9 Sustainable Agriculture: Future of Plant Biotechnology

Abstract

Agricultural sustainable development is a very complicated issue and substantive by other factors like water resource shortage, cultivated land decline, environmental pollution etc. Early civilization was strongly base on agriculture and as such a need for alteration of crop which has been a longstanding practice which is traceable to 2500–2000 BC as recorded that in Africa the ancient Egyptians. However the scientific and technological advances of the past century have greatly expanded the breadth and power of agricultural innovations. There now exist a remarkable array of technologies to improve crop production and is documented in this chapter besides the biotechnological approaches to improve crop sustainability are also mentioned in the last section of this chapter.

Keywords

Biotechnology · Sustainability · Traditional · Innovation network · Models

9.1 Challenges of Sustainable Agriculture

Although food self-sufficiency is predicted to be acceptable in the next 50 years, agricultural sustainable development is still challenged by water resource shortage, cultivated land decline, environmental pollution, faults in the mechanisms for protection of cultivated land and inefficiencies in the management of land tenure rights.

9.1.1 Agricultural Water Use

In agricultural production, the use of agricultural water for irrigation and animal husbandry plays an important role and is the main component in the total use of water. The total use of agricultural water in China in 2000 was reported to be

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378.3 billion m^3, representing 68.83% of the total national water use. In 2000–2050, quota estimation and scenario analysis were used to predict agricultural and other water demands in China. The results show that demand for agricultural water will increase from 384.4 million m^3 in 2010 (64.29% of all water use) to 402 million m^3 in 2050. At the same time, by 2040, the national total demand for water will reach 677 billion m^3, which is close to the maximum available water resource in China (China's exploitable water resource is approximately 850–1100 billion m^3; Li and He 2000). There will therefore be a potential conflict between water demand and supply, and in the future there will be more competition for water. Agricultural water use will undoubtedly remain less competitive because in agriculture, the value of water output per unit is lower than in industry. In addition to scarce water resources the efficiency of agricultural water use is relatively low. The average use coefficient of the irrigation pipe is below 0.6, which means that nearly half of agricultural water is wasted during transport and about 140 billion m^3 of water is lost annually. Currently, 0.96 m^3 of water is required in developing countries to yield 1 kg of grain, which is twice that of developed countries. Israel, for example, only needs 0.43 m^3 of water to produce 1 kg of grain (Jiang 2001). The efficiency of water use can be increased in two ways:

(i) To modify pipe systems in order to reduce unnecessary transport losses.
(ii) Water saving technology and equipment must be advanced. Current flood irrigation can, for example, be transformed by small border irrigation or long border irrigation, sprinkler irrigation technology and equipment, drip irrigation and micro-sprinkler irrigation technology (Wang and Jiang 1998).

9.1.2 Cultivated Land Resources

9.1.2.1 Driving Forces for Cultivated Land Loss in the Future

Land supply and demand and land use are determined primarily by population, economy, society and natural conditions (Li et al. 2001). From the point of view of complex socio – economic and natural systems, the driving forces for the loss of land in cultivation around the world in recent decades have included an increase in the population with a trend of continuous growth, socio – economic development and environmental pressure (Yan et al. 2005). The growing population is the biggest challenge for global sustainable development and the main reason for the shortage of resources and environmental degradation (Heilig 1999). Continuous population growth before 2030 will undoubtedly increase the demand for cultivated land, grassland, and forest and construction land. The economic benefit of land use is the decisive parameter in the distribution of land resources, and cultivated land is often regarded as a relatively low economic benefit (Brown 1995). The growing demand for cultivated land can therefore only be met by the use of marginal land. However, intensive expropriation of marginal land would cause environmental problems, such as soil erosion and land degradation, which would threaten land use sustainability (Tian et al. 2003).

Developed countries 'experience shows that industrialization is always accompanied by the loss of cultivated land. During the process of industrialization, the decrease in cultivated land in developing countries appears normal. China's cultivated land is reported to be declining at an alarming rate, threatening China's food security and sustainable agricultural development. During 1996–2003, China's GDP increased by CNY 4880 billion, based on statistical data from CSSB; during the same period, China lost 6.65 Mha of cultivated land. This means that an increase in GDP of CNY 1000 leads to a loss of cultivated land of 1.36 ha. The cultivated loss of land due to industrialization is mainly a result of building and urban expansion use. The loss of cultivated land in 1996–2003 accounted for approximately 1.33 Mha of cultivated land, accounting for 43.8% of the total loss of cultivated land (excluding the loss of the Grain-for-Green Programme). Although urbanization has both positive and negative effects on cultivated land (Li and Liu 2003), an average decrease in cultivated land productivity is observed. Some studies have shown that more than 0.2 ha of reclaimed land must compensate for the loss of productivity of only 0.06 ha of cultivated land used for urban expansion (Yu and Hu 2003). The quality difference between the lost cultivated land and the recovered land that replaces it has reduced the overall quality of the cultivated land in China. According to research by the Institute of Remote Sensing Applications, CAS, the center of cultivated land in China has moved north 28.34 km and from 1985 to 1996 the quality of cultivated land has decreased by 2.52% (Gao et al. 1998). The patterns of land use are clearly influenced by policy. Previous inappropriate policies, such as "grain production as the core of agriculture" (yi liang wei gang), have caused environmental problems in China, although agricultural land has been increased in order to implement the policy (Yan et al. 2006). In the case of India, although the urban population has increased significantly in the last two decades, from 217 million in 1991 to 377 million in 2011 (Indian Census 2011), most of the country's urban transition has not yet taken place. India's urban population will grow by nearly 500 million between 2010 and 2050 (United Nations 2014), according to the United Nations. The area of non-agricultural land has more than doubled over a 50-year period, from 9.36 million hectares in 1951 to 22.97 million hectares in 2001 (Chadchan and Shankar 2012). India continues to lose its agricultural land by: (a) urban conversion (Fazal 2001) (b) reduction in farming suitability (Prokop and Poreba 2012) and (c) abandonment of agricultural land (Dhanmanjiri 2011). The country is currently facing the dilemma of increasing agricultural productivity while converting highly productive agricultural lands to urban uses (Brahmanand et al. 2013). The world has recognized these problems and adapted its agricultural policies to include the protection of the environment and environmental restoration. Several programs have been successfully implemented since the 1990s (Natural Forest Protection Programme, the Desertification Combat Programme, the Grain-for-Green Programme). Although these programs, in particular the Grain for Green Programme, cause a great deal of land loss in cultivation, their environmental benefits are vital in the long term for sustainable agricultural development. More serious environmental degradation due to inappropriate human activity has led to a reduction in cultivated land and a reduction in the quality of cultivated land, such as land degradation and soil erosion, desertification and salinisation.

9.1.2.2 Protection Mechanisms for Cultivated Land

In order to ensure global food security and sustainable agricultural development, effective protection of cultivated land is essential. The current protection mechanisms generally have two major problems: (i) programming for land use, in which the authority of the relevant administrations can not be effectively countered, and there is no joint programming for land use and urban construction, and (ii) the protection of basic agricultural land, which focuses solely on the area of agricultural land in a protected area, but does not take into account the productivity of agricultural land, which leads to the degradation of agricultural land.

In order to overcome these restrictions on sustainable agricultural development, it is suggested that the following measures should be taken: (i) harmonization of different patterns of land use in order to meet the demands of economic development and agricultural production, (ii) improvement in the protection of the environment and the environment when additional land is cultivated, (iii) development of appropriate land (iv) increase capital investment to consolidate land and recultivate abandoned land. In addition, improving the efficiency of land use will also reduce the pressure on agricultural production due to the lack of cultivated land. According to our estimate, accommodation capacity can be improved by approximately 40% if the plot ratio is increased from 0.3 to 0.5. About 3.7 Mha of land is reported to be saved if land for residential use in rural areas is reduced to 120 m^2 per capita and 6 Mha of land is saved if it is reduced to 100 m^2 per capita. In the next 30 years, it is therefore possible to meet the demand for land for construction for a high population.

9.1.3 Tenure Mechanism of Agricultural Land

The basis of land tenure rights in agriculture is the system of household responsibility (HRS). Agricultural land is collectively owned, but individual households are responsible for land use and management. As farmland owners, households can benefit directly and indirectly. Land offers potential employment opportunities for farmers who have fewer opportunities to work in cities (Brandt et al. 2004), but, more importantly, access to agricultural land can help farmers avoid uncertainty in the supply of food and income and provide the necessary food security and insurance (Tao and Xu 2005). In the 1980s, the HRS stimulated the enthusiasm of farmers for production and accelerated agricultural production (CSSB 2006). However, the positive effects on the long-term improvement of agricultural productivity have gradually disappeared and the negative effects are becoming increasingly apparent. The HRS is associated with at least three problems:

(i) Agricultural land is divided into small parts and one household should farm each piece. The average agricultural land area for each household was found to be 9.3 mu (1 ha equals 15 mu) and in the mid-1980s was even subdivided into smaller parts. The average area for one household decreased to 8.47 mu in 1990 (Zhao 2001). These fragmented areas of land can only support small-scale farming and restrict the use of modern agricultural technology.

(ii) The identification of farmers is a decisive factor in obtaining access to agricultural land. If access is lost, there is no economic compensation. Peasants engaged in non-agricultural activities are therefore reluctant to give up their access rights, which leads to a lack of investment in the inefficient use of some agricultural land.

(iii) To some extent, the separation of ownership and access to agricultural land has made farmers focus primarily on short-term outputs from agricultural land, leading to a decrease in the quality of land and damaging the sustainability of land use (Yu et al. 2003).

There are shortcomings in the current policy on land expropriation. Farmland can be converted into building land by expropriation, but the expropriation process lacks careful planning and the price of compensation is quite low (Guo 2001). This encouraged the rent of government land and encouraged the sale of land (Zhang 2000). In addition, a reasonable price is not created by an effective land market (Dowall 1993). The lack of an economic compensation system is an important reason for inefficiency in the protection of cultivated land, which leads to breaches of land use regulations and unreasonable land use. The current land tenure rights system should be reformed and HRS improved in order to solve these problems. It is suggested that the following measures be taken: (i) to identify separate land ownership rights and access rights, and to define reasonable rights and responsibilities of owners (collectively) and managers (peasants), (ii) to strengthen the supervision of land use in cultivated land by collective and government action, (iii) to improve the transfer mechanisms for land use rights, and to establish multiple distributions of land use rights in accordance with market rules (iv) establish market distribution mechanisms for agricultural land (Zhang 2000), and accelerate the introduction of price mechanisms suitable for the land market, (v) establish and improve the compensation tax system for the use of land and the reclamation of new building land, and increase the effects of economic measures, such as land prices and land taxes, on the adjustment and control of land use, and (vi) establish economic compensation mechanisms for the protection of cultivated land and adapt mechanisms for the participation of benefits in order to solve external problems and unparalleled cost profits in the protection of cultivated land.

