Reconciling Traditional Knowledge with Modern Agriculture: A Guide for Building Bridges

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ABSTRACT

In the years since the Convention on Biological Diversity was adopted, issues of traditional knowledge have come to affect the legitimacy of the multilateral trading system, in general, and its IP (intellectual property) aspects, in particular. In order to engage indigenous knowledge in furthering socio-economic development, policy-makers will need to reconsider the prevailing notion of a fundamental dichotomy between indigenous and scientific knowledge and begin to challenge both types of knowledge. This chapter concentrates on traditional knowledge—and how it relates to the ecology of agriculture, in all of its variants—and compares it to recent advances in scientific knowledge and the resulting applications of biotechnology in global agriculture.

The chapter argues that this dichotomy between traditional and scientific ways of knowing is not only artificial but problematic, in that it hinders exchange and communication between the two. The dichotomy between traditional knowledge and scientific knowledge is most apparent in, and lies at the root of, perceived differences between the approaches of today's organic farming and technology-intensive farming systems. While indeed there are important differences, traditional knowledge and scientific knowledge share important similarities. Knowledge, in both cases, is based on human observation and experience and is tested, replicated, and transmitted within its respective community through social institutions and mechanisms put in place for that purpose. Moreover, deeper examination of the genetic integrity of plants used within organic and biotechnology-based agricultural systems shows that the respective crop varieties being used under each system are more similar than they are different. Increasingly, organic farming is building on scientific knowledge, and agricultural biotechnology is seeking to draw on traditional knowledge.

This chapter challenges policy-makers and scientists to examine and, ultimately, to move beyond those conceptual worldviews, or constructs, that maintain the current divide between traditional knowledge/organic agriculture and scientific knowledge/agricultural biotechnology.

By building the bridge between traditional knowledge and science and becoming free to draw upon the best existing ideas and practices from both, a larger palate is available to draw from. But, more importantly, by integrating the innovation systems of both traditional and scientific communities, a much larger range of new ideas and practices could be generated. The chapter calls such dynamic integration the "participatory approach" to agricultural innovation, building upon the "unifying power of sustainable development" and leading to balanced choices in agricultural production chains and rural land use.

Such an integration would require adaptations of Western social institutions and mechanisms of intellectual property in order to interface in a more nuanced fashion with quasi-public-domain knowledge that is external to the published records of Western science and IP systems. At the same time, indigenous communities will need to learn to adapt their social institutions and mechanisms that govern what is, in a sense, sovereign or communal property to coexist with and at times be translated into formal IP rights and practical uses that are external to their traditional systems.

1. INTRODUCTION: GLOBAL TRENDS IN BIODIVERSITY PROTECTION

Since the adoption of the Convention on Biological Diversity in 1992[1] the legal status of plant genetic resources and traditional knowledge

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has received increasing attention in international fora, non-governmental organizations (NGOs), and academic research. Several factors have stimulated this ongoing debate: the steady loss of biodiversity in plant genetic resources;[2] the contrast between protected plant varieties and genetically engineered products, on the one hand, and traditional crops and landraces in the public domain, on the other hand; the advent of the Agreement on Trade-Related Aspects of Intellectual Property Rights (TRIPS) under WTO; and the International Treaty on Plant Genetic Resources for Agriculture.[3] The Doha Agenda Ministerial Declaration[4] explicitly endorsed the issue of traditional knowledge as a subject for further negotiation. What was, some years ago, a concern limited to the ecological aspects of preserving biodiversity has moved to center stage. Today, policy-makers recognize that traditional knowledge affects the legitimacy of the multilateral trading system, in general, and its intellectual property aspects, in particular, as well as its interface with modern agricultural and environmental policies.

One of the difficulties in advancing toward any resolution or consensus in this debate is the relationship between varying negotiation processes in different fora. Another related problem involves the contradictory relationships between regulatory agencies at different levels (international, regional, and local) in dealing with traditional knowledge.[5] While it will be of prime importance to move toward a reconciliation between the CBD and the TRIPS agreement,[6] any progress must take into account the full complexity of issues related to biodiversity.[7, 8] Such reconciliation will not come easily.

To productively engage indigenous knowledge in efforts for economic development, policy-makers will need to reconsider the notion of a dichotomy of indigenous and scientific knowledge and begin to challenge both types of knowledge. Doing so will mean developing both greater autonomy for participating in the production of new knowledge and envisioning new approaches to regulating science. The Cartagena Biosafety Protocol, in particular, is today seen by many in the scientific community as having gone too far, imposing inordinately high levels of regulation, focusing excessively on transgenic plants (as opposed to other potential biosafety risks), and taking into account only the risk side of the equation of human welfare. Agricultural innovation has always been knowledge based, relying foremost on farmers' experience. With the development of modern science and its applications to agriculture, the situation has changed considerably. Without a doubt, agriculture owes many of its recent advances to the rapid growth of scientific knowledge, in both ecology and molecular biology. Yet, this advancement has been accompanied by a lack of awareness of traditional agricultural knowledge and even an active disregard for it.

To move toward a possible resolution, terms of the debate, it is of prime importance to reconcile the terms of the CBD and the TRIPS Agreement. In critiquing what some would call a utopian attempt to strengthen the position of indigenous peoples relative to other populations, it is necessary to examine the basic question of *how power structures knowledge*. Otherwise attempts to address the interests of indigenous people will inevitably fail. This will also necessitate challenging and changing government policies, questioning science, and strengthening independent decision-making processes among indigenous peoples. Simply to document traditional knowledge will not be enough. To bring indigenous knowledge to bear on agricultural and economic development, we must go beyond the dichotomy of indigenous versus scientific knowledge and work toward a better integration of the two.

It is also essential to adapt the regulation and application of IP systems to include humanitarian (that is, nonmarket) aspects of knowledge use in order to reconcile science-based agriculture with the needs and practices of traditional agriculture. Industry leaders and academicians in the field of biotechnology have recognized this, voluntarily developing and introducing new approaches to IP management that begin to affirm the inextricably public aspects of knowledge generation and to acknowledge that the extremely low cash flow of smallholders in the developing world will not generate significant royalties.[9, 10]

It will be necessary to overcome the compartmentalized views held within the halls of Western science and begin to integrate traditional knowledge into the scientific learning process. The Rio Convention is a remarkable framework document toward these ends. It succeeds in creating an opening for this kind of shift by focusing, not merely on conservation, but also on the sustainable use of genetic resources and the fair sharing of benefits that may arise from them. In particular, the provisions concerning access and benefit sharing (ABS) and the protection of traditional knowledge emerged as a viable way forward, creating room for the development of innovative solutions.

