishing the extent of contributions from genetics from issues that are or should be affected by politics and/or economics.

Agricultural genomics will reveal what genes or combinations of genes do in plants and livestock. As genomics compiles a complete list of genes and what each of them does, it will increase the predictive power of genetic constitution on performance. This way, genomics promises to have major impact on our understanding of plant performance and the importance of genes for that performance. This will help to identify in plants and livestock the variations that have high value. This will make plant breeding more efficient, but will also allow breeders to evaluate biodiversity within crops, gene banks and other stocks in a better way. Genomics could make crop growing more local and effective, encourage growth of plants with combinations of genes/characters that suit the needs of farmers and farming communities. Genes show redundancy (more than one gene gives a given phenotype), interaction (genes need to act in combination to give a given phenotype) and dependence on environment. Genomics will reveal relevant gene actions and interactions within a crop and contribute to insight into the interactions between that species and any others in its environment.

Genes in model species may have direct equivalents in more complex species. Not only many of the genes are very similar; they are also often organized similarly on chromosomes. Model systems have therefore a high value in genomics. The conservation of genes and their organization means that characterization of a gene or a region in a whole genome can provide important clues about the place and function of genes in related species. This way, the *Arabidopsis* and rice genomes will provide route maps of potentially valuable genes as templates for genes in crop species. Genomics will accelerate the speed and fine-tuning of functional analysis by comparison.

Genomics of plant pathogens may identify the causes of plant diseases and hint at new ways how to fight these and/or indicate strategies for minimizing the likelihood of development of resistance. It can also point to how pest organisms resist existing treatments and may suggest new targets for novel pest management and the industrial manufacturing of such compounds. Crops that have increased disease resistance reduce the environmental impact and farming costs. It will prevent pollution by reducing the use of pesticides and weed-killers in agriculture. It may in addition boost the use of plants as clean up of soils contaminated with heavy metals or other undesired compounds.

Modern crops have been selected to produce high yields under intensive farming conditions such as high fertilizer use. Genes responsible for tolerance to less favorable conditions may have been ignored in the prior selection processes. Genomics will allow re-examining all the genes and their functions in cultivated plants, wild varieties and gene banks. These can be introduced or reintroduced. It will contribute to the design crops that are adapted to their environment, rather than crops that demand a change of environment to suit them best. Alternatively, it could trigger novel agronomic practices. New varieties that are able to tolerate drought, heat, cold or salty conditions could enable food production to be increased without taking more land into cultivation.

Genomics will reveal genes important for nutrient production, flavor or texture, the presence of food allergens or toxins, and contribute to the safety and nutritional value of foods. Knowledge how genes equip plants to use nutrients may pave the way to varieties that yield more for less. Genomics will be of help to monitor the environmental impact and presence of GM, non-GM, ecological agriculture and wild plants. It will address environmental questions into ecosystem functioning and allow monitoring interactions of different species in ecosystems in a way that is likely to impact on conservation policies.

Overall, agricultural genomics researchers are promising to deliver a technological toolbox for making crops more suitable for particular end uses *[5,12,13]*. It is claimed to bring about a paradigm shift in the development of crops for human use that will revolutionize agricultural production. Products that provide human health, nutrition benefits, increase productivity and sustainability, reduce field and storage losses and set new standards for food safety. Rice, maize and wheat collectively account for over half of the world's food production. The potential for agricultural genomics is therefore arguably even larger than its human health counterpart in terms of economy and quality of life.

2.1.4 Threats for genomics and threats of genomics

Different stakeholders in society are likely to view the relationships between genomics and threats in different ways. Genomics researchers, and all others (governments, granting agencies etc.) convinced about the need, benefits and positive outcome of the genomics endeavor, tend to focus on threats FOR genomics. As threats are seen all developments and situations that will hamper the growth and realization of the promises of a powerful new technology. Others may be less convinced and may point to potentially negative impacts of genomics in society: the threats OF genomics. We will here give an outline of both types of concerns.

(a) Threats for genomics

Currently the biggest threat for agricultural genomics as perceived by genomics researchers is in our opinion that society will not accept agricultural genomics because it will consider 'genomics' synonymous with 'genetic engineering'. Given public fears with respect to genetic engineering, this would imply a rejection of genomics. Apart from the benefits missed, an issue to consider as well is that such a rejection would also deny experts to do the type of work they know and like best. The 'genomics equals genetic engineering scenario' is far from hypothetical. Both genomics and genetic engineering deal with genes, genetic material and improvements of plants. The distinction is a subtle one at most, which is easily forgotten or miscommunicated. The term 'genomics' may turn out to be a poor one.

In a summary of all the Dutch genomics initiatives, a Dutch journalist writes 'The four areas that will get support are…research into the genetic engineering of tomato and potato…' (text translated from Dutch *[14]*). This gives an impression how the scenario may develop once it is in the public domain. Agricultural genomics may already have image problems in relation to genetic engineering. Worldwide, most prominent proponents of agricultural genomics were previously proponents of genetic engineering. This is also the case in the Netherlands. Moreover, the promises of agricultural genomics are not very different from the earlier promises of plant genetic engineering, nor are the (potato) research topics.

A future threat for agricultural genomics, even when excluding genetic engineering, may be certain aspects of (over?)regulation. The level of regulatory scrutiny currently imposed on a genetically engineered crop is high and unprecedented for any product of plant breeding. A recent US study *[15]* could be interpreted in the direction that crops in general may pose a priori undesired and/or unknown environmental/food risks and should be monitored *[16]*. A similar risk scrutiny could then be imposed on any product from agricultural genomics. Development and costs of such regulatory requirements may have significantly negative impacts on agricultural genomics. The regulation issue could be considered a spill over of the genetic engineering debates and may reflect a tendency in notably Western society for presenting, or at least suggesting, to its people a ' risk-free' world. Alternatively, when agricultural genomics ends up in the hands of a few, very large, life sciences companies, these companies could consider regulation as a protective measure for their markets and market share. This way, companies at the forefront of genomics innovations could be tempted to use regulation as a strategy to do away with potential competitors. Such developments may have equally negative impacts on future agricultural genomics.

(b) Threats of genomics

Agricultural genomics, especially when presented as a 'new' technology, will have to face all the suspicions any new technology is usually confronted with. Agricultural genomics can be considered a next step in the process of agricultural biotechnology that started with the discovery of the Laws of Genetics by Mendel and the double helix structure of DNA by Watson and Crick. Agricultural genomics will have to face all the ethical, moral, social and technical issues associated with agricultural biotechnology in general. These are concerns about corporate control, ownership, distribution of profit and benefits, overall approach as well as safety.

In the development of agricultural biotechnology, private funds have slowly taken over public funds in size and impact. This development is continuing in the development of agricultural genomics. Agricultural genomics is a costly enterprise. High throughput technologies may make a single data point relatively cheap; total costs are considerable, due to the sheer numbers involved. Private investments far outweigh public funds, supported by mergers and continuous scale-up of life science companies. This implies that a few companies may decide over genomics research targets and applications. The corporate control of biotechnology in general, and future agricultural genomics in particular, is likely to generate considerable social concern. Despite all the promises, agenda setting in genomics seems still focussed on short-term goals. These relate to conventional, high-yield industrial agriculture aimed at profit. In an overview of genomics developments, it is predicted that genomics will change the agrofood industry into a high-tech/high-value business *[17]*. This implicitly assumes that such a change is both a desire from and in the interest of society. Such assumptions seem to require confirmation.