9.1.4 Fertilizers and Pesticides Usage

In 2005, 47.66 Mt. fertilizers were used in China, including 22.29 Mt. nitrogen fertilizers, 7.44 Mt. phosphate fertilizers and 4.90 Mt. potash fertilizers (CSSB 2006). Fertilizers ‘contribution to yield in China, however, is still low. The average contribution of fertilizers to the yield of grain is only 46.43%, which is increased by approximately 8.84 tons of fertilizer/tons used (Peng 2000). On the basis of this contribution to yield, fertilizer consumption in the twenty-first century will be increased by at least 10.22–11.08 Mt. in support of a 100 Mt. increase in yield. In Asian countries, the average consumption of fertilizers in cultivated land in China and India is 356.7 kg per hectare, which is twice the maximum consumption of fertilizers in developed countries; the consumption of nitrogen fertilizers in cultivated land is 170.9 kg haK, 2.5 times higher than the world average; phosphate fertilizers are 56.6 kg haK, 1.86 times higher than the world average. These numbers suggest that fertilizers in Asian countries are being overused. On the other hand, fertilizer efficiency is relatively low. The efficiency of fertilizer nutrient use is reported to be only 30−40% in developing countries, which is only half that in developed countries (60−70%) in developed countries. Over-consumption and low fertilizer efficiency cause a large number of unabsorbed fertilizers in the soil, leading to a number of environmental problems. The China Council for International Environment and Development Cooperation (2004) reported that approximately 1.23 Mt. of nitrogen is discharged into rivers and lakes annually, 494,000 tons into underground water and 2.99 Mt. into the atmosphere. About 60 per cent of the annual use of fertilizer N in the Yangtze River area is lost from non-point sources of gaseous and agricultural products (Shen et al. 2001). China has the highest consumption of pesticides in the world. The total consumption of pesticides increased from 86 in 2003 to 1.33 Mt. 2003 from 862,000 tonnes in 1983. Abuse and low efficiency of the use of pesticides are also common in conjunction with fertilizer problems. According to the Chinese Academy of Agricultural Sciences (Zhang et al. 2004), 40% of pesticides used in the production of rice and 50% in the production of cotton are not necessary. The high proportion of highly hazardous pesticides in agriculture is another problem with the use of pesticides. Methamidophos, dimethoate, parathion, methylparathion and dichlorophos were frequently used in 1990 and accounted for 90,800 tonnes (Zhong et al. 2000). In Asia, Africa, Latin America, the Middle East and Eastern Europe, the environmental pollution caused by pesticides is now serious. Even in earlier years, DDT, lindane and dieldrin residues in fish, eggs and vegetables were far beyond India's safe range (Wu 1986). In India, the human body's DDT content was the highest ever. In the 1990s, the global sale of pesticides remained relatively constant, ranging from $270 to $300 billion, of which 47% were herbicides, 79% were insecticides, 19% were fungicides/bactericides and 5% were insecticides (Table 9.1). Herbicides ranked first in three major pesticide categories (insecticides, fungicides) between 2007 and 2008.

Fungicides/bactericides rapidly increased and ranked second. Europe, supported by Asia, is now the world's largest consumer of pesticides. China, the United States, France, Brazil and Japan are the world's largest producer of pesticides, consumers or traders. Fruit and vegetable crops are used with most pesticides worldwide. Pesticides, mainly herbicides, are mainly used for maize in the developed world. In agricultural environmental systems, pollution caused by careless and over-use of pesticides and fertilizers has become more severe. It is reported that there were 891 agricultural pollution events in 23 provinces in China in 2000, 40000 ha of agricultural pollution In addition, the lack of use of organic fertilizers has resulted in a

Table 9.1 List of some ambiguities in innovation

	Type of uncertainty	Issues on which there is uncertainty
1.	Technological uncertainty	Characteristics of the innovation (such as costs or performance)
		Relation between the innovation and the infrastructure in which it is embedded
		Uncertainty to what extent adaptations to the infrastructure are needed
		Possibility of choosing alternative (future) options
2.	Resource uncertainty	The amount and availability of raw material, human and financial resources
		How to organize the innovation process (e.g. in house or external R&D?)
3.	Competitive uncertainty	Behaviour of (potential or actual) competitors and the effects of this behavior
4.	Supplier uncertainty	Actions of suppliers as regards timing, quality and price of the delivery
5.	Consumer uncertainty	Consumers preferences with respect to the innovation
		Consumers' characteristics
		Long-term development of the demand over time
6.	Political uncertainty	About current policy (e.g. regarding interpretation or effect of policy, or a lack of regulation) or about future changes in policy, as well as reliability of the government

Source: – (Meijer et al. 2007)

reduction in organic soil, unbalanced soil nutrition and a reduction in fertility (Ma and He 2002). The content of organic matter in cultivated land in Asia fell to 1.5%, much lower than in North America (2.5–4.0%) and Canada (3.0–4.5%); the content of organic matter in black soil in the north-west Himalayas fell from 8–10% to 1–5% (Liu 2002). In order to achieve more sustainable agricultural production and agroecosystems, effective measures must be taken to control the abuse of fertilizers and pesticides and to improve the efficiency of the use of fertilizers and pesticides. We propose these measures: (i) Standardize pesticides and train farmers to correctly use the relevant technology, (ii) Improve existing production techniques and strengthen research and development on new fertilizers and safe pesticides, and (iii) Improve farming technology to eliminate the overuse of fertilizers and pesticides.

9.1.5 Ecological Agriculture

A new opportunity, eco-agriculture, is the combination of modern scientific, technological and traditional agriculture in the world. This requires the use of ecological theory and system science methods. Eco-agriculture has been widely recognized throughout the world as an effective tool and a general approach to sustainable agricultural development. The development and application of eco-farming is not without problems, however:

(a) The lack of sufficient research on the theory and methods of eco-farming. Technological innovation, the introduction and application of high technologies in eco-farming are slow and do not support the development of eco-farming.
(b) Low industrialization in eco-farming. At present, eco-agriculture is only a production system that focuses on agricultural production and neglects the production-market relationship. In addition, the characteristics of global agricultural production prevent eco-farming from industrializing. These include: more population with less cultivated land; a shortage of agricultural input; and the HRS system.
(c) Inefficient measures to promote eco-farming. Although economic, social and ecological benefits have been achieved in eco-farming regions, effective technologies and eco-farming methods have not been more widely popularized and the benefits of eco-farming for environmental protection are limited.

In order to develop eco-agriculture globally, the following measures will be required:

(i) Strengthening research in the theory and technology of eco-agriculture. The research should focus on: (1) Theory of agricultural ecological systems, (2) The application of the theory of scarcity of resources, the theory of externality and methods for eco-agriculture, (3) The introduction and use of high technology, such as genomic technology, information technology and other technologies, (4) The assessment of the impact of modern techniques on ecosystems and measures to protect against negative effects (5) Advancement in the design of the ecological engineering model.
(ii) Establishing advanced eco-agricultural engineering models based on current models and application conditions. It is also convenient and effective to optimize traditional technology for ecological benefit.
(iii) Seeking a model for eco-agricultural industrialization that fits local conditions. Zhou et al. (2004) proposed three practical ways: the comprehensive development way through optimization grouping or regrouping, the economic way according to marketing direction and the protective way according to limit of resources.
(iv) Popularizing eco-agriculture through information service and financial support. More technology information service and financial support need to be provided to households to promote the conversion from the traditional production model to the eco-agricultural model.

9.2 Sustainable Agriculture Innovation Network

The thinking of agricultural innovation systems (AIS) has become an increasingly used framework for analyzing technological, economic and institutional changes in agriculture (e.g. Devaux et al. 2009; Spielman et al. 2009). In the AIS approach, innovation is considered to be the result of a networking process and interactive learning between a heterogeneous set of actors, such as farmers, input industries, processors, traders, researchers, extensionists, government officials and civil society organizations (Röling 2009). The AIS approach emphasizes that agricultural innovation is not only about new technologies, but also institutional change. Assuming the interaction between heterogeneous actors related to various dimensions of agricultural innovation (e.g. development of technology, institutional change, reorganization of the supply chain, market development, creation of social acceptance), it has been noted that AIS can be regarded as a complex adaptive system (CAS) (Hall and Clark 2009; Spielman et al. 2009). These are defined as self-organizing systems "whose properties cannot be analyzed by studying their components separately formed by many different types of agents, in which each defines its strategy, reacts to the actions of other agents and changes in the environment and tries to modify the environment in a way that suits its needs. Assuming the interaction between heterogeneous actors related to various dimensions of agricultural innovation (e.g. development of technology, institutional change, reorganization of the supply chain, market development, creation of social acceptance), it has been noted that AIS can be considered as a complex adaptive system (CAS) (Hall and Clark 2009; Spielman et al. 2009). These are defined as self-organizing systems "whose properties cannot be analyzed by studying their components separately formed by many agents of different types, in which each defines its strategy, reacts to the actions of other agents and changes in the environment and tries to modify the environment in a way that is appropriate to them (Spielman et al. 2009). Elsewhere, this environment is indicated as the incumbent 'socio-technical regime' (Geels and Schot 2007), and efforts to change it in favor of the realization and durable embedding of an innovation have been called 'effective reformism' (Roep et al. 2003).

There are several studies on the self-organizing nature of agricultural innovation systems and how they are linked to effective reformism processes, but their analytical focus is often at a high level of aggregation, such as the macro-level of a whole country and a very long time horizon, such as a process of change that takes several decades. Examples include studies on innovation in zero-tillage by Ekboir (2003), developments in the Green Revolution in India (Biggs 2007), innovation in food systems in Uganda (Hall and Clark 2009), rice innovation in Nepal (Pant and Hambly Odame 2009), agricultural development in Kenya (Ochieng 2007), and innovation in irrigation systems in Morocco (Poncet et al. 2010). Despite the usefulness of such an analysis to understand the main forces of socio-technical change in agriculture, such a focus risks failing to fully understand the activities of innovating actors in support of such change. The question addressed in this article is how forces contribute to socio-technical change at the micro level of individual innovation networks. By providing detailed insights into how actors interact with their environment at various levels in agricultural production systems and agri-food chains in their innovation efforts, we hope to contribute to building blocks for adaptive agricultural innovation policies that can address the unpredictability of agricultural innovation policies that can deal with the unpredictability of innovation processes. The article continues by drawing a conceptual framework of agency and innovation networks.

9.2.1 Innovation Agency and Structure

However, the CAS perspective on AIS interaction comprises several types of interaction between actors and their environment (e.g. between human actors and artifacts, i.e. technologies), the emphasis in this article is on social interaction in innovation processes. This focuses on the relationship between the agency of actors and the social structure described in the structuring theory of Giddens (1984). The Agency is capable of taking action and making a difference during events (Giddens 1984). Resources and competencies in the context of innovation determine the "innovation agency" available to an actor or organization for innovation (i.e. knowledge, skills, material, and financial resources). It also includes institutional features such as actors' norms and rules, a so-called 'innovation template' that orients and legitimizes action (Edwards 2000). No single actor can pursue its innovation objectives in self-organizing innovation systems without taking other actors into account due to a lack of sufficient power and resources (Aarts et al. 2007). This perspective allows actors to interactively shape a support network in order to achieve individual and collective goals (Engel 1995) and to obtain resources whose nature and source is unknown (Edwards 2007). The idea of a support network presupposes an innovation network with voluntary membership, known as "innovation configurations" (Engel 1995) and "coalitions" (Biggs and Smith 1998). This does not mean that the interests of partners in the innovation network are automatically aligned, since innovation networks are the negotiating scenes (Wiskerke and Roep 2007). In addition, an innovation network is not stable in the sense of a support network: It can change in composition over time. These innovation networks depend on many other peripheral players in their institutional environment, whose involvement may not be voluntary, but based on mutual interdependence. In Giddens' theory of structuring, actors and structures (i.e. their institutional environments) have a dual relationship, because the "structural properties of social systems of social systems are both medium and outcome of the practices they recursively organize" (Giddens 1984). This means that their environment conditions actors, but they actively or passively change their environment by their actions, so that another form of conditioning is exercised in turn. This reflexive relationship between actors and their institutional environment, which actors can adapt, change or complement, was called mutual embedding in the study of innovation systems (Markard and Truffer 2008). Actors carefully monitor the actions and aspects of the environments in which they operate, taking into account past, present and future events (Edwards 2007), in order to achieve their objectives and reduce the uncertainty in the process of achieving them (Geels and Schot 2007). Innovative actors' objectives are often embodied by more or less articulated visions that have an influential function to mitigate guidance, convincing, binding and uncertainty (Berkhout 2006). This is especially important, because innovation exposes many uncertainties to innovative players. These include, for example, complementary acquisition of resources, consumer demand development, adversity or instability in policy and legislation, and the behavior of network partners and competitors (Meijer et al. 2007). Although actors can deliberately try to reduce these uncertainties in their institutional environment, they are always limited in their influence. In limiting or conditioning further activities, unintended consequences of the agency as well as external events outside the sphere of influence of agents themselves play an important role. These are therefore an important source of structural variation (Alexiou and Zamenopoulos 2008). For example, consumer preferences, government policies and market factors at regional, national and global levels influence innovation (Blay-Palmer 2005).