In addition, the dichotomy between Western science and traditional knowledge has caused a growing divide in the views held by the leaders of the international agricultural research community. The concept of biodiversity has too often in the public arena evolved into an unreflected mantra of environmentalists. While many today can agree that agriculture needs to become more sustainable—and that sustainability, in a broad sense, does have an important relationship with measures of biodiversity—what is needed is a precise analysis of the role of biodiversity within the actual context of all the complex elements of global agriculture, including the compelling need for ever-higher productivity.

This chapter concentrates on traditional knowledge—and how it relates to the ecology of agriculture in all of its variants—and compares it to recent advances in scientific knowledge and the resulting applications of biotechnology in global agriculture. The notion of a deep contrast between agriculture that is based on traditional knowledge and agriculture based on scientific knowledge is challenged. While on the surface there are major cultural and philosophical differences in the conceptual underpinnings of traditional and scientific knowledge, there are also striking similarities. In order to overcome major misunderstandings and to create new and sometimes surprising understandings, this chapter advocates a discursive system of debate that takes into account different kinds of knowledge and proceeds under a recognition of the "symmetry of ignorance."[11]

2. DEFINITION OF TRADITIONAL KNOWLEDGE

Comparing indigenous cultures and Western culture, the contrasts in mode and structure seem obvious, leading to the assumption that the thinking of human beings from such diverse situations must somehow be intrinsically different. The religious rites and rituals of indigenous peoples can be perceived to be without parallel in contemporary postindustrial Western society. Worse yet, the tendency of some Western intellectuals is to romanticize indigenous cultures, celebrating the untapped richness—yet thereby making the perceived contrast even greater and obscuring or ignoring the commonalities in human thinking across all cultures.

According to Berkes, et al.,[12] traditional knowledge is a way of knowing similar to that of Western science in that it is based on an accumulation of observations, but it is different from science in several other fundamental ways. The anthropologist Levi-Strauss[13] argued that traditional knowledge and Western science are two parallel modes of acquiring knowledge about the universe, yet he observes that "*the physical world is approached from opposite ends in the two cases: one is supremely concrete, the other supremely abstract.*"

Similarly, the philosopher Feyerabend[14] distinguished between two different traditions of human thought: abstract traditions (to which science belongs) and historical traditions (which include most systems of knowledge by people outside Western science), the latter being those through which knowledge becomes encoded in rituals and in the cultural practices of everyday life.

Traditional knowledge may be holistic in outlook and adaptive by nature, gathered over generations by observers whose lives depended directly on the quality of information and its use. It often accumulates incrementally, its reliability is assessed through trial and error, and it is transmitted to future generations orally or by shared practical experiences.[15]

Case studies reveal that there exists a diversity of local, or traditional, practices for ecosystem management.[16] These include multiple-species management, resource rotation, succession management, landscape-patchiness management, and other ways of responding to and managing ecological pulses and surprises. Social mechanisms behind these traditional practices include a number of adaptations for the generation, accumulation, and transmission of knowledge, the use of local institutions to provide leaders/stewards and rules for social regulation, mechanisms for cultural internalization of traditional practices, and the development of appropriate world views and cultural values. The use of the term *traditional ecological knowledge* has become established, among others, through the work of an international conservation union (IUCN) working group[17, 18] and *traditional ecological knowledge and wisdom* (TEKW) has become established as a major term in all fields of ecology, including agriculture.[19, 20, 21] (Figure 1)

3. RESOLVING THE CONTRASTS BETWEEN TRADITIONAL AND SCIENTIFIC KNOWLEDGE

Agrawal[22] and Agrawal[23] both claim that by distinguishing indigenous knowledge from scientific knowledge, theorists are caught in a dilemma. Focus on indigenous knowledge has gained indigenous peoples an audible voice in development circles. Yet, this distinction creates and perpetuates the dichotomy between indigenous and scientific ways of knowing. This dichotomy is especially problematic because it often hinders exchange and communication between the two. Further, both Agrawal and Agrawal argue that the basic distinction between indigenous and scientific knowledge is artificial.

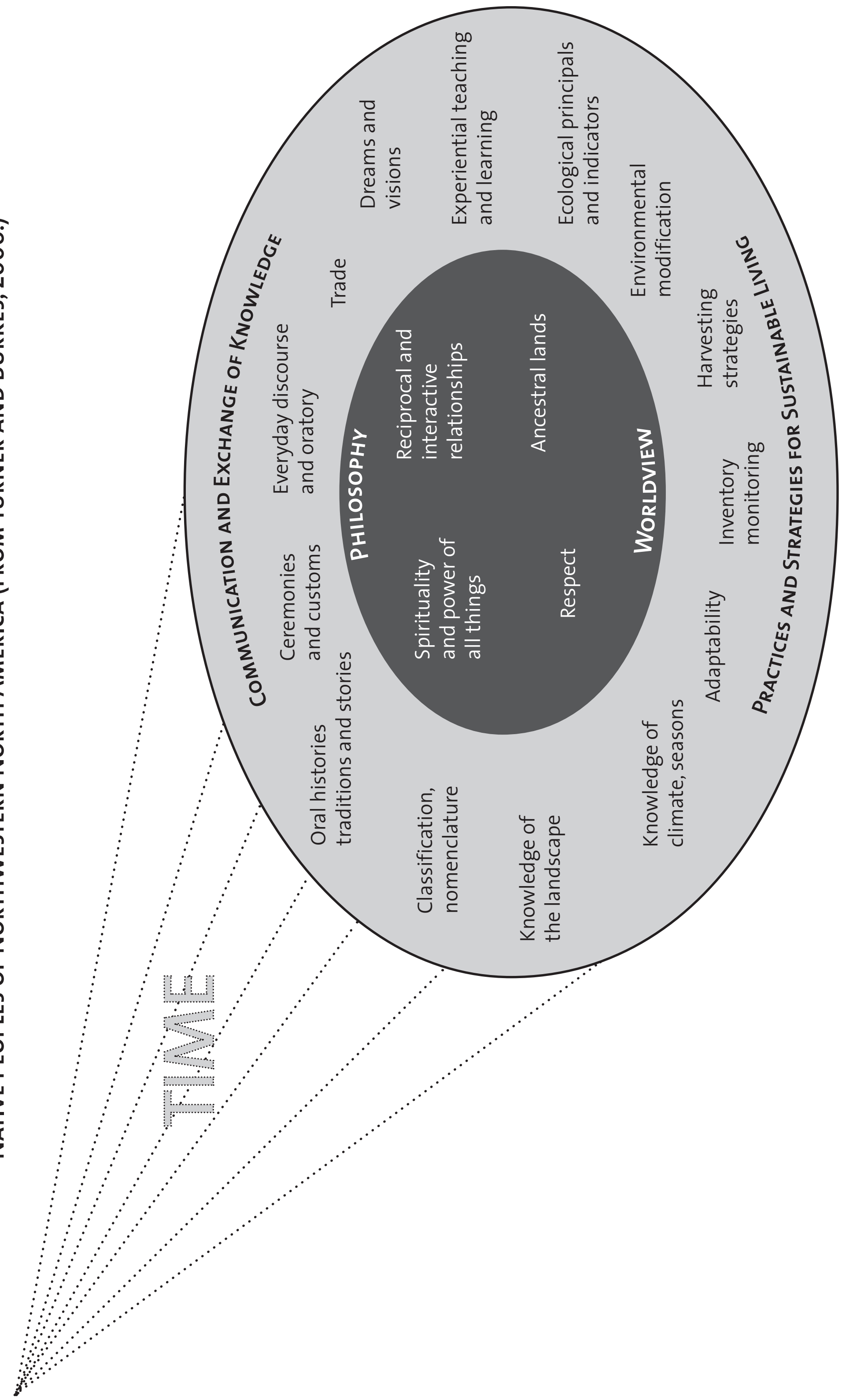
This artificial barrier, I will contend, is one of the primary reasons why there appears to be such a distinct contrast between traditional organic or subsistence farming and technologically intensive agricultural methods, including biotechnology. Most scientists depict traditional knowledge as somehow unable to learn from experience, fuzzy in its concepts, and closed to conceptual inputs from the outside, whereas science is open to new thought, precise in its empirically tested progress, and responsive to the real needs of farmers. Critics of science, however, mistrust it for being too abstract, analytical, and divorced from the needs of real people.