Concerns about corporate control are immediately related to issues of ownership and intellectual property (IP). Different from plant breeding, ownership in agricultural genomics is based on patenting and patent protection. Genomics research is seen as economic investment that requires return. For example, the Dutch CBSG plans for 2010 a strategic portfolio of 5-10 patent families, and a licensing income to make IP protection activities break even *[11]*. The patenting frenzy of agricultural biotechnology *[18]* will continue in agricultural genomics. This will raise concerns about the equity, accessibility and desirability of agricultural genomics and its applications.

When agricultural genomics is seen as a high-input, high-cost, high-protected enterprise, a related legitimate concern is about the benefits of such genomics for the developing world. The developing world will face most serious problems with food supply. This concern is known as 'the genomics divide' *[19]*. In the current settings of genomics, it is unclear whether these problems will truly affect the genomics research agenda. Not everybody in society is likely to consider agricultural genomics into the quality of potato for baking French fries a priority target for research. Agricultural genomics could be seen as again a technological solution for problems that may have at least as many negative impacts as it presents solutions. It can be perceived to contribute to a further industrialization, economization and mechanization of agricultural production that is seen as undesired. In probably small parts of society, this will be related to difficult concepts as 'the integrity of life'. Particular schools in plant breeding are still debating the acceptability of markers and similar discussions can be expected on the large-scale approaches of agricultural genomics. Moreover, any impact of agricultural genomics on a further industrialization of food production may trigger uncertainties about the safety of genomics products.

Overall, there seems place and need for substantial research into the mechanisms of agenda setting in agricultural genomics research, the extent of corporate control and the diversity of society's evaluation of such issues. Policy makers and genomics researchers seem aware of the need to include society and the need to deserve a 'license to produce' and 'a license to sell', rather than to exclude society and go on. How this awareness works out in day-to-day management decisions is yet unclear and requires more analyses and possibly new approaches.

2.1.5 Future scenarios for genomics

The UK ESRC Genomics Scenario Project *[3]* has presented four future scenarios for genomics. These scenarios are called: (1) *Genomics Inc.* Genomics gains public acceptance because of appropriate safety standards and new applications. Genomics is dominated by a handful global life science conglomerates; (2) *Broken Promises.* Genomics has hard times. Applications prove more difficult than expected, and prominent genomics accidents turn the public opinion against the technology; (3) *Out of our Control.* Genomics faces both challenges for some applications and success in others. Miracle products create public acceptance, despite accidents, uncertainties and growing differences between the developed and the developing world; (4) *Genomics for All.* Genomics is successfully implemented, with appropriate management to have genomics play an important role in building a global society dedicated to equity and sustainability. In the ESRC project genomics is unfortunately considered synonymous with biotechnology (in the text) and implies genetic engineering (from the text). We consider this a serious drawback in an otherwise interesting study with insightful scenarios.

The four ESRC scenarios basically represent the four extremes in a two x two matrix of the parameters success (+1, –1) and acceptance (+1, –1). Such a matrix consists of:

(i)	agricultural genomics delivers its promises and is accepted	(+ 1, +1)
(ii)	agricultural genomics delivers its promises, but is not accepted	(+ 1, –1)
(iii)	agricultural genomics does not deliver any of its promises, but is accepted	(– 1, +1)
(iv)	agricultural genomics does not deliver its promises, and is not accepted	(– 1, – 1)

In these scenarios, scenario (iii) may be considered remarkable: why would a society accept something that does not deliver? Agricultural genomics may not work in research or applications, because genes, a cell, an organism, or life itself may turn out more complex and complicated than anticipated. Agricultural genomics may succeed in surviving in society for a long time on small successes added to the promise of a future success that may be realized.

Apart from such hypothetical scenarios, it seems likely that how genomics will develop depends on the deliverables of the first years and technological progress in high-throughput technologies. It seems reasonable to predict after some time that genomics researchers will be unhappy or feel too much restricted by the variation present in the gene pool of crops. They may attempt to change or augment that gene pool. Without genetic engineering, genomics may use large-scale mutagenesis technologies to make targeted changes in plant genomes. In addition, research may focus on the molecular mechanisms of species incompatibility. When combined with mutagenesis, genomics may succeed in relieving crossing barriers and broadening the gene pool available for plant improvement without formally using genetic engineering. In society, this is likely to revive concerns about 'playing God'. Alternatively, the increased knowledge of plants and plant performance may eventually ease society's concerns about such and other changes. In dialogue it may be decided that the risk/benefit balance of some applications is changing towards careful allowance, but who will decide, when, and on the basis of what arguments is unclear.

2.2 Sustainability

2.2.1 What is sustainability?

Literally, sustainability means 'the ability to sustain'. This implies either to maintain something or keep it going for a period of time, or something that is supporting by giving help, encouragement or support. Over the last decades, notably the first connotation of sustainability has broadened considerably into the concept of sustainable development. Historically, an important year was 1972. In 1972, the Club of Rome published its 'The Limits to Growth', the Ecologist published 'Blueprint for Survival', and the United Nations UN held its first conference on the Human Environment in Stockholm *[20]*. These activities and publications reflected the increased awareness and concerns of (groups of) scientists and policy makers with respect to the environment. Attention focussed on the limits of natural resources, the deterioration of the natural environment and foreseen future problems of population growth combined with populations striving for sufficient food, resources and energy. Current global economy is based on energy, chemicals and materials derived from diminishing fossil carbon sources. The present level of energy consumption, production and growth relies on continued withdrawals from the finite store of fossil carbon. Obviously, this is not a situation that can sustain.

The increased environmental awareness culminated in what currently can be considered the best-known, widely adopted, and now almost 'traditional', definition of sustainable development. This was given in the 1987 publication 'Our Common Future', generally referred to as the Brundtland report, after the Norwegian chair of this Commission *[21]*. Sustainable development is here defined as 'development that meets the needs of the present without compromising the ability of future generations to meet their own needs'. It was reinforced by the UN Earth Summit in Rio de Janeiro in 1992 and its successors. This definition of sustainable development acknowledges that natural resources are limited, economical systems tend to ignore limits, and that the well being of future generations requires to respect such limits *[20]*. Each generation is given the (moral) obligation to maintain the world in the same or better condition for the next generation.

The Brundtland definition of sustainable development has prompted a global debate with very many participants on the precise meaning of sustainability. This has resulted in many different interpretations, modifications and reformulations of what is sustainability. A Worldbank inventory listed no less than

190 different attempts *[22]*. Some take the apparent or potential confusion pragmatically: 'We are concerned less, however, with how the concept of sustainability is variously interpreted… and more with how it might best be crafted to serve conservation desiderata' *[23]*. This way, sustainability has become linked to a large variety of human activities, concepts and concerns, such as (in alphabetical order): biodiversity preservation, business ethics, consumption, corporate social responsibility and governance, eco-efficient processing, fair trade, North-South relationships, the precautionary principle, species conservation and many others. On financial markets, no less than about a hundred sustainability indexes have been created and the sustainable business debate is shifting from PR to competitive advantage: sustainability sells *[24]*.