It is now clear that shaping innovation involves "selling a good story" (e.g. visions, speech), told by the right people (with conviction, credibility, power), at the right time, at the right place, and to the right people (acquiring complementary resources, building and capitalizing on momentum and using windows of opportunity). Since innovation actors must constantly react to their environment, which they actively try to change in their favor, it has been argued that this calls for adaptive innovation management (Smart et al. 2007), based on ideas from generic literature on CAS management (Westley 2002). This means that agricultural innovation policies should not seek to fully plan, control and manage the agricultural innovation system, but should be based on the likelihood of events, increase the likelihood of desired results and reduce the likelihood of unwanted results (Poncet et al. 2010). Although the AIS approach has proven its value as an analytical framework, it must still be transformed into an operational concept with policy options and targeted interventions to improve the ability to innovate everyday (Spielman 2006). The present study hopes to contribute to the understanding of innovation's microfoundations and thus optimally formulate adaptive innovation policies. Spielman et al. (2009) indicate that the analysis of the history of innovation focusing on important events is a useful method for mapping the dynamics and structured analysis of the interaction of innovation systems at the micro level, which was also applied in the analysis of "mainstream" innovation systems, where it is referred to as the analysis of innovation journeys (Van de Ven et al. 1999). Data were collected through semi-structured interviews with innovation networks and institutional environmental actors, who were both respondents telling their own experiences and informants giving a broader picture and observations. The interviews have been fully transcribed and analyzed using qualitative data analysis (Atlas 5.0). In order to reconstruct agency-structure interactions, the perspectives of both innovation network and institutional environmental actors were analyzed. This analysis was supplemented by an analysis of a range of internal network documents (minutes of meetings) and external documents (e.g. policy documents and journal articles). In addition, this multi-stranded approach allowed triangulation: A research methodology to prevent the risk of post-factual account distortions, increasing internal validity. Non-technological innovation is increasingly regarded as important for more socially sustainable farming systems, for example by reconfiguring the value chain (Devaux et al. 2009) and new arrangements for cooperation between different farms and non-farms (Veldkamp et al. 2009). One case relates to non-technological, organizational innovation in order to achieve social sustainability in arable farms that are too small to survive and have insufficient assets to sustain autonomous growth. This innovation can essentially be regarded as an innovation under the radar. Such innovations are not driven by politics or research, but are emerging from the bottom up and increasingly considered as relevant sources of change (Hall and Clark 2009). These farmers sought to formally pool land, labor and other resources to increase scale in order to establish a joint venture (called Sjalon). This is an exception to the normal situation for individual family farms in the Netherlands. Other initiatives to increase the collective scale have emerged (Stevens 2007) in response to the need to create economies of scale in order to cope with low agricultural products prices (Röling 2009). The other case deals with innovation induced by research, which relates to the development of a concept of poultry husbandry that is respectful of the environment and animal welfare (Rondeel). This concept is the result of an interactive policy design process involving policy, business and societal stakeholders from the poultry sector (Groot Koerkamp and Bos 2008). This case forms part of in broader developments in animal welfare innovations in Dutch animal husbandry (Wiskerke and Roep 2007), in contrast to a production system characterized by industrialized animal production with low animal welfare. It combines both technological innovations (development of the Rondeel system) and non-technological innovations.

9.2.2 Event Analysis Sjalon

The starting point of Sjalon was a farmer's recognition that his farm was too small for his son to create a sustainable farming future. He decided to form a brainstorming group with non-agricultural actors (e.g. a machine vendor, an agricultural researcher) to develop the idea of increasing the scale by setting up a collective farm with a clear division of tasks. After a land measuring device symbolizing expansion, the project was called Sjalon. After a facilitator was hired to structure the process and help acquire resources such as financing and knowledge to concretize and materialize the plan, brainstorming gradually transformed into actual plan development. An important event was a research project by the Free University of Amsterdam, which calculated the effect of establishing a collective farm and thus made the vision more tangible. This enabled Sjalon to obtain funding from the province of Flevoland to draw up an initial business plan, assisted by an accounting firm and an applied research institute, which calculated the cost and return of collective farms. This business plan helped Sjalon obtain further support from influential parties such as the Ministry of Agriculture, Nature and Food Quality (Netherlands acronym: LNV). LNV referred TransForum (Veldkamp et al. 2009) to the Sjalon initiative, an innovation program to fund and facilitate the transition to sustainable agriculture. In addition, clear figures have been instrumental in recruiting potential participants into the plan and approaching banks for credit facilities for Sjalon. However, Sjalon never succeeded in attracting sufficient participants to set up the initially planned 600 ha farm (which is large according to Dutch standards), which also influenced banks 'willingness to provide loans, but eventually the remaining three participants managed to start a 100 ha farm. From 2004 to 2008, a legal problem was whether a collective farm would be legally permitted, given land tenure legislation in the Noordoostpolder (North-East Polder: NEP). Much land in this area is owned by the government and allocated by the Treasury Department (TD) to farmers on long-term leasehold. Since this leasehold is personal, a situation that combined several leases (as would be the case in Sjalon) would be considered illegal sub-leasing. After long negotiations between Sjalon and the TD, an arrangement was concluded in 2008 that allowed individual farms to join a collective farm legally. Sjalon was therefore founded on 14 March 2008 as a limited liability company.

9.2.3 Agency in Particular Agency-Structure Interaction Loci in the Sjalon Case

The Sjalon innovation network dealt with the reduction of a number of uncertainties in the interaction with the institutional environment: (a) to obtain financing for their collective farm venture (financial uncertainty), (b) to obtain legal approval for a type of farm that did not fit leasehold legislation (political uncertainty), and (c) to ensure that farmers in the NEP are interested in participating in the NEP.

9.2.4 Sjalon Interaction Locus A: Finding Funding to Sustain the Development and Implementation of the Innovation

Sjalon's efforts to obtain financing can be divided into two separate but interconnected efforts: One to obtain funding to support the search and development process and the other to obtain funding for the eventual collective farm. As for the former, although the brainstorming group initially financed the facilitator, the Sjalon had to find additional funds for research and development and consultancy. The facilitator arranged for students from the Free University Amsterdam to carry out a feasibility study free of charge through his network of contacts. This study proved instrumental for Sjalon in obtaining funding from the deputy of the province of Flevoland, who was approached through informal facility contacts. The idea of Sjalon arrived at the right time for the provincial deputy and was in line with the ideas and sympathies of the deputy. Although there was no clear provincial development policy on initiatives to increase the scale, Sjalon was able to apply for an innovation subsidy and obtain it. This subsidy financed a legal-fiscal exploration of the legal form of Sjalon and drafted a business plan. This plan showed that a significant increase to more than 600 ha was needed to make the plan viable. Due to restrictions on state support, the province could not support this financially. They could only help to make spatial planning possible. The province therefore referred Sjalon to LNV, which would have more funding available (although LNV stated that it fell more within the remit of the provinces and municipalities). The Sjalon network met LNV's initial skepticism and felt that it was not taken seriously. Since the researcher in the brainstorming group was the then agriculture minister's nephew, however, he approached his uncle informally. Since the minister felt that Sjalon was a self-organized initiative that fitted well with the policy of agricultural innovation aimed at bottom-up changes, he ordered that a formal letter sent by Sjalon to LNV be taken seriously. Then LNV officials entered into talks. As a result of these talks, LNV officials referred Sjalon to the TransForum innovation program financed by the government. TransForum has taken over the financing of the previously hired facilitator and has financed additional research and development and consultancy (to recalculate and adjust the previous business plan), as well as facilitation itself. The business plan was also important in dealing with the dual purpose of the bank. First, the then director of the local cooperative agricultural bank created a positive attitude towards the idea. This director began championing the idea and gave the Sjalon network the impression that the bank was prepared to take a risk and to support an innovative effort. It later served to convince the bank that there was a prospect of return on investment when the new bank director judged the plan on the basis of normal credit provision criteria and hesitated to provide a loan because there were no comparative cases for assessing risks and returns. It was unfortunate that the old director had left, according to the Sjalon network, because they had to face a less favorable financial environment that had become risk aversive. In addition, as the business plan now envisaged a 100-ha farm, it did not meet the bank's initial expectations.

9.2.5 Sjalon Interaction Locus B: Overcoming Legislative Barriers to Collective Land Tenure

The first phase of the relationship between Sjalon and the Treasury Department (TD) between August 2004 and March 2006 was initially troublesome, despite the fact that Sjalon was actively seeking contact because Sjalon was expected to attract many leaseholders. At an early stage, the Sjalon realized that their ideas would have legal implications for leasing arrangements. Sjalon's plans to amalgamate lands would be an illegal sub-lease, according to the interpretation of the TD. The TD saw this as an unwanted phenomenon that often occurred, but could not be tolerated. Illegality would arise because the land user should also be the lease for a certain period of time. Since the TD pursues a public good objective, they preferred to make these lands available for other purposes. The TD proposed a solution that would give individual leaseholders their individual leasehold rights to Sjalon, who would then become a collective leaseholder. Because some potential participants found this emotionally unacceptable-they would lose their individual tenure rights if they left Sjalon-the TD built into a special clause. This clause included that, if he could show that the new individual farm would be viable, leasehold rights would be returned to the individual farmer when he left Sjalon. This was TD's customized solution, which remained within the current law, although because of its unusual nature it had to be finetuned with the Ministry of Finance. This solution was communicated to Sjalon by the TD, but there was no favor. Since Sjalon thought there could be no further discussion, they did not enter into further discussions. Instead, Sjalon sought expert advice from a land tenure law professor in June 2007, who advised that the use (by Sjalon) and tenure (participants 'leasehold) could be legally separated. The TD thought Sjalon needed time to assimilate his proposal and waited for his answer. However, when the TD received a letter from professor on behalf of

Sjalon proposing the alternative, it was unpleasantly surprised. The TD thought Sjalon was too pushy to formulate the leasehold on them. The TD thought Sjalon was too pushy, wanting the leasehold formulated on its terms, which would lead to an unwanted sub-lease situation in one way or another. This conflict was mitigated by the facilitator of TransForum, who characterized it as follows: Through Sjalon's eyes, one gets the image of the TD as a bureaucratic obstacle, blocking participation in Sjalon, while the conversation with the director of the TD gave me the impression of an organization that is willing to go very far in supporting Sjalon, to the limit even a bit further, but that has to operate within the complex tenure situation in the NorthEastpolder. The facilitator organized an open discussion, in which once again it was explained what the TD proposal entailed; this resulted in Sjalon accepting the proposal.