The reality in both cases is different from the perception. Closer consideration reveals that the differences are indeed much smaller. Traditional knowledge that has accumulated since ancient times and been transmitted by oral tradition has often turned out to be strikingly precise when tested against empirical observation. Indeed, given the test of time, traditional knowledge is verified or falsified by experiment and observation. And, in Western science, oral tradition is certainly present: scientific communities with different views and lexicons continue to exist regionally despite the homogenizing influences of the scientific literature and the Internet (for instance in botanical nomenclature). Feyerabend notes critically, that scientists are often closed to matters outside science.[24] However, as Karl Popper[25, 26] rightly claims, a line must be drawn when a theory cannot be falsified: in such a case a theory should not be called scientific. Traditional knowledge is of course open to similar scrutiny.

Indeed, there are a number of authors who emphasize the commonalities between scientific and traditional knowledge without making the mistake of turning the terms into synonyms. Horton,[27, 28] for instance, cannot understand why some persons, familiar with theoretical thinking in their own Western tradition, have failed to recognize its African equivalents. He contends that they simply have been blinded by differences in idiom and that exhaustive exploration of features common to Western and traditional African thought should come before any enumeration of differences. The same can be argued for the comparison between Western, science-based agriculture and all kinds of traditional agricultural practices.

The following sections seek to advance such a comparison between two apparently very different approaches to agriculture. In this case, the comparison is between organic agriculture and biotechnology-based agriculture, leaving out, for reasons of simplicity, the wider range of other agricultural approaches. Based on the lines of reasoning developed above, effort is made not to be distracted by the "idiomatic" contrasts or

Figure 1: Components of Traditional Ecological Knowledge and Wisdom of the Native Peoples of Northwestern North America (from Turner and Burkes, 2006.)



distinctions drawn between the two, but to explore the commonalities. In fact, both strategies considered here comprise elements of traditional knowledge and empirical precision. Differences drawn between the two are based on emphasizing methodology, a view that will be tested and challenged.

4. DEFINITION OF PRESENT-DAY ORGANIC FARMING

Organic farming (including some aspects of agroecological approaches to farming as referred to by Altieri and Nicholls[29]) started as a heterogeneous set of alternative-management methods in agriculture. This explains the multiple origins of organic farming and the fact that certifications of organic-farming practices have been introduced separately in various times and places. Organic farming is now growing rapidly and becoming a viable industry in its own right. Harmonizing standards and regulations are being developed and imposed more or less strictly on organic farms, both by states, like California,[30] and by national government agencies, like the U.S. Department of Agriculture.

Today, the International Federation of Organic Agriculture Movements (IFOAM) is serving to unite the various organic movements of the world, with members in 108 countries and support from the UN Food and Agricultural Organization (FAO). IFOAM advances basic views on organic farming, such as the following four principles:[31]

1. **Principle of health.** *Organic Agriculture should sustain and enhance the health of soil, plant, animal, human and planet as one and indivisible.*
2. **Principle of ecology.** *Organic Agriculture should be based on living ecological systems and cycles, work with them, emulate them, and help sustain them.*
3. **Principle of fairness.** *Organic Agriculture should build on relationships that ensure fairness with regard to the common environment and life opportunities.*
4. **Principle of care.** *Organic Agriculture should be managed in a precautionary and responsible manner to protect the health and well-being of current and future generations and the environment.*

Specific rules for organic agriculture are still the subject of international debate, given efforts to improve them, to find the right mix between regulatory strictness and diversity of applications. Some important documents in circulation intentionally go beyond the basic agreed-upon principles of organic farming[32,33,34,35] in order to stimulate discussion and to propose targets.

The main Swiss rules for organic agriculture are as follows:[36]

- *Natural cycles and processes are respected.*
- *The use of chemical-synthetic substances is avoided.*
- *The use of GMOs is not allowed, nor their derivatives, exception: products for veterinary medicine.*
- *The products shall not be treated with radiation, and no products having undergone irradiation shall be used.*

Since 2005 an official definition document on organic agriculture[37] has been in a process of transparent deliberation and elaboration. The latest language, which has not yet received definite approval, describes it as follows:

Organic agriculture, as defined by IFOAM, includes all agricultural systems that promote environmentally, socially and economically sound production of food and fibers. Recycling nutrients and strengthening natural processes helps to maintain soil fertility and ensure successful production. By respecting the natural capacity of plants, animals and the landscape, it aims to optimize quality in all aspects of agriculture and the environment. Organic Agriculture dramatically reduces external inputs by refraining from the use of synthetic fertilizers and pesticides, Genetically Modified Organisms and pharmaceuticals. Pests and diseases are controlled with naturally occurring means and substances according to both traditional as well as modern scientific knowledge, increasing both agricultural yields and disease resistance. Organic agriculture adheres to globally accepted principles, which are implemented within local socio-economic, climatic and *cultural settings. As a logical consequence, IFOAM stresses and supports the development of self-supporting systems on local and regional levels.*[38]