Meanwhile, sustainability has become a priority for the world's policy makers. The concept is now at the core of laws in many countries around the world. In current policies, sustainability attempts to combine economic values and feasibility with appropriate technologies and social commitment regarding environmental and social values. Aim is to promoting environmental, ethical and social consciousness and responsibility. In this context, sustainability can be thought to reflect a desired fundament of human activity. Such developments show that sustainability has become, or is on the process of becoming, a societal norm. Generally, people will do what they believe is 'right', *i.e.*, whatever is consistent with their personals beliefs and/or the norms of the society they live in.

Sustainability may be a norm that was formulated by governments and supranational organizations (at the macro level of society) and that is now taken up by organizations and cooperations (the so-called meso level of society). However, it may still need confirmation and implementation on the micro level of society: the individual citizen. How to translate the social norm sustainability into the behavior of individuals is a research topic by itself, which may involve sociological and psychological approaches. Although sustainable development may ask for adjustment of individual lifestyles and patterns of consumption, the issue and approach of government intervention is still heavily debated, notably in relation to the respect for people's freedom of choice. Regulations may be a way to impose a norm on individuals whose personal belief systems are contrary to that norm, but may not be the most effective *[20]*.

A societal norm of sustainability generates numerous normative and scientific questions that will have to be resolved in future research and considerations. For example, the wishes of future generations are unknown and may be different from what we think such desires could (should?) be. The many definitions of sustainability, often general and vague, do question how such a norm can be of any practical value. Possibly, the theory of interpretation, or 'hermeneutics', of the German philosopher Hans-Georg Gadamer can help to understand how a general societal norm of sustainability is interpreted in case of particular, concrete issues at hand *[22,25]*.

2.2.2 The concept of agricultural sustainability

Brundtland's widely adopted connotation of sustainability as awareness of the environment and natural resources can be considered to reflect an existing body of ideas that originate from agriculture and agricultural practice. At one time, humans foraged to provide for food and material needs. As population centers developed, the move of mankind from hunting/gathering to agricultural systems and population centers was accompanied by increasing needs for a reliable production over seasons and over generations. In this context, agricultural activity is closely connected with and depending on the environment in which it takes place.

However, in the view of many, somewhere along the course of time, mainstream agriculture has lost its roots of sustainability. The development of increasingly intensive and specialized forms of agriculture has culminated in what some refer to as 'industrial agriculture' or 'chemical farming systems'. The farm is viewed as a factory with inputs and outputs, aiming at increased yields with reduced costs, often by exploiting the economy of scale. It is accompanied by use of and reliance on agrochemicals, large-scale monocropping, mechanization and energy consumption. Such agriculture sees as its primary objective to produce as much food and fiber as possible for the least cost. According to Lyson *[7]*, current conventional agriculture is anchored to the scientific paradigm of reductionist experimental biology, in combination with the reductionism of neoclassical economics, driven by continued (desire for) industrialization.

However successful in the past, virtually every aspect of this conventional agriculture is turning problematic. The problems center on both the environmental aspects and on the social and community aspects of agriculture. There are problems with the supply and quality of water, erosion, soils that become unfertile, contamination by pesticides, use of manure, and various levels of pollution of groundwater, soils and atmosphere. This makes agriculture a major cause of damage to the earth's ecosystem at large *[26]*. Because of such complications and harmful effects, industrial agriculture may be impossible to continue. The projected costs for waste management, water quality, and counterbalancing carbon dioxide emissions are tremendous *[27]*. This could be taken to indicate that mainstream agriculture is losing economic feasibility. With world demands for food, consumer goods, materials, and energy continuing to spiral upwards, this is likely to result in more detrimental effects in future years.

In the context of sustainability, the potentially or obvious destructive activities of current agriculture can in many instances no longer be denied, but mankind depends on the continuation of its produce for economic activities. The need and the way to come to a more ecological agriculture are still contested between stakeholders. Major issues of discussion are the importance of yield and economy of production. A lot of attention is focussed on new agricultural systems that conform to -or go back to- the societal norm of sustainability. A whole range of technologies is (being) developed to foster sustainable development in agriculture. Many names are proposed for such agriculture: biological, clean, ecological, organic or simply sustainable. Although these may actually differ in relative emphasis and in details of operation, they all indicate environmentally sound and socially responsible systems of agricultural production. It is agriculture thought to be based on a paradigm that Lyson *[7]* describes as ‘ecological’. In the context of this essay we will therefore use the term ‘ecological agriculture’ for all potential variants and variations of more sustainable agriculture and not attempt to differentiate between the various implementations. Ecological agriculture is thought to require major changes in the approach of agricultural production.

Ecological agriculture should meet the challenges of economy, society and ecology. This type of agriculture denotes a holistic, systems-oriented approach to farming that focuses on the interrelationships of social, economic and environmental processes *[7]*. It treats a farm as an integrated whole composed of interacting elements aimed at optimizing rather than maximizing yields, focusing on renewable resources and recycling. It is not guided by the productionist logic of competition, but emphasizes community problem-solving as social foundation. An essential difference with conventional agriculture may be the position relative to nature: dominance versus harmony. Lyson *[7]* predicts that ecological agriculture is unlikely to replace conventional agriculture until a new (or modified) social science paradigm is adopted that is also nonreductionist in character.

This reductionism - holism perspective on ecological agriculture in comparison to conventional agriculture may be a useful steppingstone for the identification and analysis of differences and analogies in these two perspectives. Ecological agriculture is by default considered or presented as a different and above all a more sustainable form of production. A recent long-term Swiss study published in Science *[28]* was taken as positive sign that ecological agriculture is entering the regular scientific community *[29]*. It was also taken to show definitively that ecological agriculture is kinder to the environment, more efficient and more sustainable than traditional agriculture. The premise that ecological agricultural processes offer by definition environmental benefits over processes or production methods that are more conventional may and should continue to be evaluated. This should initially be done in a case-by-case approach. This requires the development of methods and benchmarks that can assess sustainability and environmental impact. A case study of biodegradable polymer production from feedstock is a good example of the complexity of such assessment *[30]*.

2.2.3 Future trends in sustainability

Although the Brundtland definition of sustainability may have been widely adopted, there are still various issues to elucidate with respect to its meaning and implementation. These issues require further research. The scope of the ecosystem to be considered needs further attention. Another important issue for further research will be the issue of sustainability within a generation, rather than the focus on future generations. In the Netherlands, the concept of the ecological carrying capacity (ECC; in Dutch: milieugebruiksruimte) is developed to implement and monitor sustainability. In this concept, sustainability requires that the (economic) activities of a generation stay within the limits of the ECC. There is quite some discussion and criticism on such approaches. It is unclear if the ECC can ever be described in a sufficiently objective way, because a major factor is politics and political decisions. The ECC may also not easily allow for the incorporation of new knowledge, normative issues and new societal norms. Possibly, the ECC could be incorporated in a scenario approach in which different human activities are combined with ecological values *[22]*.