9.2.6 Sjalon Interaction Locus C: "Selling the Story" to Recruit Potential Participating Farmers

Beginning with a vision of a collective farm of 600 ha, Sjalon had to attract many farmers who would be willing to amalgamate their land and conform to a less individual entrepreneurial orientation than they used to. The enthusiasm and active networking of the main champion farmer to engage potential participants was instrumental in recruitment, as many respondents indicated. In addition to this championing, the buzz was created by service providers supporting Sjalon and by articles in agricultural newspapers and magazines. The Sjalon network presented the plan and prospectus during a number of special meetings in 2006. This led to the signing of a letter of intention by six farmers. In the end, however, only three participants signed up, leading to a farm of 100 ha. One reason potential participants did not commit was that, despite the prospectus and other explanations, they could not obtain a clear picture of what Sjalon meant and were afraid that they would lose their independence from work and leasehold contract. Many respondents said that this difficulty in correctly interpreting the plan was due to the fact that it was developed in a relatively small circle over a long period of time. It was then sold as a ready-made package to potential participants who had no complete package to potential participants, who did not have full knowledge of the underlying ideas and assumptions. Another dilemma arose because the idea of Sjalon began with a planned size of more than 600 ha. When it became clear that this could not be achieved, the plan lost some of its attractiveness for many farmers. Farmers who were not willing to participate, on the other hand, indicated that they wanted to see the concept's "proof of principle," so it was better to start soon, albeit smaller. This was experienced as a major 394 L by the Sjalon network. Klerkx et al. / Agricultural Systems 103 (2010) 390–400 incentives to really launch the initiative in order to attract others by showing positive results. Another reason for non-interest was the strong association between other farmers very much associated the concept with the championing farmer. In the event that they had negative personal associations ("wants to play the boss"), or social associations with him (the NEP is a tightly knit community in which reputations are well known), they also rejected the concept of Sjalon. On a higher level, there were a number of non-conducting factors in the socio-economic environment of potential participants outside the direct reach of the Sjalon network. One factor was that the Sjalon idea was not supported by the municipality. This was because it was a plan to strengthen agricultural activities, while the municipality favored other economic activities in order to reduce the agriculture of the municipality. In the municipality, an influential pastor who was both a farmer and an exofficial in the farmers' organization also criticized the plan. He considered the idea personally unviable. While he did not use his position to oppose the plan openly and publicly, it contributed to a non-conducting atmosphere. Sjalon's strategy was to bypass these people and not involve them except to arrange for formalities, but they nevertheless influenced the development of Sjalon. In addition, the banks and accountants of potential participants had a lack of a final business plan (the initial one had rough estimates) and despite the buzz created by the magazine, newspaper, articles banks and accountants of potential participants had not previously actively pointed to the Sjalon as a good opportunity for "weak" farmers to keep a viable business (which was how Sjalon wanted to sell itself). Their advice was conservative in the eyes of the Sjalon network and facilitators. Banks and accountants rebutted the argument that they could not act as advocates because of their position as neutral service providers (accountants) or had to adhere to certain criteria of judgment (banks). Other factors were that other cooperative farms had collapsed due to internal power struggles in the meantime, which influenced Sjalon's image among potential participants. Agricultural products prices have also risen significantly. Many respondents indicated that this reduced the need for less well-documented farmers to seek strategies for survival such as the one proposed by Sjalon. Consequently, in March 2008, only three farms finally joined a limited liability company, hoping that other farmers would find it attractive if it worked successfully.

9.2.7 Event Analysis Rondeel

Rondeel began with the interactive design project Caring for Hens (CfH) (Groot Koerkamp and Bos 2008), which resulted in visualizations and requirements (BoR) for new poultry farming systems (Plantage and Rondeel). The most obvious distinctive feature of the Rondeel concept is that it is a round hen housing system as opposed to normal rectangular systems. It also integrates standards of animal welfare comparable to free space and organic (open air) laying hen husbandry (e.g. natural shelter) with the advantages of closed hen housing systems producing cage eggs or barn eggs (e.g. protection from airborne diseases). Kwetters and Vencomatic (a manufacturer of poultry husbandry systems) formed a technical committee to develop a working prototype after a failed attempt to cooperate between Kwetters (an egg packing company participating in CfH) and the Animal Science Group (ASG-a research institute facilitating the CfH project). Vencomatic addressed technical problems such as nesting, collection of eggs and transportation of manure.

Kwetters dealt with the marketing of a segment between free range and organic eggs, with increased animal welfare as its main point of sale. The ASG researcher who managed and supported the CfH project as a technology champion, in addition to technical development activities (e.g. a manure drying carrousel based on the airflow effect of the chimney), the technical committee sought suitable locations for the construction of the new system. Initially, the search was concentrated in Barneveld, a municipality in which the poultry industry is clustered and which a global poultry center is. Members of the technical committee approached officials from Barneveld and several farmers from Barneveld interested in building a system from Rondeel. They also contacted various service providers (architects, construction contractors, feed suppliers, and researchers from ASG, environmental consultants, animal welfare consultants and business incubators). This network supported the fine-tuning of the design, facilitated the process of obtaining permits by checking compliance with construction and environmental standards and provided access to subsidies. At the same time, talks with the Dutch Animal Protection Society (APS) started with the technical committee. APS was a partner in CfH and piloted a certification system for poultry meat (Volwaard Chicken) indicating the value of animal welfare (by assigning welfare stars). They later hired a specialized animal welfare and corporate social responsibility (CSR) consultant to assist them in the talks. The aim was to negotiate one's assignment criteria, for the assignment of one, two, or the maximum of three welfare stars. Rondeel was temporarily assigned two stars by APS, and later even three. Kwetters and Vencomatic, together with the CSR consultant, successfully applied for TransForum financing and facilitation in their search for development funds. After Rondeel became a TransForum project, Kwetters 'internal strategic choices led to the project's withdrawal. Kwetters 'withdrawal opened new perspectives, in particular on alternative ways of distributing and marketing the egg. TransForum initiated workshops on the functioning, marketing and future development steps of the network to support the formation of new ideas and the consolidation of the network. This led to a greater sense of co-development between Vencomatic and farmers, who were first considered to be mere adopters of Rondeel. In addition to existing network partners, such as Vencomatic staff, CSR consultants, architects, officials and farmers from Barneveld, other consultants and champions from other welfare innovation networks (e.g. the Volwaard Chicken Network and the pork network described by Wiskerke and Roep (2007) participated. These workshops also resulted in cooperation between Rondeel Ltd. and the Southern Farmers 'Organization (ZLTO), which had experience with Volwaard Chicken marketing. Since the Rondeel housing system requires higher investment than normal hen housing systems, the production costs of the welfare value egg are higher. This makes it more expensive than usual eggs from the barn. For the Rondeel network, there was a great uncertainty as to whether consumers will see the difference and pay extra (a typical welfare innovation problem (Binnekamp and Ingenbleek 2006). Therefore, interested farmers, as well as their banks, hesitated to invest if the risks of non-return on additional investment were not covered (if the eggs had to be sold as eggs from the barn). This was a typical situation between the development and application of concepts between "valleys of death" (Meijer 2008) or "chicken and egg" (Ansari and Garud 2009), which inhibited further development. The problem was that in order to have sufficient volume of the product, there must be sufficient Rondeels, but in order to have sufficient Rondeels, there must be sufficient guaranteed purchases of eggs from retailers (supermarkets); however, supermarkets were reluctant to market the egg because of the risk of their non-sale; And they also demanded a large volume immediately; but supermarkets still didn't think about marketing the egg, they first wanted the Rondeel to work, but no Rondeels would be built without a guaranteed purchase. In order to resolve this dilemma, Rondeel Ltd. engaged in talks with ZLTO and LNV in order to obtain a guarantee that would cover the additional investment in the event that the Rondeel eggs were unsuccessful and had to be sold at a lower price as normal barn eggs. This guarantee was given by LNV in July 2009, allowing the construction of the first hen housing systems. Generally number of agency-structure interaction loci in the Rondeel case is indicated that will be further analyzed. These reflect the way in which the Rondeel network dealt with: (a) obtaining building and environmental permits for the design of a hen housing system that did not fit neatly into an established category (political uncertainty), (b) obtaining a guarantee to cover additional investments in the event of a failure of Rondeel (financial uncertainty), and (c) obtaining certification from the Animal Protection Society as a proxy for Rondeel (financial uncertainty).

Rondeel Interaction Locus A

The adoption of a new design by current environmental and construction legislation. The design of Rondeel differs from other forms of hen housing systems because it is round. It is therefore not fully described in the legislation on the construction of the hen housing system and environmental regulations. This could lead to potential conflicts with regulatory bodies over issues such as construction dimensions, fire safety, landscape esthetic fit and gas emissions. However, construction and environmental permits were issued quickly in the case of Rondeel. There were a number of factors that caused this, as one factor was that the municipality of Barneveld adopted the innovative concept of Rondeel, since Barneveld could use it as an international poultry centre. In this aspiration, the marketing manager of Kwetters framed Rondeel (helped by vivid illustrations of the CfH project and a later model of scale). The CEO of Kwetters, who strategically pointed out that other municipalities were also interested, further enhanced the willingness of Barneveld; Barneveld was even more eager to have the first Rondeel built. As a result, economic development officials were champions of innovation in their organization. They did so by chasing their colleagues, the officials responsible for the permit procedures, by emphasizing that this was an innovative concept that would benefit the municipality. The system developers (i.e. Vencomatic R&D staff and ASG researchers who advised them) had a parallel purposeful strategy to equip the Rondeel with existing husbandry subsystems (feeding, extraction of manure, ventilation, etc.), which had already been approved for ammonia emission standards. Authoritative ASG calculations supported this approval, although researchers and environmental consultants recognized that in practice these figures could be different. Instead of a prolonged admission and verification procedure for emissions (taking >5 years), the hen housing system nonetheless met existing standards. In addition, because Vencomatic hired a local environmental consulting firm and architect with good connections to the Barneveld civil servants, some of the remaining conflicting issues have been refined in interaction. For example, this concerned the Rondeel's fit with its round shape in the landscape. A more troubling problem was obtaining fire safety approval. This was because the Rondeel was regarded as a closed building with resulting security problems despite having outdoor spaces. Since the responsible fire department liked the project, however, he helped the architect in close interaction with the fire department to look for a solution. A specialized consulting agency later verified this solution, fireproof curtains that fall down in the event of a fire. Vencomatic has thus enhanced this strategy to frame Rondeel's component technology and appearance to comply with existing rules using specialized consultancies and researchers to verify compliance with existing standards. This made it possible to execute the integral concept as designed, with only minor adaptations.

Rondeel Interaction Locus B: Overcoming Risk Adversity Towards Non-proven Market Concepts

Rondeel Ltd. had to find ways to cover this risk in order to overcome the lock-in situation whereby the building of the hen housing system depended on the guaranteed sales volume and vice versa, therefore makes investment risks acceptable to Rondeel Ltd. and farmers. While innovation subsidies from innovation programs such as TransForum were available for the coverage of research and development costs, a major problem was to find risk financing (in the form of venture capital) or a guarantee. This was necessary to cover the risk of the surplus investment required compared to normal housing systems for barn hen. In this regard, Rondeel Ltd. and the support network around it pointed out that the public policy discourse was very supportive of innovations to improve animal welfare, such as Rondeel (e.g. Verburg 2008), but that they were not prepared to provide financial guarantees in practice. This was problematic because Vencomatic could only cover part of the financial risk as Rondeel Ltd's mother organization. Banks would only finance up to the amount of a normal housing system for barn hen, the returns of which are known. The initial search for risk financing with Oost NV, a business incubator, by the Rondeel Technical Committee (as was carried out before Rondeel Ltd. was established) proved unsuccessful. This was because Oost NV targets Barneveld's Gelderland Province. Since Vencomatic was from the Province of Brabant, Oost NV did not consider it to be its concern. In addition, the Economic Affairs Ministry funded Oost NV and the Rondeel system were considered to be an agricultural affair related to LNV. Later on, Rondeel Ltd. tried to convince ZLTO and LNV that they needed to provide risk financing or at least a guarantee. They did this by holding high-level talks between Vencomatic's CEO, ZLTO's president, and LNV officials. However, both ZLTO and LNV said they could not support specific companies: ZLTO because it is a political representative of all farmers, and LNV because of European state support rules. However, ZLTO provided in-kind support by providing the Volwaard Chicken with its experience and expertise, as they endorsed the Rondeel concept.