It is notable that debate over the very definition of organic agriculture persists. The problem is that top-down regulation of organic agriculture means coming to terms with standards met also in traditional agriculture, such as defining levels of toxicity for biopesticides, which is often not easy.[39]

Altieri summarizes agroecology, following Reijntjes, Haverkort, and Waters-Bayer,[40] with the following principles:[41,42,43,44]

- *Enhance recycling of biomass and optimizing nutrient availability and balancing nutrient flow*
- *Securing favorable soil conditions for plant growth, particularly by managing organic matter and enhancing soil biotic activity*
- *Minimizing losses due to flows of solar radiation, air and water by way of microclimate management, water harvesting and soil management through increased soil cover*
- *Species and genetic diversification of the agroecosystem in time and space*
- *Enhance beneficial biological interactions and synergisms among agrobiodiversity components, thus resulting in the promotion of key ecological processes and services*

Details of modern breeding methods are still controversial in organic agriculture communities. While genetic engineering itself is widely rejected, IFOAM agrees to the use of tissue culture and genetic assays, including genetic-marker-assisted breeding.[45] Note that Altieri and colleagues do not explicitly exclude transgenic plants in principle, while they clearly do not agree with the practices of multinational corporations advancing this technology. Some organic rules do not take any position on mutagenesis (traits introduced by genetic changes resulting from exposure to radiation or chemicals). This may not be unusual, since many successful crop traits have come from this method in the past.

Another breeding-related controversy is that of new hybrid crops: whereas many organizations in organic agriculture accept hybrid maize, since this is a biological phenomenon that cannot be easily reversed or avoided, most are opposed to the introduction of more hybrids in other crops.

In summary, organic farming has strong roots in traditional-agricultural knowledge. Today, it is drawing more and more on scientific research. Finding the right balance between these two sources of knowledge will continue to precipitate discussion within organic agriculture communities. Furthermore, the spectrum of different variants within organic and agroecological farming continues to expand and widen, ranging from integrated-pest-management techniques, used in conventional farming, to mainstream organic forming, to agroecological farming, and even to extreme forms of biodynamic farming.

In a number of developing countries, there are clear intentions to develop transgenic plants for use in subsistence farming, as indicated by statistics published by Cohen[46] and the FAO.[47]

5. DEFINITION OF BIOTECHNOLOGY-BASED AGRICULTURE

5.1 *Transgenic crops and genomic integrity at the molecular level*

Van Bueren, et al.,[48] explore the nature of genetic engineering at the molecular level, in an effort to explain why organic farming cannot accept plant varieties manipulated by biotechnology. Following Verhoog, et al.,[49] they posit "naturalness" as not only the avoidance of synthetic chemical inputs and the application of agroecological principles in cultivation, but also the maintenance of the "intrinsic integrity" of the organisms being cultivated, including the integrity of their genomes. Their definition of the integrity of plant genomes is as follows:

*The general appreciation for working in consonance with natural systems in organic farming extends itself to the regard with which members of the movement view individual species and organisms. Species, and the organisms belonging to them, are regarded as having an intrinsic integrity. This integrity exists aside from the practical value of the species to humanity, and it can be enhanced or degraded by management and breed*ing measures. This kind *of integrity can only be assessed from a biocentric perspective … Organic agriculture assigns an ethical value to this integrity, and encourages propagation, breeding, and production systems that protect or enhance it.*

And further:

… biocentric perspective, organic agriculture acknowledges the intrinsic value and therefore the different levels of integrity of plants as described above. The consequence of acknowledging the intrinsic value of plants and respecting their integrity in organic agriculture implies that the breeder takes the integrity of plants into account in his choices of breeding and propagation techniques. It implies that one not merely evaluates the result and consequences of an intervention, but in the first place questions whether the intervention itself affects the integrity of plants. From the above described itself affects the integrity of plants.

Then, based on the nature of plants and their characteristics, a number of criteria, characteristics, and principles for organic plant breeding and propagation are excluded for violating the integrity of plants: for example, all breeding methods using chemicals or radiation—such as colchicine or gamma-radiation-induced mutants—all methods not allowing a full life cycle of the plant, and all methods manipulating the genome of the organisms. Unfortunately, the authors do not inquire very deeply into questions of the extent to which the structures and assembly of common crop species DNA has in fact been changed or manipulated by centuries of traditional selection and breeding.

For example, all varieties of wheat used today—by organic as well as conventional farmers—are a product of processes by which the genome has been subjected to numerous fundamental changes, and those changes have been successfully integrated inside the organism known today as wheat. These modifications include the addition of chromosome fragments, the integration of entire foreign genomes, and radiation-induced mutations (in the case of *Triticum durum*). Indeed, chromosome inversions and translocations are well documented in most major crops.

Thus, the reality of all systems of agriculture is such that most of the principles of genomic integrity, as advocated by Van Bueren and colleagues,[50,51,52] have long since been violated in almost all existing crops, and the naturalness or genomic integrity cannot be regained, unless theoretically one goes back to the ancestral genomes (which, in the case of each of the major crops, have not survived the intervening centuries of classical breeding). So, in reality, the principle of the “intrinsic integrity” of agricultural plant genomes is, at best, a fiction.

Other advocates of preserving the intrinsic integrity of organisms advise against crossing the natural hybridization barriers between species. Yet, species barriers have been overcome by traditional-breeding methods for decades, as well as by methods of biotechnology. Here the most salient example is somatic hybridization, which involves the nonsexual fusion of two somatic cells. The advantage of this method is that, by the fusion of cells with different numbers of chromosomes (for instance, from different species of *Solanum*) fertile products of the crossing can be obtained immediately. As a result, the polyploid plants that are obtained contain all of the chromosomes of both “parents,” instead of the usual half set of chromosomes obtained through sexual reproduction. In order to achieve such somatic hybridization, required are cells, the walls of which have been digested away by enzymes, that are then enclosed only by their cell membranes (so called protoplast cells). With the loss of their cell walls, protoplasts also lose their typical shape and become spherical, like egg cells. The mixture of cells is then exposed to electric pulses to induce fusion. In order to get the “right“ fusion product (since the fusion of two cells from the same parent plant can also occur) distinct selectable markers are necessary from each of the original parent plants. Only cells that survive this double selection are genuine products of fusion. The easiest way of implementing two such selectable markers is by genetic engineering, such as incorporating antibiotic resistance genes into the original parent plants. Such processes of protoplast fusion have been investigated and applied to potatoes, for instance. Under European Union (E.U.) regulations concerning the deliberate release of GMOs into the environment, somatic hybrids are not considered GMOs and do not require authorization. In fact, the most recent draft of E.U. organic regulations, in which the introduction of GMOs in organic cultivation is forbidden, follows the definition given earlier.[53, 54]