The most interesting future area for research into the societal norm sustainability is in our view the, predictably many, cases in which there is some kind of disagreement. People with different views on sustainability may not agree on decisions or choices. Of particular interest for further study are the situations of a dilemma of sustainability. A dilemma of sustainability arises when different solutions to sustainability are incompatible; when a sustainable solution for one is non-sustainable for another. Moreover, the interpretations of sustainability may not only exclude each other, but the sustainable solution in one field (or area or sector) may cause another field (or area or sector) to become less sustainable. Ultimately, the sustainability requirements of the second may be an obstacle for the sustainability of the first. This type of dilemma of sustainability is probably most easily understood in terms of conflicting economic sectors *[22,25]*, but may not need to be limited to the economic considerations of society. Conflicting societal norms or worldviews may also be at the basis of a dilemma. A dilemma may be largely theoretical and involve the opinions/ viewpoints of parties, but it may also involve (economic) sectors and the need for actions/ decisions.

The dilemma of sustainability is recognizable in many contemporary conflicts, such as in some clashes between agriculture and nature management (see examples in *[22]*) and the role of genetic engineering in ecological agriculture. Lyson *[7]* believes that ecological agriculture and conventional agriculture represent two essentially incompatible approaches and paradigms. This also points to an interesting dilemma of sustainability that justifies further analysis. In such cases, what people actually do, could be taken as a starting point for analysis, not what their opinions are. The emphasis in future research should shift to the analysis of the impact of activities, the impact of doing and applications *[22,25]*.

In such dilemma's, or dilemmatic situations, achieving sustainability therefore demands extra activity, either cooperation, or a further search into alternative solutions or agreement on a (legal?) system to judge and/or rate relative (loss of) sustainability. A related issue is the amount of (un)certainty that is allowed or accounted for by the contending views. Such dilemmas are thought to require more flexibility in ethics *[31]*. Consensus and/or mutual understanding usually entail compromise. Constructivist approaches that would address the problem in terms of negotiation and debate may not result in the best possible solution, if any, because it can be interpreted as focussing on differences *[25]*. More transparent, hence result-oriented, may be an approach that aims at achieving a mutual understanding of sustainability between the rivaling viewpoints.

From the perspective of Gadamer's theory of interpretation, the conflict between sectors is a controversy rather than a difference in concept of sustainability. In an analysis of dialogue and conversation, Gadamer stresses the mutuality, the respect required, the genuine seeking to understand what the other is saying, the openness to test and evaluate our own opinions through such an encounter *[22]*. When conflicting viewpoints are considered as controversial interpretations of a more general concept of sustainability, mutual understanding of sustainability may be more easily achieved.

Research into the way different traditions or viewpoints can be obstacles to each other, for example by the analysis of joint interpretation of general texts, like laws and regulations, may reveal prejudices hampering mutual understanding.

Within this concept of sustainability, an additional challenge is development and implementation of a research and development agenda of science and technology for sustainability. This will be an essentially integrative activity, bridging across the life sciences, the agricultural sciences and the social sciences, in an effort that may eventually develop into the field of 'sustainability science' *[32]*.

2.3 Sustainability and genomics in agriculture

Combining sustainability and genomics is the combination of a difficult, multidimensional concept with a complex technology. To do so, agricultural genomics researchers have to translate their research activities into sustainability. Such a translation will mainly focus on the applications or applied aspects of genomics research. Having shown above that sustainability in general is seen as very positive in current society, genomics could try to become associated with this norm. Such an association may be used to translate scientific approval in societal approval, or to counterbalance societal concern.

Sustainability in its most broad connotation has to do with (natural) resources (see above). Genomics can for example help replacing petroleum with biomass derived mostly from plants. Such a biomass is or could be a renewable natural resource, hence more sustainable. Actually, many of the goals of agricultural genomics as summarized above seem to reflect the need and desire for increased sustainability in the sense of renewable resource use and a significantly reduced environmental burden of agrochemicals. In this context, the issue is whether sustainability is used to legitimize agricultural genomics, or, *vice versa*, whether this genomics research and results will effect or change the norm sustainability of society. Moreover, if so, how that may happen. This relationship between legitimization, research and sustainability in relation to genomics is an issue that merits more analysis.

In an as somber as thought-provoking contribution, Lyson *[7]* comes to the conclusion that agricultural biotechnology is fully embedded in conventional agriculture. As such, it is anchored to the perspective of reductionist experimental biology and reductionist neoclassical economics, with emphasis on specialization, speed, quantity and profit. In contrast, ecological agriculture is characterized by a non-reductionist, community-based, problem-solving perspective, with emphasis on diversity, cooperation, quality and beauty. Given this perspective of incompatible and fundamental differences between agricultural biotechnology and ecological agriculture, he predicts the future development of parallel distinct systems of food production *[7]*. In the context of this analysis, more analysis of the relationship between agricultural or plant biotechnology and agricultural genomics is of interest.

Ecological agriculture is thought to require major changes in approach of agricultural production. The central question then is whether agricultural genomics can fit in that approach *[33]*. Or, *vice versa*, whether any (new?) agricultural production scheme can afford to do without or deny the potential benefits of agricultural genomics. It will be of considerable interest to analyze the views of ecological agriculture on genomics. Although this will require research beyond the scope of this exploratory essay, it is good to point out that current ecological agriculture in Europe rejects genetic engineering fully. Any product that is the result of genetic engineering, irrespective of the (environmental) properties of that product, is considered non-ecological, hence non-sustainable and unacceptable. There are still discussions going on about this strict, almost dogmatic point of view against genetic engineering. This discussion itself may be influenced by the applications of agricultural genomics in relationship to the desires for sustainability. For now it seems a reasonable prediction that any genomics product that has involved genetic engineering will be rejected.

It will make a huge difference whether any rejection by ecological agriculture applies to a specific product, or to the whole research chain of genomics. In the latter case, genomics may face the same problems with public acceptance as genetic engineering has. If the causes of the rejection by ecological agriculture are concepts as 'natural' and 'respect for species and crossing boundaries', genomics without genetic engineering may be considered supportive for ecological agriculture. However, if the rejection is based on ideas about corporate control, ownership and industrialization, also without genetic engineering genomics may be judged negatively. It will largely depend on the potential contributions genomics can make to the goals and incentives of ecological agriculture.

In this context, it should be considered whether (1) sustainability is the norm and ecological agriculture is a (or the?) way how to put it in practice, or (2) ecological agriculture is the norm and sustainability is the added value, or (3) both sustainability and ecological agriculture are different norms that have become combined (or blurred?). Further analysis of the societal link between ecological agriculture and sustainability may result in predictive capacities for the way genomics will be approached by society, or will have to be presented to society. On the one hand, the specific products required by and for ecological agriculture are likely to be very different than those that are being developed to fit into current conventional agricultural systems. On the other hand, genomics may also bring the two agricultural systems closer together *[33]*. Possibly, the incompatible differences between agricultural biotechnology and ecological agriculture as suggested *[7]* do not apply to agricultural genomics. Otherwise, such differences could be considered to constitute a dilemma of sustainability. This seems to create an interesting challenge for the theory of interpretation outlined above.

