Features

Why farming with high tech methods should integrate elements of organic agriculture

Klaus Ammann, klaus.ammann@ips.unibe.ch

In the previous article [Ammann, K. (2008) Feature: integrated farming: why organic farmers should use transgenic crops. New Biotechnol. 25, 101–107], in a plea for the introduction of transgenic crops into organic and integrated farming, it was announced that the complementary topic, namely that high tech farmers should integrate elements of organic agriculture, will be a follow up. Some selected arguments for such a view are summarised here. Basically, they comprise a differentiated view on agro-biodiversity outside the field of production; landscape management methods to enhance biodiversity levels. Both elements are compatible with basic ideas of organic farming. First, Precision Farming is given as one example of the many ways to support agricultural production through high technology, with the aim of reducing energy input, maintaining excellent soil conditions and enhancing yield. It is clear from this analysis that modern agriculture and certain elements of organic–integrated agriculture are compatible. There are sectors of high tech farming, such as the introduction of a better recycling scheme and also a better focus on socio-economic aspects, which need to be taken up seriously from organic–integrated farming, a system which puts a lot of emphasis on those elements and for which important research data are available. In the final part a new concept of dynamic sustainability is presented.

Introduction

This text is a follow up to the previous publication in this journal 'Integrated farming: why organic farmers should use transgenic crops' [1]. In this first part, the main topics were: (a) principles of organic farming; (b) in basic processes, no difference exists between natural mutation and genetic engineering; (c) conventional crops have more transcriptomic disturbances than transgenic crops and (d) therefore there is no basic reason for organic farmers to not to use selected GM crops, as long as they fit into organic farming systems they can help to control pests and weeds in an ecological way and at the same time secure better yields and higher agricultural production. In a short outlook, it was also mentioned that agricultural biodiversity needs a subtle and balanced view and conventional agriculture should take up more ecological thoughts and strategies. Clearly, traditional knowledge is still an unknown reservoir of ecological wisdom, while social networking structures are also, in many cases of modern agriculture, a desideratum for many reasons.

The complementary text here was announced in the conclusions. This time we ask the question of whether farming with transgenic crops should adopt some of the organic/ecological production strategies. The answer will be similarly differentiated as in the previous article.

Concepts of farming with high technology methods: the example of Precision Farming

There are hundreds of ways to practise farming with high technology methods, just as there are innumerable ways to practise ecological and organic farming. It is not the aim of this article to give a complete overview of modern farming methods, but rather we concentrate here again on giving a comparison of farming with organic/ecological methods and farming with the use of high technology applications, including transgenic crops. Again the aim will be to reduce the contrasts, often exaggerated and driven by ideology on both sides. In the previous article, the concept of organic farming was described with the recently published principles of IFOAM (International Federation of Organic Agriculture Movements). In the case of mainstream agriculture this is not so easy, because literally hundreds of organisations have their own

1871-6784/$ - see front matter doi:10.1016/j.nbt.2009.06.933

guidelines and constitutions. There is an extremely broad palette of opinions and views manifested in hundreds of papers. Therefore we resort again to an aspect of modern agriculture, which is still in stark contrast to organic farming – and again, the strict boundary in between is to be questioned.

Farming with high technology methods can be understood as *Precision Farming* (PF). As with all such expressions, it is a label for a strategy, here often with the meaning of satellite steered farming with geographical information systems or other (remote) sensing methods, combined with high tech sowing and harvesting machines. PF is not a single technology, but rather a suite of technologies that can be assembled into a system [2] including in most cases modern breeds of crops, transgenic traits produced by professional seed companies.

A boost in new breeding can be expected by the new breakthrough zinc-finger technology [3,4] which makes it possible to insert transgenes in higher plants at a precise locality. This was possible formerly under the label of 'gene targeting', but under much lower, less manageable frequency [5,6].

Farmers are expected in the near future to adopt various component technologies, depending on their needs and other site-specific characteristics of the business.

PF is a set of farming methods, introduced primarily in the naturally treeless regions (previously covered by prairie vegetation) and rich soils of North America, and ideal for industrial farming with heavy machines and high production levels, but nowadays rapidly spreading all over the world in countries with good infrastructure resources in agriculture.

PF can also be used for remote control in relatively small structured agriculture, for instance for improved crop discrimination in India (Hyderabad), where it was possible to distinguish by satellite remote sensing (Resourcesat-1) [7] between *ca.* a dozen crops/cultivation types. Many research papers demonstrate nicely, with colourful illustrations, that satellite mapping is *en vogue* and will deliver ultra-exact imaging in the future. However, the activity still concentrates on research, and the applications do not yet reach a broad range as GM crops do *per se* [8].

PF has also been evaluated to assess important soil parameters, such as organic matter (OM), in real-time mode [9]. In regard to calibration, Christy compares two predictions of OM with field data yielding high correlation (R^2 = 0.95). Such high R^2 figures are not unusual in multivariate calibration, as has been shown for instance with biomonitoring air pollution with a set of 40 species of epiphytic lichens [10–12].