The concept of the naturalness or intrinsic integrity of plant genomes is also challenged by observations of Arber (a 1978 Nobel laureate) of the insertion of genes across natural species barriers in the case of naturally transgenic grasses.[55] Arber compared designed genetic alterations (including genetic engineering) with spontaneous genetic variations, those variations on which natural selection then operates to drive evolution:[56]

Site-directed mutagenesis usually affects only a few nucleotides. Still another genetic variation sometimes produced by genetic engineering is the reshuffling of genomic sequences, e.g. if a given open reading frame is brought under a different signal for expression control or if a gene is knocked out. All such changes have little chance to change in fundamental ways, the properties of the organism. In addition, it should be remembered that the methods of molecular genetics themselves enable the researchers anytime to verify whether the effective genomic alterations correspond to their intentions, and to explore the phenotypic changes due to the alterations. This forms part of the experimental procedures of any research seriously carried out.

Interestingly, naturally occurring molecular evolution, i.e. the spontaneous generation of genetic variants has been seen to follow exactly the same three strategies as those used in genetic engineering. These three strategies are:

(a) small local changes in the nucleotide sequences,
(b) internal reshuffling of genomic DNA segments, and
(c) acquisition of usually rather small segments of DNA from another type of organism by horizontal gene transfer.

However, there is a principal difference between the procedures of genetic engineering and those serving in nature for biological evolution. While the genetic engineer pre-reflects his alteration and verifies its results, nature places its genetic variations more randomly and largely independent of an identified goal. Under natural conditions, it is the pressure of natural selection which eventually determines, together with the available diversity of genetic variants, the direction taken by evolution. It is interesting to note that natural selection also plays its decisive role in genetic engineering, since indeed not all pre-reflected sequence alterations withstand the power of natural selection. Many investigators have experienced the effect of this natural force which does not allow functional disharmony in a mutated organism.

Genetic modifications of plant genomes may in fact be common. Recently, another natural transgenic plant was discovered by Ghatnekar, Jaarola, and Bengtsson,[57] involving the introgression of a functional nuclear gene from Poa to *Festuca ovina*. Yet other work reinforces the comparison, at the genomic level, between natural evolutionary processes and modern modifications of plant genetics through biotechnology.[58,59,60]

Still, despite such similarities, there is one major difference: natural genetic variation and selection acts on a completely different timescale from transgenic agriculture. Naturally occurring mutants that survive in the wild can take from hundreds to millions of years to survive selection pressures and finally take over against their pre-existing competitors. With transgenic crops the timescale is totally different. They run through a research, development, and regulatory process that lasts, on average, 15 to 20 years after which the successful ones are completely deregulated. These can then be propagated nationally and cover millions of hectares within an extremely short time span on the evolutionary clock.

This basic insight of molecular biologists has been confirmed in analysis of modern breeding processes. The best example here is a comparison at the genomic level between transgenic and non-transgenic wheat by Shewry et al.:[61]

Whereas conventional plant breeding involves the selection of novel combinations of many thousands of genes, transgenesis allows the production of lines which differ from the parental lines in the expression of only single or small numbers of genes. Consequently it should in principle be easier to predict the effects of transgenes than to unravel the *multiple differences which exist between new, conventionally-produced cultivars and their parents. Nevertheless, there is considerable concern expressed by consumers and regulatory authorities that the insertion of transgenes may result in unpredictable effects on the expression of endogenous genes which could lead to the accumulation of allergens or toxins. This is because the sites of transgene insertion are not known and transgenic plants produced using biolistics systems may contain multiple and rearranged transgene copies (up to 15 in wheat) inserted at several loci which vary in location between lines.[62,63] Similarly, this apparently random insertion has led to the suggestion that the expression of transgenes may be less stable than that of endogenous genes between individual plants, between generations and between growth environments. Although there is evidence that the expression of transgenes introduced by biolistic transformation is prone to silencing in a small proportion of wheat[64,65]… recent reviews[66,67,68,69] … demonstrate the utility of biolistics transformation as a basis for stable genetic manipulation.*

Such studies confirming the stability of transgenic integrations[70,71] have been extended to other methods of transformation, such as the direct insertion of DNA fragments,[72] with some questions remaining about the long-term stability of agrobacterium-mediated transformations.[73] But, some of the most interesting observations in this line of inquiry about genome integrity have been documented by Baudo, et al.,[74] showing that the measured genomic disturbances from traditional breeding can be greater than the genomic disturbances from genetic transformation:

Detailed global gene expression profiles have been obtained for a series of transgenic and conventionally bred wheat lines expressing additional genes encoding HMW (high molecular weight) subunits of glutenin, a group of endosperm-specific seed storage proteins known to determine dough strength and therefore bread-making quality. Differences in endosperm and leaf transcriptome profiles between untransformed and derived transgenic lines were consistently extremely small, when analyzing plants containing either transgenes only, or also marker genes. Differences observed in gene expression in the endosperm between conventionally bred material were much larger in comparison to differences between transgenic and untransformed lines exhibiting the same complements of gluten subunits. These results suggest that the presence of the transgenes did not significantly alter gene expression and that, at this level of investigation, transgenic plants could be considered substantially equivalent to untransformed parental lines.

An ironic consequence of such results is that organic farming—by definition seeking to maintain the integrity of the plant genome by minimizing artificial DNA disturbances—should in such cases favor the genetically engineered variety. A more general conclusion may be that transgenic crops should not have been subject to regulations based purely on the fact that they resulted from the methodology of genetic engineering. Rather, it would have been more consistent to have a close look in each case at the product itself.

5.2 *The Green Revolution and agricultural biotechnology*

The social impacts and implications of modern agricultural biotechnology have their origins in the *Green Revolution*, a term coined by William Gaud at a 1968 meeting of the U.S. Agency for International Development (USAID) referring to the extremely successful agricultural movement through which new crop varieties, improved irrigation, adopted fertilizers and pesticides, and installed mechanization resulted in crop yields increasing dramatically, particularly in Asia.