Depending on its research agenda and achievements, agricultural genomics may change its perspective with sustainability and ecological agriculture in society. For the future of genomics, its relationship with sustainability should therefore become better defined and clearer in society. Initially, this could be attempted on a case-by-case basis and may be used for generalizations in the future. Unless the public comes to agree that the benefits of agricultural genomics are equivalent to a sustainable, desirable and acceptable agricultural practice, society is likely to fail to recognize and realize much of the potential benefits of agricultural genomics.

3. Genomics and sustainability: the case potato

3.1 Potato in The Netherlands

Potato (*Solanum tuberosum* L.) ranks fourth as crop in the world and is the first dicotyledonous plant on the list of most important crops in the world. Of all crops, potato produces the highest yields of energy and protein per equivalent area. The Netherlands is the seventh largest potato producing country in the world (data 1997; *[34]*) and potato is the most important crop in arable farming in the Netherlands *[35]*. Its current economic value in both the primary and processing sector is high *[11]*. Vincent van Gogh's painting 'the Potato Eaters' (see cover) both reflects and has shaped Dutch culture. The importance of potato in the Netherlands is due to a good climate for growing, in combination with appropriate soils, high quality starting material, appropriate expertise, good infrastructure and high-level research. Potato production is not regulated in the EU agricultural system, and in view of current trends towards deregulation, it is unlikely that this will happen *[36]*.

Three types of potato are produced in the Netherlands: seed potatoes, ware potatoes (direct consumption and processing) and starch potatoes. In 2001, over 7 million metric tons of potato in total were produced on almost 164 thousand ha of about 2 million ha arable land available (8%; Table 1). This is about 17% of the total potato production in the EU. Less than 0.5% of the Dutch ware potato area (500 ha) is used for ecological (organic) potato growing *[37]*. The area used for potato in the Netherlands is thought to stabilize, but farms may become larger and more efficient *[36]*. The Netherlands is by far the largest producer of seed potatoes in Europe. Of these, over 70% are exported to over 80 different countries. Half of that export is within the EU. In addition, export of ware potato is considerable. About 1.4 million ton fresh potato and over two million ton of processed potato are exported *[37]*.

Table 1. Potato production in The Netherlands [37] *and Europe* [38] *in 2001; ha = hectare; ton = metric ton.*

Potato (unit)	Area (1000 ha)	Yield (ton/ha)	Total (mil. ton)	Area EU (1000 ha)	Total (mil. ton)
Seed	39	35	1.4	110	2.8
Ware	76	47	3.6	967	34.9
Starch	49	42	2.1	230	8.0
Total	164	43	7.0	1307	45.7

Worldwide, the Netherlands has achieved the highest yield per hectare of ware potatoes. In 2001, yield was 47 ton/ha (Table 1). To date, about 75% of the ware potatoes are industrially processed into French fries, chips and other, often frozen products. Consumer trends towards convenience food are supporting the development of industrial processing. The Dutch processing industry is the largest exporter of frozen French fries in the world. The Dutch cooperative AVEBE is the world's largest producer of potato starch. It produces over 0.5 million ton potato starch per year, which is used in a variety of processes and products in food, pharmacy and others *[11]*. In 2001, average total consumption in The Netherlands was about 81 kilo per person per year, 53-kilo fresh potato and 28-kilo processed potato products *[37]*. Currently, The Netherlands has about 250 cultivars, of which 90 are grown for consumption. The cultivar Bintje is already popular for almost a century.

Important characteristics are considered cooking type, size, shape, color (peel/flesh), taste, ease of peeling, dry matter and harvest time *[37]*.

The economic importance of intensive farming in potato production has obvious disadvantages. Notably the use of agrochemicals is high: in 1990 potato farmers used more than 12 million kilo active ingredient (a.i.) *[35]* with up to 14 kg a.i. /ha. This is about 20% of all agrochemicals used yearly *[39]*. Over the years, this situation has not improved much, despite numerous policy intentions and incentives. Most of the agrochemicals (77%) are targeting fungi *[39]*. These target mainly the potato disease 'late blight' (in Dutch simply: 'aardappelziekte') that is caused by the oomycete *Phytophthora infestans*. To fight this disease, up to 15-20 sprayings may be required per season. In 2000, 4.460.000-kg fungicide was used in Dutch agriculture *[40]* and potato production requires about 50% of all the fungal agrochemicals in the Netherlands. Total fungicide costs amount to 50-70 million Euro/year *[11]*. Since 1999, The Netherlands has the 'Masterplan *Phytophthora*', an attempt to reduce the environmental impact of this disease *[37]*. Novel threats affecting notably Dutch seed potato production are various bacterial diseases *[36]*. In addition, potato viruses and nematodes, the latter causing potato sickness (in Dutch 'aardappelmoeheid') may affect the crop.

The reasons for the need for agrochemicals in potato production are thought to be the use of disease-prone cultivars, extensive monocropping, lack of crop rotation and prevalent farming practice *[39]*. For example, the popular cultivar Bintje is relatively prone to a number of diseases, among which late blight. Actions by environmental action groups targeting 'the poisonous potato' (in Dutch: 'de gifpieper') has had some effect and supermarkets have reacted on the pressure to stop selling Bintje. Although Bintje is still very important in the production of French fries, its area is gradually going down. Despite considerable research, no cultivar has yet been registered that combines all the positive characteristics of Bintje with higher levels of disease resistance.

Policy decisions now oblige Dutch farmers to reduce the use of agrochemicals. However, *Phytophthora*, the fungus causing late blight, is giving more and more problems due to changes in the life cycle of the fungus. The amount of fungicide used is not declining as planned. Growers are aware of the environmental impact, but give priority to crop protection. Proper protection against late blight may require considerable adjustment of agronomic practice. Similar problems with this disease occur in ecological agriculture. Particularly for ecological agriculture, potato is a difficult crop. There is no decent method to combat *Phytophthora* in ecological agriculture. Copper use may have caused more environmental problems than solutions. It will be forbidden by 2002. In the Swiss study on ecological farming *[28]*, potato tuber yield in the ecological trials was 34 to 42 percent lower than with conventional treatments. Of all crops analyzed, potato yield was the most severely reduced compared to the conventional agricultural system. In addition to lower tuber yield, non-conventionally-grown potato showed a greater proportion of small tuber classes to reduce the marketable yield, as did the increased damage due to wireworms. The disappointing results were explained by a high plant demand for nutrients in a relatively short vegetation period, in addition to the high susceptibility of this crop to pests and diseases.