LNV stated that they had been responsible for financing the CfH project, a feasibility study, and now provided financing and facilitation for research and development through TransForum. LNV said companies should take some risk and should not rely on government alone. In order for the state to play a role, it would be necessary to develop generic instruments, since state support rules prevented individual companies from receiving support. Since the risk financing/guarantee problem could not be solved by formal means, Rondeel Ltd. to influence LNV first through informal probing by an ASG representative, but this was not appreciated. In addition, LNV said it was unrealistic for Vencomatic's CEO to expect that a guarantee could be provided solely on the basis of the Rondeel vision. Despite this setback, a new contact opening was forged thanks to the mediation of the CSR consultant hired as part of the TransForum project to facilitate processes and expertise in the marketing of welfare innovations. This was because of his good links to LNV. The people at Rondeel Ltd. highly appreciated this consultant's role, as the following quote shows:[the consultant], here we call him' the crowbar for opening closed doors.' Rondeel Ltd. sent a written formal support request and arranged a new formal meeting. A more detailed business plan with well-calculated financial figures has been drawn up on the basis of this meeting. The minister often referred to Rondeel as a promising concept, so the application and the business plan made explicit reference to this. Given the state support rules, LNV was willing to see what would be possible. Coincidentally, Rondeel was found to be able to use an existing guarantee regulation for large investments to individual farmers. The maximum amount of the guarantee had risen thanks to a recent change in this Regulation. This meant that this system could accommodate Rondeel. Furthermore, it facilitated the interaction with retailers. Retailers had earlier been hesitant to co-develop the Rondeel egg concept until there was a perspective of guaranteed supply, but now they became committed.

Rondeel Interaction Locus C: Getting Societal Support for Rondeel's Husbandry Concept

The third locus for interaction concerns Rondeel Ltd.'s dealings with what could be seen as a friendly actor in Rondeel's environment, the Animal Protection Society (APS). This is because APS supports innovations in animal welfare. This issue of welfare stars is linked to trade with retailers in order to convince retailers of the egg's' unique selling point.' In particular, the visualization/scale model of Rondeel and the BoR opened the doors to welfare star negotiations, as these showed that APS 'interests were clearly in line. However, hurdles must be overcome in the certification process. One hurdle was that the APS had to interpret the results of the pilot project it had carried out with its welfare certification system and has its members 'approval. This pilot project aimed to award the Volwaard Chicken welfare stars. APS perceived certain risks in attaching its reputation as a civic advocacy organization to a product (e.g. in the event of a food safety scandal involving a certified product), so it first had to evaluate the experience with Volwaard Chicken before assigning welfare stars to other products. These deliberations led to a delay in the awarding of stars, which Rondeel Ltd. used to convince others in the quest for support, such as LNV in the guarantee issue. In addition, although the vision and the BoR attracted APS, the fact that the hen housing system could not yet be tested in practice meant that two stars were awarded provisionally. Rondeel sought three, and based his arguments on this number of stars. Another problem to be resolved was the interactional uncertainty between the CEO of Vencomatic and the APS representative. Conflicts over the critical opinion of APS on other Vencomatic products, coupled with the CEO's simplicity as an innovation champion, were bound to have a negative impact on the Rondeel trajectory. Naming the CSR consultant who also mediated the issue of the LNV guarantee as a neutral intermediary to take the sharp edges off the interaction and mediate an agreement mitigated.

9.2.8 China-UK Sustainable Agriculture Innovation Network (SAIN)

9.2.8.1 SAIN's Mission

To help achieve a resource-efficient, low-carbon economy and an environmentally friendly society SAIN will provide a coherent framework for the development and implementation of cooperation between China and the United Kingdom on environmentally sustainable agriculture, thus supporting the objectives of the current dialog on sustainable development as a basis for long-term cooperation between China and the United Kingdom (SAIN 2011a, b).

9.2.8.2 SAIN's Origins

The cooperation between China and the United Kingdom on sustainable agriculture dates back more than 20 years, but most of this has been inter-institutional, especially between universities. It has never been established in a long-term strategic framework designed to meet the objectives of national policy. The previous collaboration was of a technical nature and focused on soil erosion, management of crop nutrients, integrated pest management and biological control, waste management and plant breeding. More recent cooperation is mainly concerned with climate change, the impact of agriculture on the environment, ecosystem services and poverty in rural areas and the management of water resources. It is increasingly aimed at building capacity and supporting the development of policy, but much of it remains fragmentary and does not take into account possible synergies between different activities. However, events have provided the basis for a more ambitious approach in the last 3 years. First, the emergence of a scientific consensus on areas of mutual interest resulting from the UK-China Partners in Science Conference-Appropriate Science and Technology for Rural Sustainable Development held in November 2005 in Yangling, Shaanxi. Second, the Sustainable Development Dialog (SDD) was launched in November 2005, providing a new platform for cooperation between China and the United Kingdom, including a Sustainable Agriculture and Fisheries Work Programme. In November 2008, the signing of a Memorandum of Understanding (MOU) on Sustainable Agricultural Cooperation between the British Secretary of State for Environmental Food and Rural Affairs (DEFRA), Hilary

Benn, and the Chinese Minister for Agriculture, Sun Zhengcai, also indicated a strong commitment to the growing agricultural partnership. The ministers agreed to establish as an important vehicle the Sustainable Agriculture Innovation Network China-UK Sustainable Agriculture Innovation Network (SAIN) as an important vehicle for delivering on the MoU and the SDD Agriculture and Fisheries Work Programme (SAIN 2011a, b).

The main objectives of SAIN were: –.

(a) Support the implementation of the UK-China SDD and its theme for the management of natural resources by promoting innovation in three areas: Policy development; institutional mechanisms for collaborative research; and the implementation of policy and science on the ground.
(b) Stimulate innovative thinking and research on all aspects of sustainable agriculture and its relationship with the environment;
(c) Communicate information on issues relating to environmentally sustainable agriculture and opportunities for change and disseminate best practices to key audiences (farmers, policy makers, companies)
(d) Contribute to global sustainability through greater sharing of expertise between developed and emerging economies.

A high-level Board of Directors (GB), supported by a Secretariat Office in each country and four working groups (WGs), will supervise SAIN. The Secretariat Office in China is located at the North West University of Agriculture and Forestry (NWAFU), and the United Kingdom Secretariat Office is located at the University of East Anglia. The Governing Board of key government and academic stakeholders as well as independent experts will guide the program priorities and modalities. Each Working Group (WG) will lead a specific workflow and will be co-chairedby UK and Chinese experts with approximately five members from each WG from each country and supplemented by other national and international experts where appropriate. The SAIN Coordinators in the Secretariat Offices will be de facto members of the WGs. The WGs will function as a virtual network reaching out across both countries and with a rolling programme of well defined time-limited tasks. The membership and location of the WGs and the substance of their work may change in the future as new challenges, priorities and opportunities emerge (SAIN 2011a, b).

9.2.9 SAIN's Initial Work Focused on Four Inter-Related Themes

(a) Research and better communication tools are used to improve the management of soil and crop nutrients and reduce pollution from non-point sources.
(b) Increased use of agricultural biomass and manure for the production of biogas, liquid biofuels and organic fertilizers.
(c) Addressing the interface between agriculture and climate change, including the impact of climate change on agriculture and the way in which agriculture

contributes to greenhouse gas emissions, and therefore needs to adapt to it. This includes maximizing the potential contributions of I and II to adaptation and mitigation of climate change and helping to ensure that other agricultural policy issues are also addressed in support of climate change objectives.

(d) Providing policy advice on how the concept of a circular economy can be applied to agriculture by taking advantage of opportunities for greater recycling, minimization of waste and more efficient use of water and other critical resources.

However the main benefits of SAIN are:

(a) Improved focus on innovation in policy and increased relevance of research and development for SDD objectives and policy formulation
(b) Greater emphasis on cooperation in the development of integrated policy
(c) Better connections and more synergy between joint projects
(d) A more holistic approach to development of programmes. Enhanced complementarity with other bilateral and multilateral donors ‘activities. Increased translation of research and development into action on ground
(e) Increased sharing of expertise and research
(f) Better implementation of core policies
(g) Improved learning (including expertise sharing between developed and emerging economies)

The Chinese Ministry of Agriculture supports SAIN and the United Kingdom Department for Environment, Food and Rural Affairs (Defra), providing financing to the United Kingdom and China Secretariat. Initial stakeholders include the NWAFU, China Agricultural University, the Chinese Academy of Agricultural Sciences, the Chinese Academy of Sciences, the Nanjing Agricultural University and the United Kingdom Research Council in China, and DFID, the FCO, BBSRC and CABI in the United Kingdom. As the WGs are appointed and the Work Program is developed, participation will be increased (SAIN 2011a, b).

9.3 Traditional Biotechnology and New Technological Approaches

9.3.1 Traditional Biotechnology

Early civilization was strongly based on agriculture and, as such, the need to alter the crop, which was a long-standing practice, which can be traced back to 2500–2000 BC, according to which ancient Egyptians in Africa produced wine using fermentation techniques with the help of microbiology, apart from the breeding of animals such as geese and cattle for dietary and nutritional use in their society. The fermentation technology was also used in bakery to cause an increase in dough, which resulted in 50 bread varieties more than 4000 years ago. The study and understanding of advance plants in the seventeenth century was relatively poor. Nevertheless, plant breeding was a popular practice when Gregor Mendel, "the father of genetics," who was a plant breeder, studied the inheritable characteristics of peas and gave a better understanding of genetic inheritance, which led to a new terminology called crossbreeding, which is now known as hybridization. In addition, in 1865, at two meetings of the Natural History Society of Brünn in Moravia, he published a paper called Versuche über Pflanzenhybriden (Experiments on Plant Hybridization), which was criticized, but considered merely useful for hybridization rather than inheritance, and as such ignored. In this paper, it was shown clearly how dominant and recessive alleles produce their remarkable characteristics and possibly transfer them to offspring. A group of scientists who worked on breeding problems rediscovered the work in 1900 and made Mendel's findings more popular. Subsequently, Mendel and a new understanding of genetics found tangential points to traditional self-pollination and cross-pollination achieved significant advances in plant breeding with reference to the study. The identification and incorporation of characteristics in plant breeding is crucial. Breeders therefore traveled around foreign lands in search of plants with specific desirable characteristics.