One of the key innovations that drove the Green Revolution was the genetic improvement of plant varieties, especially the introduction of dwarf and semi-dwarf traits, in which stem height was reduced but the size of panicles, and thus seed production was not reduced. However, the yield gains of the Green Revolution also depended upon the application of high doses of chemical fertilizers and copious irrigation. Abundant yields attracted a variety of pests, and, therefore, chemical pesticides needed to be applied in greater volume. In addition, new crop varieties were also selected for photo-insensitivity, so that they could be adapted for multiple cropping sequences, patterns, and latitudes.

Evenson and Gollin[75] provide a thorough assessment of the Green Revolution, showing how over the period 1960 to 2000 the international agricultural research centers, in collaboration with national agricultural-research programs, contributed to the development of modern varieties in many crops. These varieties contributed to large increases in crop production. Productivity gains, however, were uneven across crops and regions. Consumers generally benefited from the resulting decline in food prices, but farmers benefited only where cost reductions exceeded those price reductions.

Two names are intimately linked to the Green Revolution: Norman Borlaug (who was awarded the Nobel Peace Prize in 1970)[76,77,78] and Monkombu Sambasivan Swaminathan (who was awarded the World Food Prize in 1987).[79,80] Yet, very early on, Swaminathan warned of unwelcome developments related to the Green Revolution:

The initiation of exploitive agriculture without a proper understanding of the various consequences of every one of the changes introduced into traditional agriculture, and without first building up a proper scientific and training base to sustain it, may only lead us, in the long run, into an era of agricultural disaster rather than one of agricultural prosperity. [81]

As the successes of the Green Revolution were becoming manifest together with its detrimental effects—including the upsurge of insect pests, growing insect resistance against widely used pesticides, and negative effects on the soil fertility—Swaminathan felt obliged to call for an Evergreen Revolution, beginning as early as 1968, yet continuing all the way through 1990.[82, 83] Unfortunately, farmers' access to free electricity to draw groundwater for irrigation, the negligence of legumes in crop rotations, and the indiscriminate application of chemical fertilizers and pesticides culminated in the degradation of soil and water. The damage to the ecological foundations essential for sustainable advances in productivity led to the onset of fatigue in agricultural systems.

Lessons drawn from the Green Revolution are that steps taken toward productivity enhancement should concurrently address the conservation and improvement of soil, water, and biodiversity, as well as providing for the atmosphere and renewable energy sources. Keeping these goals in focus, the goals of the Evergreen Revolution for achieving higher productivity in perpetuity were developed. What this calls for is a system of agriculture that involves sustainable management of natural resources, while progressively enhancing soil quality, biodiversity, and productivity.

Only much later has biotechnology proven to be able to contribute to the goals of the Evergreen Revolution, since it helps to enhance some of the ecological factors.[84,85,86,87] Biotechnology has proven to reduce pesticide use, positively influence nontarget insect populations, and induce no-tillage management practices that are beneficial to soil fertility.[88, 89]

An example of new biodiversity strategies fostered by a company known for the production of pesticides has been published by Dollaker and Rhodes.[90, 91] They propose to integrate crop productivity and biodiversity within pilot projects, jointly addressing the challenges of achieving crop productivity and biodiversity conservation objectives. Three pilot initiatives, developed by Bayer CropScience in Brazil, Guatemala, and the U.K. in collaboration with a variety of local stakeholders, illustrate how conservation objectives can be embedded in land-management practices that enhance agricultural productivity and profitability, thereby addressing both food security and biodiversity-conservation challenges.

A new variant of industrial farming, developing in the United States, is called precision farming. It is a management system based primarily on a combination of information technologies, including networked computing, satellite monitoring, and automated guidance systems for farm machinery. Precision farming can save time and energy and, by reducing unnecessary applications of chemicals and irrigation, can lead to a more ecological farming with higher yields.[92,93,94] Methods of precision farming do not contradict the main principles of organic farming and, thus, could be seriously considered as helpful auxiliary methods.

6. SUSTAINABILITY AND BIODIVERSITY

All agricultural systems must include the ability to provide an economic return to the farmer; unprofitable agricultural systems will not survive unless they are subsidized. In the cases of the United States and Europe, such policies are problematic in the long run for many reasons. Today's farming systems must provide opportunities to produce more food on smaller acreages.

Related to this imperative are issues concerned with maintaining and enhancing output, such as soil fertility and reducing losses to weeds and pests. It is less easy to argue that a natural or diverse ecosystem is a critical input to sustainable agriculture.

While ecologists frequently stress the interrelationships between species, it is difficult to see how the existence of species such as the swallowtail butterfly or a rare orchid could contribute to a farming system's sustainability.[95] The degree of redundancy in ecological communities is largely unknown and remains a rich field of investigation for ecologists. Agricultural systems can benefit from a higher biodiversity (not necessarily within the production surface) by presenting in the near vicinity of the production fields, biological networks hosting highly diverse arthropod populations, making the whole region more resistant to rapid pest invasions.[96, 97] This is not to say that agriculture could continue in the absence of all nonfarmed species. Rather, there is a suggestion that only a subset of all existing species is essential for food and fiber production.[98, 99]

6.1 *About sustainability in farming systems*

Definitions of *sustainability* are manifold. Some, such as that of the FAO[100] concentrate on ecological factors alone, while others concentrate only on management factors. The question that concerns us is whether organic farming or biotech farming is more sustainable. The answer is not clear, since the comparison often does not involve the same basic elements.

In one example that challenges the common view, Edward-Jones and Howells[101] come to the conclusion that organic-farming systems are not sustainable in the strictest sense. Considerable amounts of energy are put into organic-farming systems. The majority of the compounds utilized in crop protection are derived from nonrenewable sources and incur significant processing and transport costs prior to application. Nevertheless, the long-term balance of inputs clearly favors organic-farming systems.[102,103,104,105] Whereas nutrient (nitrogen, phosphorus, and potassium) inputs into the organic systems seem to be 34 to 51 percent lower than with conventional systems, mean crop yield was only 20 percent lower over a period of 21 years, indicating on balance an efficient production. In the organic systems, the energy to produce a dry matter unit of crop harvest was 20 to 56 percent lower than in conventional agriculture and correspondingly 36 to 53 percent lower per unit of land area.

On the other hand, many of the "biopesticides" used to control pests are not without toxicological hazards to humans and the environment. As an example, there are a number of research groups working on the difficult question of how to avoid, or at least reduce, the input of copper sulphate as a biopesticide. It is clear from some studies, that copper deposited in high concentrations has a negative impact on soil microbes. Pedersen, et al.,[106] found that total microarthropod abundance was highest at intermediate copper concentrations and linearly related to grass biomass. For single-species populations, no clear picture of abundance in relation to soil copper was seen, but two collembolan species, *Folsomia quadrioculata* and *Folsomia fimetaria*, were among the most sensitive. The resulting Shannon-Wiener index of biodiversity decreased linearly with increasing soil copper concentrations. Those results imply that a short-term strategy would be to avoid high concentrations of copper in the soil, but in the long run it will be better to avoid copper sulfate as a biopesticide altogether.