In a recent evaluation of Dutch potato growing, it is concluded that maintaining the leading position of The Netherlands in potato producing and export requires the development of new cultivars. These should have the appropriate characteristics for target markets, in combination with a high-quality guarantee system, notably for diseases *[36]*. The growth of ware potatoes aims at yield maximization. Cultivars need to combine several characteristics in order to be attractive: yield, resistance, suitable for target climate, good storage properties, and they should suit both industrial application(s) as well as direct consumption.

3.2 Potato genomics: towards sustainability?

In The Netherlands, research on potato genetics is highly advanced *[11,35]*. Potato improvement by breeding is, however, a complex and time-consuming endeavor, mainly due to the difficult genetics of potato. Commercial potato has several genetic characteristics that hamper easy exchange of genetic material. The characteristics of most direct practical interest (yield, resistance, storage, suitable for both industrial application and direct consumption) may also not be the easiest targets to achieve with the help of genetics and breeding.

Potato is a main target in the CBSG. In addition to supporting research on *Arabidopsis* and complementary investigations into tomato, the CBSG has defined several potato genomics projects *[11]*. These build on prior knowledge and materials, but will add or expand the 'genomics' component of large-scale characterization of genes and gene products. Projects aim at improving resistance and quality. Various approaches center on the question how a durable solution for the *Phytophthora* problem can be found employing resistance genes. Both the oomycete-plant relationships and resistance sources in plants will be investigated. In addition, the genetic basis for complex quality traits related to growth, storage, processing and their interdependency will be elucidated. Some researchers feel that for true genomics the whole genome sequence of potato should be known or determined. For potato, in view of its relative large genome size, this would imply a major effort and the CBSG has chosen to make a start in the expectation that international initiatives will follow.

Particularly for potato, it is less clear that current ecological agriculture will offer acceptable results. Contributions of genomics in the form of resistances such as a *Phytophthora* resistance, or economically feasible multiline potato cultivation, would therefore seem to get or deserve acclaim of ecological agriculture. When considered sustainable, it may establish or enforce a lasting link between the societal norm sustainability and agricultural genomics. Although current ecological agriculture rejects genetic engineering, the societal norm of sustainability may allow or trigger discussions. The obvious environmental problems with fighting *Phytophthora* and the perceived need for speed in generating solutions may trigger stakeholders to renewed discussions about the application of genetic engineering. When the genomics approach of marker-assisted breeding is seen or perceived as (too) slow, and/or does not indicate feasible alternatives, the desire for sustainability may be compromised. If so, it could be discussed, for example, whether introducing genes from the *Solanum* gene pool by genetic engineering only to speed up a process that could be achieved by breeding as well, should be considered or *a priori* rejected after all. Alternatively, the use of genes from the *Solanum* gene pool that cannot (yet) be crossed in, could be considered.

Is potato a very suitable object for genomics research? Its genome is large and not yet known and its genetics is complicated. Despite the promises of comparative genomics, suitable (useful) information about tuber formation and quality may not be obtained from model species as *Arabidopsis* or rice. This may be less true for resistance and plant-pathogen interactions. The choice for potato can therefore be considered the result of a societal demand: potato is important for Dutch society and economy. In the current research setting, both the government and all companies involved in the CBSG demand return-on-investment. It shows and confirms the ongoing economization of life science (genomics) research.

The basic applied research targets of the CBSG are not so much different from earlier, pre-genomics research goals that also focussed heavily on resistance and quality. The genomics approach is expected to result in a higher or faster success rate, but actual research choices seem based on the current-day assessment of methodological, technical and economical feasibility. That makes sense: genomics builds on prior knowledge and addresses apparent problems for improvement. As an example in a completely other setting, one cannot expect Ajax (soccer) to go and win Wimbledon (tennis). However, the focus on existing knowledge and problems may limit the view of researchers and potential alternative solutions for problems. In this context, it would seem useful to analyze to what extent this has triggered the research agenda of the CBSG and whether viable alternatives could and should be identified and pursued. It would be highly informative to analyze how the research agenda of the CBSG was assembled and how society/the public has given its input.

4. Viewpoints of selected stakeholders and the general public– a preliminary inventory

4.1 Interviews with stakeholders

4.1.1 Approach

For this essay, nine interviews of 1-2 hour length were held with various stakeholders, selected to represent a broad spectrum of societal organizations. The research aim was to get as many different and hopefully conflicting views as possible to allow a critical analysis. Appendix I details the names and affiliations of these stakeholders. Stakeholders comprise representatives of a retailer (SH), consumer (HV) and environmentalist organizations (HB), ecological farming (JV), genomics (RV) and economics (JB) research, as well as potato breeding (SA), processing (PB) and genomics (HD) companies. Four out of the nine stakeholders are directly involved in the CBSG (see Appendix I). The interviews comprised 13 basic questions that follow the logic and flow of the previous two sections of this essay (see Appendix I). Due to constraints of space, the outcomes of these interviews are presented in a highly condensed form focusing on observed differences. More detailed analysis of the contents of these interviews seems warranted and additional interviews with a more diverse variety of stakeholders may be informative.

4.1.2 Conceptual framework: genomics and sustainability (Questions 1-5)

All stakeholders link genomics with research into genes and gene function. Only three mention the distinguishing characteristic of 'large scale' and these three are all involved in the CBSG. Four stakeholders associate genomics -sometimes indirectly- with increased speed and efficiency in generating knowledge. Four stakeholders make or imply a distinction between generating knowledge and application of that knowledge. One explicitly recommends separating the two and reserving the term genomics for only the fundamental research activities. Overall, they do not give the impression to consider genomics something 'new' and one stakeholder explicitly refers to genomics as 'nothing new' compared to breeding as known. It may be that the stakeholders chosen are too familiar with the subject. On the other hand, it reflects a commonsense approach to research in general. It may also indicate that the approach 'now, genomics: better, faster' is seen by the stakeholders mainly as a strategy to generate funding.

All stakeholders essentially agree on the Brundtland definition of sustainability and translate this in the situation for future generations, prudent use of available natural resources and attention for renewal of resources. Two stakeholders explicitly mention Brundtland. Two point out that sustainability has become too much a container term. No less than five stakeholders indicate that in the current setting of society, sustainability should be seen as more broad than ecology/environment alone. In addition, economic, social and cultural aspects play a role, summarized by one as: ethics, ecology, economy (EEE). None of the stakeholders is aware of any instrumental problem in the implementation of the Brundtland connotation of sustainability. One stakeholder specifies that the period used for 'the future' should be taken into account.

All stakeholders agree that genomics could contribute to a sustainable agricultural production, for example in improved growth conditions and reduced need for chemical crop protection. It is remarkable that no stakeholder mentions improved food quality in this context. Stakeholders that translate genomics primarily into breeding seem less positive or convinced. In addition, four stakeholders make the reservation that the potential contribution of genomics will mainly depend on the particular application of genomics research. This indicates that the applications of the genomics should be assessed in a case-by-case approach.

Six stakeholders state that genomics is not necessarily essential to come to a sustainable agricultural production. The reasoning and associated argumentation differ widely, ranging from (i) throwing away valuable opportunities, (ii) it will take much more time, (iii) current knowledge is sufficient, (iv) other types of knowledge can do the same and will be developed. Two others are more hesitant, and tend to feel that without genomics no sustainable agricultural production can be achieved. Also in this case, their reasons are different. It depends on (i) the scope of sustainability or (ii) the particular applications of the genomics technology. One stakeholder hesitates as well, but then concludes that genomics is essential. In view of these differences, this area warrants further research into motivations and expectations.