These characteristics occasionally arise through the mutation process, which was considered too slow and unreliable for the desired production rate of various plants. This gesture of plant domestication also became the most important means of increasing yield, improving disease resistance and drought tolerance, improving nutrition and crop taste and facilitating crop harvesting for centuries. The Green Revolution has played an important role in popularizing the use of conventional hybridization to multiply yields in many folds through "high-yielding varieties" and has an enormous impact on crop production in the world. Nowadays, plant breeding is targeted at organic farming (OF), which can help to reduce the gaps in yield between both production systems: conventional farming (CF) and organic farming (OF). However, further analysis is needed to determine whether these systems should necessarily be considered as competing entities and whether they should necessarily be comparable in terms of productivity. Since it is not clear whether OF yields should be equal to CF yields or simply higher than they are at present. The breeding objectives for both conditions converge in order to achieve higher productivity, incorporation of resistance or tolerance to biotic and abiotic factors and higher resource-use efficiency (water, nutrients, light, etc.). Local adaptation may be more important for OF, as the recycling of resources and the quality of the inputs used may vary from region to region, even if OF practices are highly regulated. Organic plant breeding (OPB) also aims to fit cultivars into renewable organic resources farming systems. OF enthusiasts often noted that the cultivars grown for CF do not always perform well under OF conditions (van Bueren et al. 2011). However, there is no reason to believe that even in all CF environments, all cultivars produced by conventional breeding programs perform well. It is therefore unreasonable to believe that all the lines produced in an organic breeding program will perform well in all OF conditions. The interaction of genotype-by-environment (G + E) is a common situation that plant breeders have to deal with and significant progress in crop improvement can still be made if properly exploited. Even under CF, which for some OF supporters consists simply of high-input standardized practices, G E is a very important aspect to be taken into account, because in reality there are also low-input and various CF systems, which are driven by resource-poor farmers in developing countries. From the point of view of pure plant breeding, OF can therefore be regarded as a separate environment with a strong component of local adaptation, in which the necessary characteristics and selection methods should be incorporated. Characteristics and sources of variation although the general breeding objectives for both OF and CF are similar, specific characteristics are required for OF, as the use of synthetic agrochemicals in this system is prohibited. The competitiveness of weeds and the ability to establish symbiont relationships with microorganisms in the soil are relevant to OF, since they can improve the use of resources and their efficiency of use (Zdravkovic et al. 2010). Research has shown that genetic variation in the competitiveness of weeds in cereals exists (Zystro et al. 2012), and that early vigor and allelopathy can be useful in improving weed suppression (Bertholdsson 2010). In potato (Tiemens-Hulscher et al. 2014) or wheat (Baresel et al. 2008), genetic variation for the efficiency of nitrogen use has been found, and genomic regions associated with this trait have been identified in barley (Kindu et al. 2014). In addition, studies have shown that agronomic practices can improve the efficiency of nitrogen use (Swain et al. 2014). In wheat, genetic variation and genomic regions associated with micronutrient intake have also been reported (White and Broadley 2009). However, Nelson et al. (2011) found that the percentage of arbuscular mycorrhizal fungi in winter wheat was negatively correlated with iron and zinc levels.

9.3.2 New Technological Approaches

The scientific and technological progress of the last century has greatly expanded the scope and power of agricultural innovation. There are now a remarkable range of technologies to improve crop production, many of which are now in practice, including:

9.3.3 Technologies for Natural Resources Management

Nigeria's future of sustainable agriculture depends largely on proper management of natural resources, in particular soil and water. It is considered that more than two thirds of agricultural land in northern Nigeria is degraded and the situation is equally alarming (FAO 1992). As a result of poor water management, irrigated and dry land salinity also poses serious threats to cropland in these lands. Technology includes:

9.3.3.1 Soil Management Techniques

One of the promising techniques for successful soil management practice is the application of organic manure and mulching with green plants, controlled overgrazing and bio – solid integration (Chrispeel and Sadava 1994).

9.3.3.2 Water Management Techniques

Effective and efficient irrigation methods include on – site storage tanks for the collection and storage of water in fields to minimize runoff water (IFAP 2005).

9.3.3.3 Technologies for Crop Improvements

Crop performance is affected by a combination of many factors, including the collection of genes that allow the plant to produce high yields in an agricultural environment (Abbott 1999). It takes years to develop high-performance plants and efforts in Nigeria have fallen behind, although new tools and techniques are emerging that can accelerate local crop improvement. The following are the techniques:

9.3.4 Annotated Crop Genome Sequencing

This technique helps to determine the genetic sequence and individual gene function of farmers 'local crops. Documenting the sequence and functions of these genes will help to accelerate crop breeding for sustainable productivity (Miflin 2000). Efforts to sequence the complete genome of Arabidopsis, rice and maize with the full sequence of chromosomes 2 and 4 have recently been published (Mayer et al. 1999). Cook (1998) outlined some of the methods for the collaborative project on crop plants. Usually the first approach is to look for homology with other known genes. Another way to understand the function of a particular sequence is to observe their expression under a range of defined conditions using micro array technology (Ruan et al. 1998). Gong et al. (2011) established the sequence of a small heat shock protein (sHSP) gene using a gene candidate method based on homology and a rapid amplification of cDNA ends (RACE). The cDNA sequence of this gene is 920 bp (GenBank: HM132040) and contains an open reading frame (ORF) of 636 bp, which is expected to encode a protein with 211 residues of amino acids. These studies and those conducted in other species show that this has considerable potential as a powerful tool for the discovery and functional analysis of plant genes and helps to understand genetic regulatory networks and gene interaction.

9.3.5 Germplasm Techniques

New genes can be used to improve a crop from plant, animal or bacterial species and molecular techniques to introduce them to a candidate crop. Once introduced into a plant, conventional approaches to plant breeding are used to incorporate them into the local elite germplasm (Chrispeel and Sadava 1994).

9.3.6 Biochemical Engineering

Biochemical plant metabolism studies have identified proteins that are essential to the functioning of most pathways. Many key genes were isolated by purifying and (partially) sequencing proteins and then finding the appropriate cDNA and/or genomic sequences. Knowledge of changes in the specific function of a plant resulting from different treatments has led to the development of methods for isolating genes involved in metabolic pathways or their associated physiology (Miflin 2000). Osmolyte production in plants under abiotic stress conditions is frequently studied; OA results in a number of benefits that sustain the activity of cells and tissues under stress conditions (Serraj and Sinclair 2002).

9.3.7 Technologies to Overcome Biotic Constraint

Among the technologies emerging that can effectively overcome biotic constraints (weeds, disease pathogens and pest) so as to ensure sustainable yield are:

9.3.8 Plant Mediated Gene-Silencing Approach

This technique is used to induce plants to transfer genetic materials to other organisms and to target and interfere with the genetic interaction between plants and organisms. This approach benefits from the recently discovered powerful molecules known as small RNA that play a role in plant development and stress resistance. The plant-based gene silencing has shown promise to control viruses, nematodes and some insects (NAS 2009).

9.3.9 Bio-pesticides and Bio-control Approach

This approach focuses on natural means of fighting biotic constraints of crop rather than synthetic chemicals in order to avoid environmental degradation and pollution. Bio pesticides involve release of pest specific natural enemy to control its population and some allelopathic plants that can inhibit the growth of specific weeds while promoting that of agricultural crops (Bunza 2010).

9.3.10 Disease Suppressive Soils

The use of disease-suppressive soils involves management practices that encourage crop-associated microbial communities that naturally reduce plant diseases and pests. These practices might include manipulating carbon inputs, using crop rotation sequences that increase the presence of beneficial organisms, or inoculating soils with disease-suppressive microorganisms (NAS 2009).

9.3.11 Technologies for Energy Production and Storage

In view of the weather types and range of temperatures in these regions (Northern Nigeria), solar energy technology will provide reliable energy for crop production due to its potential scalability and cost. Due to the prevailing light and temperature of these locations, photosynthetic microbase fuel produced from algae and cyanobacteria will also excel well in these regions (Singh and Gu 2010).

9.3.12 Local Expertise and Participation

The new problems and technologies listed here are interdependent. A system-wide approach of all techniques must be implemented in local environmental conditions for successful crop production. Farmers need to be able to provide input and obtain information. These tasks require a committed, trained, local workforce of extension agents, scientists and engineers to be built with national efforts and international assistance (NAS 2009).

9.4 Physiological and Biotechnological Approaches to Improve Crop Sustainability

9.4.1 Physiological Approaches to Improve Crop Sustainability

In these sections, we focus on the contribution of crop physiology to plant breeding in relation to (1) the analysis of past achievements in increasing yield potential, yield stability and resource productivity, (2) the identification of characteristics that could improve the efficiency of genotypes with high yield potential and adaptation to the target environment, and (3) disentangling of complex interactions among traits and between traits and environment.

9.4.2 Analysis of Past Achievements of Plant Breeding

The concepts of crop physiology contribute to the analysis of past plant breeding achievements in increasing the yield potential; yield stability and resource productivity by identifying mechanisms indirectly affected by the selection process. The rationale is that realized changes in the phenotype resulting from yield breeding and agronomic adaptation could identify limits and opportunities for future improvements (Reynolds et al. 2009). Comparisons of cultivars released in different eras allow quantification of the contribution of genetic improvement to crop yield and the dissection of the characteristics involved, as shown in the example below.

In recent decades, breeding has consistently increased the yield potential of maize in Argentina. The higher yield of modern hybrids was linked to a higher production and harvest index of biomass (Echarte et al. 2004) and was mainly due to more grains per unit of surface area, which increased the demand for reproductive sinks during the effective grain filling period. Compared to their older counterparts, modern hybrids generally produced a more stable yield and harvest index in response to increased plant density and environmental stress, mainly associated with a higher number of grains per unit of plant growth at a critical flowering period (Echarte et al. 2004). Modern hybrids, however, could show lower yield stability in response to source reductions during grain filling because of their high reproductive demand (Echarte et al. 2006; Cerrudo et al. 2013). Modern and old hybrids had similar use of water and absorption of nitrogen during vegetative stages, but after flowering, former hybrids absorbed more nitrogen (Robles et al. 2011). Finally, modern hybrids showed a higher yield of grain per unit of nitrogen absorption and evapotranspiration per unit than their older counterparts associated with an improvement in the harvest index (Nagore et al. 2010).

9.4.3 Identification of High Yield Traits and Adaptation to Environments

For the successful use of characteristics in crop breeding, five main conditions must be met: (1) relevance for crop growth and productivity; (2) genetic variability; (3) medium to high heritability; (4) easily monitored; and (5) absence of significant agricultural trade (Bruce et al. 2002). In this section, we emphasize the contributions of crop physiology to the identification of relevant characteristics related to crop performance in the field following top-down (gene phenotype; Chapman et al. 2002) or bottom-up (gene to phenotype; Ishitani et al. 2004).

(a) **The Top-down Approach**

The top-down approach begins by identifying consistent phenotypic variation in yield or other relevant features in the field. The search for mechanisms underlying these responses continues at decreasing levels of complexity (crop, plant, tissue, cell and molecule). Molecular mapping is then used to identify quantitative trait loci (QTL) associated with the trait of interest and, finally, methods based on genomics enable the selection and cloning of genes/QTL that control these traits of agronomic interest. The following two examples illustrate the top-down approach. The number of grains per unit of spike chaff weight (i.e. SF) explained a great deal of wheat yield variation among cultivars in a wide range of environments (Gonzalez et al. 2011). An appropriate method to determine this trait quickly and easily at maturity was developed using a small sample of individual spikes (Abbate et al. 2012). In order to investigate the genetic and molecular mechanisms underlying the trait, controlled crosses were made between wheat cultivars with contrasting SF under various mating designs. These studies have shown that a few genes control SF with low interaction between G and E and medium to high heritability (Pontaroli 2012). Two mapping populations are currently performing molecular marker analysis. Several markers were found to co-segregate with SF, which warrant further investigation (Deperi et al. 2012). In comparison with 12 maize hybrids grown at 42 sites, Castro (2013) identified four maize hybrids of similarly high yield potential and contrasting yield in low yield environments leading to contrasting stability. For the two extreme hybrids in this set, he established the underlying physiological mechanisms responsible for the different yield stability in experiments in which plant density was used as an environmental stress surrogate (Andrade et al. 2002). These studies have been carried out on hybrids and their parental lines. The stable hybrid showed a higher yield of grain and a higher number of grains per unit of land area at high plant densities than the unstable hybrid. Only for the latter trait was the same response observed in their parental lines. In contrast, the partitioning of dry matter to the ear during the flowering period for the unstable hybrid and one of its inbred lines was greater. As in the example above, the next logical step would be to map the desired characteristics and develop quick, effective and easy phenotyping methods to facilitate the selection process. These top-down approaches allowed a complex characteristic assessed in a wide range of environments to be dissected into simpler components under less complex genetic control and with possible complementary effects.