Sustainability can also be measured on a larger scale with methods developed in Europe to measure landscape quality.[107] Results need to be verified, but show positive influence of organic farming in Norway. What we can learn from this is that sustainability on all kinds of farming strategies depends on the local circumstances and may not submit to overall categorization. It certainly depends on the weight given to specific factors of sustainability. In the author's view, population size and feeding the growing number of people should have a very high priority on any such scale. Again, the claim is made that traditional knowledge can contribute in important ways to developing sustainable practices in agriculture and silviculture.[108]

6.2 *Biodiversity and farming systems*

It is important to distinguish between overall biodiversity in a given farming-landscape system, including the production area and biodiversity within the production system itself, the farm fields. The latter is often illusionary. Weeds within harvested fields are to be avoided, either by old-fashioned tilling or by various environmentally acceptable herbicides. The reason is simple: for example, in wheat production systems some of the weeds cherished by conservationists such as *Agrostemma ghitago* are highly toxic because of their saponin and githagenin contents and can spoil the harvested grain even in low quantities.[109]

Many of the crops growing in farming systems around the world have ancestral parents that lived originally in natural monocultures.[110] There are many examples of natural monocultures, such as the classic stands of kelp, *Macrocystis pyrifera*, which was, in fact, analyzed by Darwin.[111] Ecologists now recognize that simple, monodominant vegetation exists throughout nature in a wide variety of circumstances. Indeed, Fedoroff and Cohen[112] reporting on Janzen[113, 114] use the term *natural monocultures* as analogous with the term *crops*. Monodominant stands may be extensive. In one example, Harlan recorded that for the blue grama grass (*Bouteloua gracilis*) "*stands are often continuous and cover many thousands of square kilometers*" of the high plains of the central United States. It is of the utmost importance to agricultural sustainability to determine how these extensive, monodominant, natural grassland communities persist when we might expect their collapse.

More examples are given of wild species in Wood and Lenne,[115] including *Picea abies*, *Spartina townsendii*, *Sorghum verticilliflorum*, *Phragmites communis*, and *Pteridium aquilinum*. Early cultivars are also cited extensively,[116] wild rice (*Oryza coarctata*), for instance, reported in Bengal as simple oligodiverse pioneer stands on temporarily flooded riverbanks.[117] Similarly, Harlan [118] described and illustrated harvests from dense stands of wild rice in Africa (*Oryza barthii*, the progenitor of African cultivated rice, *Oryza glaberrima*). *Oryza barthii* was also harvested wild on a massive scale and served as a local staple across Africa, ranging from the southern Sudan to the Atlantic. Evans[119] reported that the grain yields of such wild-rice stands in Africa and Asia could exceed 0.6 tons per hectare—an indication of the stand density in monocultures of wild rice.

Botanists and plant collectors have, according to Wood and Lenne,[120] repeatedly and emphatically noted the existence of dense stands of wild relatives of wheat. For example, in the Near East, Harlan[121] noted that "*massive stands of wild wheats cover many square kilometers.*" Hillmann[122] reported that wild einkorn (*Triticum monococcum* subsp. *boeoticum*) in particular tends to form dense stands, and when harvested its yields per square meter often match those of cultivated wheats under traditional management. Harlan and Zohary[123] noted that wild einkorn "*occurs in massive stands as high as 2000 meters [elevation] in south-eastern Turkey and Iran.*" Wild emmer (*Triticum turgidum* subsp. *dicoccoides*) "*grows in massive stands in the northeast*" of Israel, as an annual component of the steppe-like herbaceous vegetation and in the deciduous oak park forest belt of the Near East.[124] According to Wood and Lenne[125] they are the strongest examples embracing wild progenitors of wheat. And Anderson[126] recorded wild wheat growing in Turkey and Syria in natural, rather pure stands with a density of $300/m^2$.

There are grounds for seriously rethinking the view of many agrobiologists that appear to uncritically accept that there was a loss of genetic diversity following the introduction of high-yielding Green Revolution wheat and rice varieties in the 1960s and 1970s. The same is feared to follow the rapid adoption of superior GM crops today. There are several reasons for caution in these interpretations.

There is evidence for genetic simplifications having occurred in ancient times. According to the analysis of Fedoroff,[127] thousands of years ago maize underwent a streamlining of its genome. Similar phenomena often occur in weeds like the chenopod *Atriplex prostrata* and are considered to have contributed to their exceptional migration ability since the last Glacial Maximum some 18,000 years ago.[128]

We can also paradoxically encounter an enhancement in genetic diversity in modern soybean breeding. For example, Sneller[129] looked at the genetic structure of the elite soybean population in North America, using a coefficient of parentage (CP) analysis. Whereas common sense would tell us that soybean genetic diversity has diminished considerably in the wake of genetic engineering, there is hard data proving that the trend is not so simple, in fact, to the contrary, genetic diversity can also be enhanced through the introduction of herbicide-tolerant traits. The introduction of herbicide-tolerant cultivars with the Roundup Ready® trait was shown to have had little effect on soybean genetic diversity because of the widespread use of the trait in many localized breeding programs. Only 1% of the variation in CP among lines was related to differences between conventional and herbicide-tolerant lines, while 19% of the variation among northern lines and 14% of the variation among southern lines was related to differences among the lines from different companies and breeding programs.

In more-simple numbers of soybean traits: the new management conveniences associated with the herbicide-tolerant soybeans allowed for a more-liberal use of varieties, most of them transgenic.[130] These include nearly 400 nematode-resistant varieties of soybean from 48 seed companies and five universities. All but seven of the varieties listed contain nematode resistance derived from a certain breeding line PI 88788. Of the varieties listed, 286 are resistant to the herbicide Roundup®, six are tolerant to sulfonylurea herbicides, and the remainders are conventional, nonresistant varieties.