Also when asked for potential problems with the application of genomics in sustainable agricultural production, answers and reasoning differ widely. Five stakeholders see no problems, although sometimes with reservations or constraints, one does and three are somewhat vague. In several cases, an explicit or implicit link is made with genetic engineering, either as a given fact or presented as an obvious error of judgement. Potential problems mentioned have to do with (i) the required safety of the technology; (ii) an undesired withdrawal of funding for other scientific fields by 'trendy' genomics funding; (iii) the importance and influence of corporate control and (iv) the too scientific, reductionist, mechanist approach of genomics on plant phenotype and plant performance.

Overall, we conclude that most, if not all, aspects, concerns and deliberations around genomics and sustainability as we have outlined in section 2 come back in these different views of the stakeholders interviewed. Of particular interest are the particular perspectives of different stakeholders.

4.1.3 Genomics in relation to other activities, notably genetic engineering (Question 6)

All stakeholders were positive about a potential role of genomics in classical plant breeding, genetic engineering and ecological plant breeding. Differences existed about the position of genomics relative to these three fields. Five stakeholders with the perspective of genomics feel that genomics will have 'follow up' activities in all three fields. Three stakeholders with the perspective of plant breeding see plant breeding supplemented by genetic engineering or genomics. The difference shows the importance of perspective of stakeholders.

One stakeholder stated that classical plant breeding is by definition a genomics-like activity. In plant breeding, it generally takes a lot of time to develop new cultivars. Genomics will provide new information about plants, plant disease resistance and the interaction between plant and environment. This will give extra tools: tests of multiple genes in a certain cultivar (using micro arrays) and marker assisted breeding will bring breeders faster to an 'end cultivar'. Genomics provides a scientific basis to plant breeding and may enable a change from 'black box' breeding to breeding by design. Such breeding is not considered controversial by any of the stakeholders.

Five stakeholders outline a clear relationship between genomics and genetic engineering. Genetic engineering is a technology that uses the knowledge provided by genomics. Genomics and genetic engineering are closely related because both are on the same level of genes and genetic material. One stakeholder argued that wishes of consumers to eat 'natural' products should be honored. If in the perception of the public all gene-related activities interfere with the 'naturalness' of food, the public will reject genomics. It is for this reason that ecological plant breeders hesitate to be or become involved in genomics.

Stakeholders contend that genomics will lead to an increase in genetic engineering. This is the explicit aim of some companies. 'It would be stupid not to introduce beautiful genes in a plant', one stakeholder said. However, given the negative societal imago of genetic engineering, all stakeholders indicated that genomics is possible without genetic engineering, that genomics is broader, and that it may be used in breeding. It was pointed out, however, that this imposes limitations to genomics, because than it is not allowed to exploit for instance bacteria. One stakeholder warned that the public is not able to distinguish between genomics and genetic engineering and that it is important to ensure that marker assisted breeding is not troubled by the same negative meaning as genetic engineering has become. Another stakeholder had no problems with genetic engineering, but only if all conditions about safety and labeling, etc are fulfilled and people are willing to buy the products. No stakeholder said that genomics was just another convenient name for genetic engineering.

According to seven stakeholders, genomics could be used in ecological plant breeding as a tool to improve the efficiency of the breeding process. Genomics will enable breeders to have more insights in the relationships within ecological agriculture. These relationships are more complex than those in systems of monocultures are, because there are much more organisms involved. Genomics will also provide more information about genetic variation, complex characteristics (for example genotype x environment interaction or drought resistance), which will enable to develop cultivars tailor-made for ecological agriculture.

4.1.4 Potential products of genomics in relation to sustainability and potato (Questions 7-12)

Seven stakeholders indicate that improved disease resistance qualifies best for application of genomics in relation to sustainability. This is also the most appealing application. Two mention abiotic stress and two others health promoting characters. Three stakeholders mention examples that involve microbial genomics. One stakeholder points out that agricultural genomics should especially focus on the 'difficult' traits, another says that most important is that products appeal to markets and consumers. Only four stakeholders are directly involved with potato genomics. The other five stakeholders have little or no idea ('don't know') of what kind of products can be expected when. It seems that there is a considerable knowledge gap to close between stakeholders involved and stakeholders that are not involved in potato genomics. One of the latter stakeholders fears that the first product of potato genomics will be a genetically modified potato; another expects improved potato starch.

The four stakeholders that are involved in potato genomics invariably mention markers as the first product of potato genomics, in addition to increased knowledge. Such markers could be used for diagnostics. However, the real product of potato genomics will be a new cultivar. That may take another 4 to 15 years. In the process of cultivar making, genomics (markers) will facilitate the selection process, but not necessarily speed it up. The stakeholders disagree whether such a new cultivar will have improved product quality or improved disease resistance, despite the fact that most think the latter is the more appealing. The issue of residue management is mentioned by only one of the four stakeholders.

4.1.5 The issue of labeling products made with the help of genomics (Question 13)

This question resulted in widely divergent views and resulted in some cases in long, even somewhat emotional reactions and statements. Five stakeholders spontaneously linked the question to genetic engineering, whereas in the context of this question one stakeholder obviously considered genomics as synonymous with genetic engineering. The others thought in terms of conditional applications: when the genomics product contains or includes genetic engineering, it should be labeled according to current legislation. For any non-engineered application of genomics, it would not be necessary to label.

Arguments differed widely, however. As technology or science, genomics was not thought to be of sufficient interest to consumers, or genomics applications may have nothing to do with freedom-of-choice. However, only one stakeholder explicitly recommended labeling genomics apart from genetic engineering. This stakeholder felt that such openness would generate public trust, a possibility of choice and would avoid all problems of acceptance seen with plant genetic engineering.

4.2 Multiple choice questions to the public at large

4.2.1 Approach

In addition to the interviews with stakeholders, fifty randomly approached people assumed to represent the 'general public' were asked to answer three multiple-choice questions (see Appendix I for these questions). People shopping in Harderwijk at the HEMA were approached on a weekday and on a Saturday. People were not classified in any way, such as sex, education or other parameters.

4.2.2 Viewpoints of the public at large

The quantitative results of the multiple-choice questions to the general public are given in Appendix I. The results of Question 1 show that the general public tends to consider genomics a new, difficult term for genetic engineering (or manipulation) (17 of 50; 34%), or simply does not know yet what is meant by genomics (16 of 50; 32%). A smaller group (12 of 50; 24%) links genomics with research activities. This seems to confirm the fear of genomics researchers that they will have to face the issue of public trust because of the confusion with genetic engineering. This issue is also apparent in the answers to Question 2. People seem not interested in/do not trust a potato improved with the help of genomics (22 of 50; 44%), although quite a number of people indicate they will decide on the basis of additional information given (14 of 50; 28%). Quite remarkable are the results of Question 3. For most people (24 of 50, 48%) genomics and sustainability will result in better quality, whereas in policy making and for agricultural genomics researchers the link with environment is much more prominent. This may indicate the existence of a conceptual gap between the public and other stakeholders. However, the sample size of this survey is small and does not justify a full formal statistical analysis. The survey may also have suffered from methodological problems, such as Question 1 influencing the results of Question 2. This small-scale survey should therefore be taken as a very preliminary approach into the views of the general public that may only indicate major trends, if at all. A much larger scale -and costly- survey would be required to substantiate and confirm (or reject) any putative trends.