(b) **The Bottom-up Approach**

Enzymes, metabolites and transcription factors that control key biochemical or physiological processes are identified and their genetic control is clarified in the bottom-up approach (Grillo et al. 2010). In order to develop genotypes with the desired feature, genetic engineering, mutagenesis and marker-assisted selection approaches can be used. The identification of relevant traits or genes associated with crop performance is a major challenge due to trade-offs, attenuation of traits and strong interactions resulting from scaling up across organizational levels and complex and redundant plant systems regulation (Sinclair and Purcell 2005). Therefore, scaling up across organizational levels because many factors interact and increase complexity generally attenuates the phenotypic effect of a given feature. This buffering response may reduce the relevance of many characteristics to the crop or farming system (Sinclair and Purcell 2005. Molecular genetics have provided a large amount of information on QTL and, to a much smaller extent, specific genes associated with yield-related characteristics (Mastrangelo et al. 2012). The clarification of gene function could be significantly improved by crop physiology, since it can help to close the phenotypic gap between the availability of DNA sequence and gene function related to crop performance in the field (Miflin 2000).

9.4.4 Disentangling Complex Interactions

Crop physiology also helps to disengage the complex interactions between features and environments and between features. Relevant examples of complex interactions at the level of the trait or quantitative trait locus are presented below to show that caution must be exercised when interpreting and analyzing the potential of new available information derived from crop physiology or molecular studies (Passioura 2012).

9.4.5 Interactions at the Trait Level

Water deficit tolerance is presented as an example of a complex feature. The effects of water deficit on crop productivity are not easy to predict, as they vary depending on the timing, duration and intensity of stress and factors, including previous crop history and other environmental aspects. The relevance of a particular trait varies depending on the type of drought. Features with putative advantages for adaptation to dry environments are not universal and interact strongly with other features and the environment (Tardieu 2012).

Deep roots would be a desirable feature in areas where substantial quantities of water are left in the soil at physiological maturity and the water stored in the soil can be replenished in the subsequent failure period (Sadras and Rodriguez 2007). The induction of a high resistance to water flow in the plant is also a way of saving water for later, more critical stages of growth in areas where drought is progressive and becomes more severe at the end of the growing season (Passioura 1983). Similarly, the most important component of tolerance in chickpea and pearl millet under terminal drought was the conservative use of water early in the crop cycle, partly due to a lower canopy conductance, which resulted in more water available in the soil profile during reproduction (Zaman-Allah et al. 2011). In addition, early flowering would be a positive feature in which crops are exposed to severe terminal water stress, so that plants can complete their growing cycle without severe stress at critical stages in determining grain yield (Debaeke and Aboudrare 2004). However, full-season cultivars would be preferred in environments or seasons with mild or no terminal water stress, as the yield potential is directly linked to the maturity group (Capristo et al. 2007). If the crop is based on rainfall during the season, early vigor would increase the efficiency of water use by reducing soil evaporation (Richards and Lukacs 2002). Expansion of the leaves and stomatal responses to dehydration, characteristics showing genetic variability (Sinclair et al. 2010), may have a variable value depending on the target environment. In environments where crops depend on stored soil water, reducing leaf area and stomatal conductivity would be desirable to save water for later, more critical reproductive stages. However, it would be appropriate to maintain high rates of leaf expansion and productivity under stress for short periods of drought during vegetative growth, since this strategy would allow the crop to use incoming radiation and resources more efficiently to relieve stress.

9.4.6 Interactions at the QTL or Gene Level

The following two case studies illustrate the physiological interpretation of complex molecular data. The first example refers to a genetic linkage analysis of two characteristics, namely growing degree-days in sunflower families derived from the cross between lines HA89 and ZENB8 (León et al. 2000, 2001). Two QTLs, A and B, were strongly associated with the response of the photoperiod that controls thermal flowering time. With the help of molecular markers, near-isogenic families for these

QTLs were developed through backcrosses. This genetic material has been used to study the effects of both QTL on the response of the sunflower photoperiod response, considering the moment of apex change, i.e. Stage 1.3 in the scale of Marc and Palmer (1981), and its subsequent rate of development (Fonts et al. 2008). When QTL A was selected homozygous as HA89 parental line and QTL B homozygous as ZENB8 parental line, the longest time for floral induction and floral differentiation was observed. This previously unrecognized gene interaction is compatible with the proposed web-cascade reaction system for time control to flowering and for the transition from vegetative to reproductive stages (Imaizumi and Key 2006). In addition, QTL B interacted significantly with both traits of the photoperiod (Fonts et al. 2008). The additive effect of QTL B on phase duration increased under extended photoperiod, indicating a short-day response. The presence ofZENB8 alleles in QTL B and HA89 alleles in QTL A resulted in a stronger developmental delay until the end of floral differentiation in long photoperiods than short photoperiods. For the development rate, a second-degree interaction was found between QTL A, QTL B and photoperiod. This higher order interaction is also compatible with the complex web of processes that control blooming responses to the photoperiod, in which light (long days) stabilizes a clock-regulated transcription factor and activates or suppresses key flowering genes (Imaizumi and Key 2006). The second example deals with the use of molecular markers to locate QTL in the same sunflower population, which is grown in a variety of latitudes from Fargo (46.8 ° N) to Venado Tuerto (33.2 ° S) (León et al. 2001, 2003), associated with oil concentration and growing degree days to flowering (DTF). Both the concentration of grain oil and DTF were associated with a QTL on the linkage group B. In accordance with the phenotypic correlations, ZENB8 was derived from additive effects for higher DTF and lower concentrations of grain oil in the linkage group B. These additive effects were also most significant at high latitudes. In combination with DTF, the highest LOD scores for this QTL were observed during long photoperiods in crops emergence. In Fargothe environment with the highest rate of decrease in temperature and radiation during grain filling, the highest LOD score for this QTL was also observed in combination with the percentage of grain oil. This environment also showed the most significant phenotypic correlation coefficients between the concentration of DTF and grain oil ($r = -0.29$; selection with P marker assisted (MAS) and transgenesis may not be completely straightforward and pose a continuous challenge (Edmeades 2013). Conventional breeding, MAS and genetic engineering for higher yield potential and adaptation of crops to the target environment can undoubtedly proceed more quickly if the physiological mechanisms of grain yield determination and their interaction with the environment are better understood.

Data from an analysis of genetic links in families derived from the cross between lines HA89 and ZENB8 (León et al. 2001, 2003). A negative sign of the additive effect means that the mean value of the trait due to HA89 alleles increases. A positive sign of the additive effect is an increase in the average value of the feature due to ZENB8 alleles. In this QTL, HA89 alleles reduce the growing degree of flowering and increase the percentage of grain-oil. This QTL's LOD scores and additive effects have a strong environmental impact. Crops were cultivated in two locations:

Fargo at high latitude (46.8 ° N) and Venado Tuerto at low latitude (33.2 ° S). Photoperiod measured in the emergence of crops In addition, some breeders used useful physiological concepts in their daily work above. In maize, breeding programs carried out at high plant densities and evaluation at many sites with different environments produced some hybrids with high yield stability and high yield potential (Castro 2013). This strong interaction between G and E for grain yields has a genetic basis and shows an opportunity to improve grain yields in medium and low yield environments. This relevant result probably reflects the understanding of breeders that high plant density is a substitute for environmental stress (Andrade et al. 2002). The weakening of the stem by removal of carbohydrates induced by a low source-sink ratio during grain filling (Uhart and Andrade 1991) was also used as a physiological concept by breeders to select the resistance to stalk lodging. In addition, another useful concept that helped breeders in their selection process was the need to optimize the physiological condition of the crop during critical periods for the determination of the grain number to obtain high yield (Egli and Bruening 2005). Physiological principles can also help to develop simple, precise and rapid phenotyping techniques that are essential for both top-down and bottom-up approaches (Pereyra-Irujo et al. 2012).

9.4.7 Biotechnological Approaches to Improve Crop Sustainability

The aim of plant breeding for stress environments is to accumulate favorable alleles that contribute to the tolerance of stress in a plant genome. Genes that confer stress resistance can be derived from germplasm collections, including wild relatives of crops in gene banks or organisms that currently live in water deficit or excess habitats, extreme temperature and salinity, which have developed to meet these conditions (Nevo and Chen 2010). Although conventional breeding (Blum 1985) has made some progress, breeding for abiotic stress tolerance is restricted: (I) by the complex nature of abiotic stress tolerance (timing, duration, intensity, frequency). Biotechnology is a viable option for the development of genotypes that can improve their performance under harsh environmental conditions, especially for (ii) and (iii). For example, advances in genomics and bioinformatics and stress biology can provide useful genes or alleles for stress tolerance. Superior genes or alleles identified in the same species can be transferred through molecular breeding (MB) to elite genotypes. In addition, there is no barrier to the transfer of useful genes or alleles from the animal or plant kingdoms to different species using an approach such as genetic engineering (GE). Biotechnology approaches therefore offer new strategies to produce appropriate crop genotypes that can withstand drought, high temperatures, submergence and salinity stresses. Zhu et al. (2010) outlines key strategies for genetic improvement in abiotic stress tolerance for crop improvement. A number of key approaches to improving crop productivity. Similarly, Ainsworth and colleagues critically analyzed biotechnological approaches that could be used to develop crops with potentially improved productivity in high temperature, high CO2 and high ozone environments (Ainsworth et al. 2008). These included manipulation of leaf photosynthesis, partitioning of photosynthesis, total production of biomass and efficiency of nitrogen use (NUE) (see Glossary). Improved NUE in crops should reduce the use of fertilizers and thus reduce greenhouse gas emissions into the atmosphere. More than 50% of all US greenhouse gas emissions from agriculture are associated with the use of fertilizers and other cropping practices (EPA 2009). The biotechnology community should use biotechnological approaches to address multiple stresses directly under field conditions rather than focusing on individual stresses (Mittler and Blumwald 2010). Our increased understanding of the molecular and genetic basis of abiotic stress responses in plants should allow us to use crop-specific MB, GE and preferably integrated programs to introduce multiple stress resistance.