Similarly, when Bowman, May, and Creech[131] examined genetic uniformity among cotton varieties in the United States, they found that genetic uniformity had not changed significantly with the introduction of transgenic cotton cultivars. In fact, when they compared the years before and after the introduction of transgenic cultivars, they observed that both the percentage of the crop planted with a small number of cultivars and the percentage planted with the most popular cultivar had declined. Thus genetic *uniformity* actually decreased by 28% over the period of introduction of transgenic cultivars. In light of the data, the theoretical concepts of Gepts and Papa,[132] that GM crops are likely to be responsible for a biodiversity decline within crops is not very convincing. It remains to be said that the continued use of locally adapted traits gained in traditional breeding should play an important role.[133, 134]

Several reviews[135,136,137] contend that the negative impact of modern biotech agriculture on biodiversity has been overestimated, and perhaps even overstated, by the organic-farming community for the purpose of marketing its alternatives on the grounds of their environmental characteristics. We begin to see that, contrary to the preponderance of negative views, there are beneficial effects stemming from no-tillage, the reduction of pesticide amounts applied to fields, and enhanced biodiversity.

But there are also many studies that show that organic farming has definite advantages over conventional agriculture, particularly regarding biodiversity. One extensive review[138] cites many field studies showing a wealth of evidence that now points to agricultural intensification as the principal cause of the widespread declines in European farmland bird populations,[139,140,141] as well as of the reduction in abundance and diversity of plant and invertebrate taxa over the past decades (well documented by Donald,[142] Preston, et al.,[143] and Wilson, et al,[144] and others).

Only a few studies have sought to integrate the changes in soil conditions, biodiversity, and socio-economic welfare linked to the conversion from nonorganic to organic production (Cobb, et al.).[145] Conclusions may not be representative for all organic conversions, but the findings are of relevance at a time of debate over changing patterns of subsidies and other incentives in agricultural policy. The study showed that there were demonstrable differences in overall environmental conditions in the comparison of organic and nonorganic farming, showing evidence of increased regional species diversity, and an eventual improvement in the profitability of the organic-farming regime. The study also showed that variations in farm-management practices strongly influence the notion of on-farm and off-farm environmental consequences.

The same positive effects of organic farming are shown in a 21-year study in Switzerland (the so called DOK study).[146] Part of the data has been published in *Science*.[147] The organic farming benefits related to biodiversity are well documented, especially with soil microbial diversity: root length colonized by mycorrhizae in organic-farming systems was 40 percent higher than in conventional systems.[148] Biomass and abundance of earthworms were higher by a factor of 1.3 to 3.2 in the organic plots as compared with conventional.[149] At the same time yield is, compared to traditional farming, dropping 20 percent. This fact triggered a debate in *Science* concerning whether such a drop in yield is tolerable with regard to the protection of biodiversity, since today we should realize the imperative to produce more food on a shrinking amount of arable land.[150,151,152] Potato yields in the organic systems were 58 to 66 percent of those in the conventional plots, mainly due to low potassium supply and the incidence of *Phytophtora infestans.* Winter wheat yields in the third crop-rotation period reached an average of 4.1 metric tons per hectare in the organic systems. This corresponds to 90 percent of the grain harvest of the conventional systems. In an overall comparison, provided the lower energy input is also taken into account, one can conclude that, theoretically, in some favorable conditions organic farming can be the more-efficient production strategy. A rather negative point is the safety of organic food: infections with the infamous *Echerichia coli* O157-H7, with its sometimes deadly consequences, seem to be a problem with respect to organic food. A number of papers demonstrate the legitimacy of these concerns.[153,154,155,156,157,158,159]

Only a very few studies exist (such as Roush)[160] that concentrate on a circumscribed agricultural practice comparing organic and biotech farming. This early paper compares directly Bt sprays used in organic farming and Bt transgenic crops, and the case is clear: Bt transgenic crops have advantages. Also, it has to be said that detailed studies of the impact of organic farming on various environmental factors are still scarce.

7. CONSEQUENCES AND CONCLUSIONS

Following the lines of reasoning presented here to their logical ends would, foremost, advocate a refrain from fostering the notion of a divide between agriculture using transgenic crops and organic-management systems. It is difficult to consistently maintain any divide along the lines of breeding technologies or the use of agrochemicals. The current perception of large differences in practices are mostly the result of differences in world view, often built, as has been argued here, on unfounded theories and even quasi-religious beliefs.

A successful integration of present-day management systems needs a new communication strategy. Such a strategy should embrace a dialogue with the public utilizing the "Three *E* Strategy" (entertainment, emotion, and education), which, according to Osseweijer[161,162] could initiate a decision-making process along the lines of the "Systems Approach," a discursive decision-making process for socially contentious issues.[163]

But a dialogue, in itself, will not create agricultural-management systems that build on local conditions, help poverty alleviation, respect elements of traditional knowledge, and combine it in a successful relationship with science. Building those bridges, in reality, need more than public acceptance. And more than decision-making processes, the effort will require making real decisions and following through on them.

Such an effort also needs the initiation of a mechanism like the *participatory projects* proposed by Slingerland et al.,[164] a working team from Wageningen that started a participatory farming project in Ouagadougou in West Africa with sorghum. Addressing iron deficiency caused by malnutrition in West Africa, this became an interdisciplinary program targeting the food-chain. In Africa current interventions are dietary diversification, supplementation, fortification, and biofortification. But such interventions alone have only moderate chances of success due to low purchasing power of households, lack of elementary logistics, lack of central processing of food, and the high heterogeneity in production and consumption conditions. Slingerland[165] proposed, based on excellent theoretical views, a staple food-chain approach, integrating parts of current interventions as an alternative. The research was carried out in several villages in Benin and Burkina Faso to take ecological, cultural, and socio-economic diversity into account. The interdisciplinary approach aimed at elaborating interventions in soil-fertility management, improvement, and choice of sorghum and other crop varieties and food processing, to increase iron and decrease the phytic acid-iron molar ratio in sorghum-based foods. The phytic acid-iron molar ratio was used as a proxy for iron-bioavailability in food. Synergy and trade-offs resulting from the integrated approach showed their added value. Phosphorous fertilization and soil organic amendments applied to increase yield were found to also increase the phytic-acid content of the grain and thus decrease its nutritional value, countered by new food processing reducing the phytic-acid levels again.

Ultimately, only a participatory approach building on the "unifying power of sustainable development" will lead to balanced choices between "People, Planet, and Profit" in agricultural production chains and rural land use, in building the bridge between traditional knowledge and science. The Golden Rice project[166] and the SuperSorghum project[167] both need to take account of these ideas in order to make those projects real successes. They include transgenic plants and, thus, need special efforts in participatory management in order to bring them to fruition.

Synergies will be of considerable importance, as soon as we begin to refrain from unproductive controversies over breeding and management methodologies. In the face of the urgent situation in many countries in the developing world, there is no time for contention and the overload of regulations. These prevent or at least slow the introduction of socially beneficial nutritional innovations, in the very countries where they are needed most. ■

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