5. Conclusions and recommendations

Based on literature, own experiences, interviews with various stakeholders and a small-scale public survey, we have explored in this essay the concepts of (agricultural) genomics, (agricultural) sustainability and how they relate to one another. Both concepts are or may become 'container terms' that have a multitude of definitions and cover a lot of connotations. It remains to be seen, however, whether that is a disadvantage. In parts, potato was used as case and steppingstone. Major aim of this essay was to identify questions and leads for future research in the social sciences, rather than come to conclusions.

For genomics, it may be better defined what 'large scale' means and where genomics stops to be considered genomics. Also, the distinguishing characteristics between agricultural genomics, plant breeding and plant biotechnology could be clarified better. A truly hot potato is the relationship between genomics and genetic engineering, in terms of both scientific activities and image of genomics. It would seem a valuable exercise to analyze in detail what societal groups are using what terminology of 'genomics' in what context and with what agenda. Whereas the stakeholders tend to stress the differences between genomics as a research activity and genetic engineering as a potential (but not automatic) application of that research, the public at large seems already in the process of confusing the two. The apparent assumption that all non-genetic-engineering applications of genomics will get automatic societal consent needs confirmation from societal research. In this context, the deeper motivation of genomics researchers is an issue that merits more study.

Sustainability is (or is becoming) considered something worth and essential pursuing, a societal norm, despite many uncertainties about its precise meaning and use. Many dilemmas of sustainability exist and will be identified in the future. These may help to implement the norm in real cases. Genomics research and applications may effect or change the societal norm sustainability, or sustainability may be used to legitimize agricultural genomics. Understanding the relationships between legitimization, sustainability and genomics merits more analyses.

From the perspective of sustainability, the approaches and assumptions of genomics can be seen as undesired and irreconcilable with its aims and approaches. This can be translated in the different perspective of holism versus reductionism. Whereas sustainability is seen as a holistic approach, genomics would be seen as the culmination of reductionism. More analysis is required to decide whether ecological agriculture and agricultural genomics are representatives of two essentially incompatible approaches, or can be combined. Can agricultural genomics fit in the approaches of ecological agriculture and if so, how? *Vice versa*, can any sustainable agricultural production scheme afford to deny the potential benefits of agricultural genomics? This creates a potential dilemma of sustainability that will be very interesting to analyze in a case-by-case approach. For the future of genomics, its applications and their relationship with sustainability should become better defined and clearer in society. Further analysis of the societal link between ecological agriculture and genomics may result in predictive capacities for the way genomics will be approached by society, or will have to be presented to society.

Agricultural genomics could be perceived as a next step in the further industrialization, economization and mechanization of agricultural production. Agricultural genomics may change the agrofood industry into a high-tech/high-value business. Whether such a change is a desire from and in the interest of society requires research attention, as does the question how it relates to sustainability. Research into the mechanisms of agenda setting in agricultural genomics research, the extent of corporate control and the diversity of society's evaluation of such issues is worth attention. In this context, it would seem useful to analyze to what extent this has triggered the research agenda of the CBSG and how or whether viable alternatives could and should be identified and pursued. It should be analyzed how the research agenda of the CBSG was assembled and how society/the public has given its input.

This essay includes the results of interviews with various stakeholders and a small-scale public survey. Additional interviews with a more diverse variety of stakeholders may be informative and a much larger scale public survey would be required to substantiate and confirm (or reject) any putative trends. Finally, we expect this essay to reflect that the interaction of the fields of expertise of the authors has been a useful experience. We hope it was as useful for the authors as it is informative for a reader. More importantly, it was fun and is ready for a follow-up.

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Appendix I.
Interviewed stakeholders, questions to stakeholders, and questions to the general public

(1) Interviewed stakeholders (N=9)

1. * dr. ir. Sjefke Allefs (SA), Agrico Research, Emmeloord (potato breeding)
2. dr. Jos Bijman (JB), Agricultural Economics Research Institute (LEI), The Hague (economy)
3. ir. Hinze Boonstra (HB), Greenpeace Intl., Amsterdam (environmental organization)
4. * dr. Peter Bruinenberg (PB), AVEBE, Foxhol (potato processing company)
5. * prof. dr. Hans Dons (HD), Keygene, Wageningen (genomics company)
6. dr. Simone Hertzberger (SH), Albert Heijn, Amsterdam (retailer)
7. dr. Jan Velema (JV), Vitalis organic seeds, Voorst (ecological farming company)
8. * prof. dr. Richard Visser (RV), Plant breeding, Wageningen University (genomics research)
9. ir. Huib de Vriend (HV), Consumer and Biotechnology, The Hague (consumer organization)

* These stakeholders are involved in the Dutch Centre for BioSystems Genomics (CBSG)

(2) Questions to stakeholders

1. What is in your opinion genomics?
2. What is in your opinion sustainability?
3. Can genomics contribute to ecological agriculture and food production?
4. Can one have ecological agriculture and food production without the application of genomics?
5. Are there any negative aspects associated with the application of genomics in ecological agriculture?
6. How do you see the relationships between genomics and (a) ecological farming; (b) genetic engineering; (c) plant breeding?
7. What products qualify for the application of genomics in relation to sustainability?
8. Which of those products has most appeal to you and why?
9. One of the target crops for genomics will be potato. Are you involved in this?
10. What do you expect of genomics in relation to sustainability with respect to potato?
11. When do you expect the first product of potato genomics on the market?
12. What kind of product will that be?
13. Do you think that such a potato made with the help of genomics should be labeled for consumers?

(3) Multiple choice questions to the general public (N=50)

1. What is in your opinion genomics?

		No	%
A	Genomics is a figure from Asterix and Obelix	2	4
B	Genomics is a company in garden gnomes and so	2	4
C	It is a difficult word for genetic manipulation	17	34
D	It is a new technology for biological research	12	24
E	Don't know	16	32
F	Other	1	2

2. When you find potatoes in the shop that are improved with genomics, would you buy those?

A	Yes, our potato badly needs some improvement	3	6
B	No, I don't trust those so-called improvements anymore	12	24
C	No, I don't want that manipulated trash	10	20
D	Perhaps, depends on the information about the improvement	14	28
E	Perhaps, depends on the price	8	16
F	Don't know	3	6

3. Can genomics contribute to sustainability? What comes to mind?

A	The food has a longer shelf life	8	16
B	The food has a better quality	24	48
C	The food is more friendly for the environment	12	24
D	The food is made with the help of genomics	4	8
E	Don't know	1	2
F	Other	1	2