9.4.8 Fundamental Agricultural Biotechnology Approaches: Prospects and Progress

1. **Molecular Breeding**

In the field of genomics, significant progress has been made over the last 10 years. Many crop species, such as rice (Yu et al. 2002), poplar (Populus trichocarpa) (Tuskan et al. 2006), sorghum (Sorghum bicolor) (Paterson et al. 2009), maize (Schnable et al. 2009) and soybean (Glycine max) (Schmutz et al. 2010) are now available for genome sequences. In addition, the advent of so-called "sequencing of next generation" (NGS) technologies has enabled the sequencing of transcriptomes or genomes of any species (and of any number of individuals) relatively quickly and cheaply (Varshney et al. 2009). As a result, genome sequences have started to become available for less studied crops such as cucumber (Cucumis sativus) (Huang et al. 2009), pigeonpea (Cajanus cajan) (http://www.icrisat.org/gt-bt/IIPG/home.html) and large and complex genome species such as wheat (http://www.genomeweb.com/sequencing/wheat-genome-sequenced-roches-454) and barley (Hordeum vulgare) (http://barleygenome.org/).These genome or transcriptome sequences, combined with genetic approaches, can be used to identify appropriate genes that confer stress tolerance that can be used to improve crops using either MB or GE approaches. The use of genome sequences to identify genes associated with drought tolerance can be demonstrated in sorghum, a species that is well adapted to drought-prone regions. Analysis of the sorghum genome has shown that the characteristic adaptation of sorghum to drought may be linked in part to the expansion of one miRNA and several family genes. Rice miRNA 169 g, adjusted during drought (Xiao et al. 2009), has five sorghum homologs (sbi-MIR169c, sbi-MIR169d, sbi-MIR169.p2, sbiMIR169.p6 and sbi-MIR169.p7). The calculated target of the sbi-MIR169 subfamily consists of members of the transcription factor family of nuclear factor Y (NF-Y) B, which is linked to the improved performance of Arabidopsis (Arabidopsis thaliana) and maize during drought (Nelson et al. 2007). Domain-containing genes Cytochrome P450 have been found to be abundant in sorghum (326 cf. 228 in rice), often involved in scavenging toxins such as those accumulated in response to stress.

Expansins, enzymes that break hydrogen bonds and are responsible for a variety of growth responses that may be linked to the drought tolerance of sorghum, occurred in 82 copies in sorghum cf. 58 in rice and 40 in arabidopsis and poplar (Paterson et al. 2009). The MB approach first identifies quantitative trait loci (QTLs) for interest characteristics, such as abiotic stress tolerance. Until recently, linkage mapping has identified QTLs (Varshney and Tuberosa 2007), but now association genetics has begun to complement these efforts in several crops (Hall 2010). Nested association mapping is also used for the genome-wide dissection of complex traits in maize (Yu et al. 2008), which combines the advantages of linkage analysis and association mapping in a single unified mapping population. Association mapping is a high-resolution and relatively less expensive approach compared to linkage mapping (Gupta et al. 2005), particularly given the availability of high-throughput marker genotyping platforms (Varshney and Dubey 2009). The collaborative project between Cornell University and CIMMYT (http/www.maizegenetics.net/drought tolerance) is an example of the systematic use of association mapping for drought tolerance. The candidate QTLs or genes can be introgressed in elite lines via marker-assisted backcrossing (MABC) after identifying the markers associated with QTLs or genes for traits of interest. Although MABC has succeeded in developing superior genotypes for traits controlled by major effect genes or QTLs, such as bacterial blight and blast resistance in rice (Sundaram et al. 2009), there are few examples of complex traits such as drought and heat tolerance, which are the key traits that need to be targeted for developing crops that are adapted to low rainfall and high temperature conditions. However, MB has been used successfully in rice, with one major QTL effect for submergence tolerance (Septiningsih et al. 2009) and drought tolerance (Steele et al. 2006) identified and used in this approach. One of the difficulties in developing superior genotypes for abiotic stresses such as drought or heat is that these characteristics are usually controlled by QTLs or several epistatic QTLs (Messmer et al. 2009). MABC does not seem to be an effective approach to introgressing such QTLs, particularly in view of the large sizes of backcross populations required to pyramidize several QTLs in the same genetic context. Two new MB approaches, however-marker-assisted recurrent selection (MARS) and genomewide selection (GWS) or genomic selection (GS) – can be used to overcome this problem (Tester and Langridge 2010). The estimated genetic gain, which can be achieved using MARS or GWS, is greater than that obtained using MABC for the transfer or pyramidization of superior QTLs or gene alleles for complex traits such as drought or heat tolerance in one genetic context (Ribaut et al. 2010). Although the MARS approach is routinely used in breeding programs in the private sector (Ribaut and Ragot 2006), no reports on the use of MARS in public breeding programs have been published. GWS is another comprehensive approach to the improvement of complex characteristics. Although MABC and MARS require QTL information for complex characteristics, GWS does not necessarily need information on marker-trait associations (Heffner et al. 2009). In essence, GWS is concerned with the prediction of the progeny's genomically estimated breeding values (GEBVs). In this context, phenotyping data and the profiling of genome-wide markers on a "training population" are first necessary; GEBVs can then be calculated on the basis of phenotyping and marker data. These GEBVs are then used to select the top line of progeny in the breeding cycle (Meuwissen et al. 2001). Several computational tools for calculating GEBVs are available or are being developed, such as the Best Linear Unbiased Prediction Method and the mixed geostatistical model (Schulz-Streeck and Piepho 2010) (http/genomics.cimmyt.org/#Software). However, at present there is little information available on the use of GWS in crop plants in public sector breeding programs, although some groups have started to explore this approach in crops such as maize (http://genomics.cimmyt.org/, http://www.synbreed.tum.de/index.php?id=31).

2. **Genetic Engineering**

The increase in genomic information and the use of related computer biology tools over the past decade has led to the identification of signaling pathways and regulatory genes and networks that control complex characteristics related to environmental stress. Crop GE with signaling components and transcription factors (TFs) leads to the expression of the target transcriptome consisting of several genes involved in the adaptation of stress. For example, the increased production of the signaling hormone abscisic acid (ABA) by over expression of the LOS5/ABA3 gene encoding the Molybdenum Cofactor Sulfurase, which is required for ABA synthesis, increased drought tolerance in transgenic rice plants under field conditions (Xiao et al. (2009). Similarly, the over expression of the rice AP37 (an APETALA2-type TF) gene resulted in the enhanced expression of several target genes and produced 16–57% higher grain yield under field drought stress conditions (oh et al. 2009). Hence, transcriptome engineering seems to be promising for the development of abiotic stress-tolerant crops. However, inducible expression rather than the constitutive over expression of TFs is preferable owing to the severe growth retardation and reduction in seed production that can occur even under normal environmental conditions in transgenic crops with constitutive expression of TFs (Liu et al. 1998). Nonetheless, several transgenic crops have been engineered using C-repeat binding factors (CBFs) and other TFs without a yield penalty (Yang et al. 2010). Transgenic rice plants overexpressing Arabidopsis CBF3/DREB1A or ABF3 TF showed improved tolerance to drought and salinity without growth retardation (Oh et al. 2005). However, only a few crops such as rice (Hu et al. 2006), maize (Castiglioni et al. 2008) and canola (Brassica napus) (Wang et al. 2005), expressing the desired TF and other genes, have been tested under real field stress conditions (Yang et al. 2010). RNA chaperones known for their active role, particularly in mediating transcription and translation both in bacteria and plants, have also been shown to increase yield under multiple stresses. For instance, Monsanto (http://www.monsanto.com/) researchers showed that bacterial cold shock proteins (Csps) can confer improved stress adaptation in multiple plant species. For instance, CspB codes for and is responsible for an RNA chaperone, which is a commonly occurring protein molecule that binds to RNAs and facilitates their function. The gene was first identified in bacteria subjected to cold stress conditions, and further research has demonstrated that CspB helps plants cope with drought stress. In maize and rice, CspB works by helping the plant maintain growth and development during times of inadequate water supply [67]. Recently, a gene encoding aquaporin (NtAQP1) was identified in tobacco (Nicotiana tabacum) and shown to provide protection against salinity stress in transgenic tomatoes (Solanum lycopersicum) (Castiglioni et al. 2008). NtAQP1 plays a key role in preventing root/shoot hydraulic failure, enhancing water use efficiency and thereby improving salt tolerance. It simultaneously increased both water use and photosynthetic efficiency in plants. Moreover, the NtAQP1 gene, which increases stomatal conductance, might also lower canopy temperature and thereby reduce the level of heat stress experienced by plants. By contrast, decreased stomatal conductance and thereby transpiration by the suppression of farnesyltransferase genes (FTA or FTB) by RNAi in transgenic canola resulted in significantly higher yields compared with controls in a 3-year field trial (Wang et al. 2009). To make up for the water loss owing to higher stomatal conductance in the NtAQP1 transgenic plants, pyramiding genes for osmolyte biosynthesis expressed specifically in roots could lead to the growth of deeper roots, potentially enabling water uptake from deeper soil layers (Sinclair et al. 2004).

To offset the adverse effects of climate variability on plants, a combination of genes is required. In addition to genes that encode effector proteins, signaling proteins and/or TFs, a repertoire of promoters is required to conduct transgenic expression in specific tissues or plant organs in a precise and predetermined manner. In order to obtain desirable transgenic plants with high yield stability under stress conditions, appropriate promoters must be selected depending on the gene used. As discussed earlier, for example, the constitutive expression of ZmNF-YB2 in maize gave increased tolerance to drought (Nelson et al. 2007). Transgenic rice plants, by contrast, over express OsNAC10 under the rootspecific promoter RCc3, but not under the control of the constitutive GOS2 promoter, conferred a yield advantage under drought stress conditions in the field (Jeong et al. 2010). Other TFs, such as DREB2A with a variety of roles in biotic and abiotic stresses, may be used to design multiple stress tolerance and increased yields (Yang et al. 2010). The main concern about TF transgenics, however, is whether they perform consistently in the field in conditions of drought and/or heat stress.

9.4.9 Integrated Biotechnology Approach

Although the biotechnology community remains focused on either MB or GE approaches (Narayanan 2002), it is clear that the use of integrated biotechnology approaches must address complex problems caused by drought and heat. In this context, the maize community is an excellent example of several major projects, including Water Efficient Maize in Africa (WEMA, http///www.aatf-africa.org/wema/en/wema), Drought Tolerant Maize for Africa (DTMA, http/dtma.cimmyt.org/), and Improved Maize for African Soils (IMAS, http//www.cimmyt.org/en/projects/ improved maize for African soils). In collaboration with international partners, including multinationals such as Monsanto (www.monsanto.com/) and Pioneer (http//www.pioneer.com/), these projects use conventional breeding, MB and GE approaches. CIMMYT provides high-yielding maize cultivars adapted to African conditions as well as expertise in conventional breeding and drought tolerance testing under the WEMA initiative. Monsanto provides proprietary germ plasm, advanced breeding tools and expertise and transgenes developed in cooperation with BASF tolerant of drought (http/www.basf.com/). The cultivars developed through this initiative will be distributed without royalties to African seed companies through the African Agricultural Technology Foundation (AATF) and made available to smallholder farmers as part of their seed companies. For example, under the DTMA initiative, more than 50 new maize hybrids and open-pollinated maize cultivars have been developed and distributed to seed companies and non-governmental organizations. These maize cultivars tolerant to drought produce approximately 20–50% higher yields under drought than other maize cultivars, and several of them have already reached farmers' fields. In contrast, the IMAS initiative is developing maize varieties that are better able to capture the small amount of fertilizer that African farmers can afford and that use nitrogen more efficiently to produce grain (i.e. increase NUE). In addition to MB and GE, there have recently been some new approaches to address complex stresses in a concerted way that should be integrated with MB and GE. (i) approaches to NGS or transcriptomics and proteomics to isolate new genes and promoters of multiple abiotic stress tolerance (Varshney et al. 2009); (ii) gene targeting for the genetic modification of crops (Osakabe et al. 2010); (iii) marker-free transgenic crop development (Parkhi et al. 2005); (iv) the development of cis-genics (Jacobsen and Schouten 2007); (v) allele mining for candidate genes in germplasm collections (Varshney et al. 2005); and (vi) the creation and use of mutations by deploying Targeted Induced Local Lesions in Genomes (TILLING) (Till et al. 2007).

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