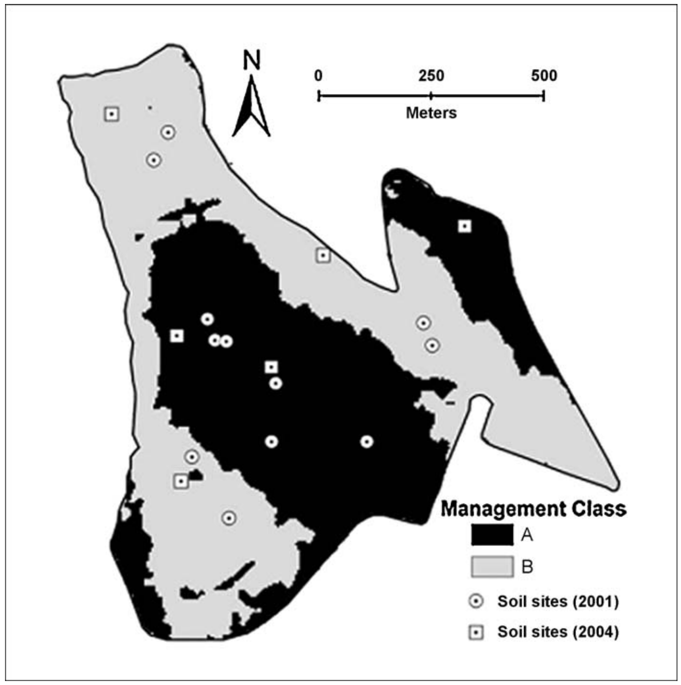

FIG. 1

The two management class map overlain with the stratified soil sample locations in 2001 and 2004, after [13].

Remote sensing in combination with intelligent statistical data analysis can facilitate the important step in the evolution from uniform field management to site-specific management. Provided researchers and producers work closely together, it will soon be possible to come to practicable site-specific management [13]. In a ten-step protocol including cleaning-up, trimming and transforming the data, Taylor *et al.* describe the decision making process to conclude for the optimal number of management classes: two classes in the case study. With the help of this information, farmers can make decisions regarding optimal fertiliser management, given that class A has much lower yield potential in a low-average rainfall year but might respond well to late-season fertiliser when within season rainfall is high. The two classes should as a consequence not be managed uniformly, see Fig. 1. However, the authors see the necessity of further expert input in the decision-making process, and potential for further methodological developments as confirmed recently by the same Australian research group [14].

A recent review [15] comes to conclusions with an integrative spirit, namely that the use of computers and sensors for real-time decisions is growing rapidly, but the real value of the technology can only be translated to optimal agricultural management if those data are integrated with agronomic knowledge and experience. The same cautious picture is obtained by Lamb *et al.* [16], calling for a more distanced view in innovation, because very few technologies associated with PB have reached the end of the hype cycle (Fig. 2), which the author takes as a normal phenomenon in innovative agricultural development. This holds true not only for PF, but also for other technologies like genetic engineering (or gene splicing), for which we are undoubtedly on the slope of enlightenment (typically enough opposed by conservative individuals who question even historic enlightenment today), and in a few cases of major GM crops we are in the plateau of successful productivity [8].

PF is of growing importance in automatic weed recognition, and several papers have been published over the years, some remarkably early, thus documenting some of the five key stages of Fig. 2 properly [18–23]. The most recent review [24] demonstrates progress in science *and* practice. There are cases reviewed of automatic weed control [25] combined with robotic weeding. Several prerequisites are necessary for a functioning robotic weed control system. (i) Machine vision-based automatic row guidance in real time (accuracy a few centimetres!), also able to work in sown (not planted) field rows, with a capacity of weeding densities up to 200 weeds/m^2; and ability to work with missing plants in the row (in organic fields where emergence is about 70%, conventional fields usually with an emergence of 90%). The vision

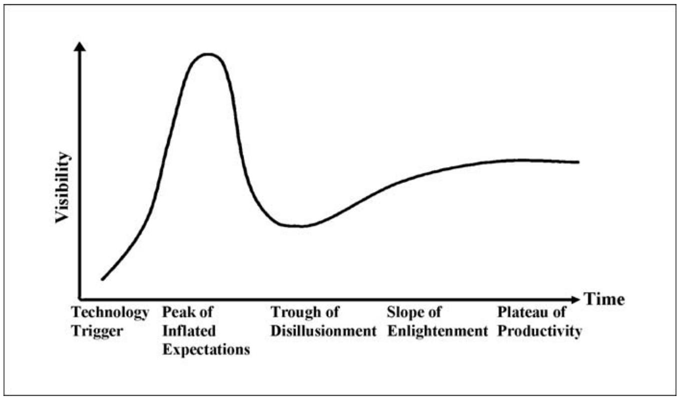

FIG. 2

The five key stages of the Gartner Hype Cycle [17].

system must be adaptable to local and regional conditions in soil and climate. (ii) Also essential is the ability of the vision system to recognise plant species on the basis of their biological morphology (Fig. 3).

But PF is not always done with remote sensing methods. Recently a comparison with two prototype soil strength profile sensors has been worked out with promising results [26]. And also when it comes to mapping yield more precisely, remote sensing methods are well established [27–31].

There is also a new trend in ecological and organic agriculture for PF, although often with a less technological touch, strongly emphasising local knowledge built on social networks and integrated decision-making systems. Electronics still plays a minor role and remote sensing via satellite imaging is – to the best knowledge of the author – still absent from the peer reviewed literature – although [13] is considering such tools. This paper still remains a rare example of organic precision agriculture, proposing 'down to earth' electronic sensors that respond strongly to clay content and soil moisture in non-saline soils to determine important parameters for the management system. Coupling the information from ECa sensors with other crop sensors, such as yield monitors and crop imagery, has been promoted [13] as a concept of management classes among Australian grain producers. Another rare Internet finding is a conference paper [32] outlining the future use of remote sensing and PF methods in organic farming. The aim of this study was to assess the effects of a GPS-controlled precision tillage system using permanent tracks on soil structure, nutrient use

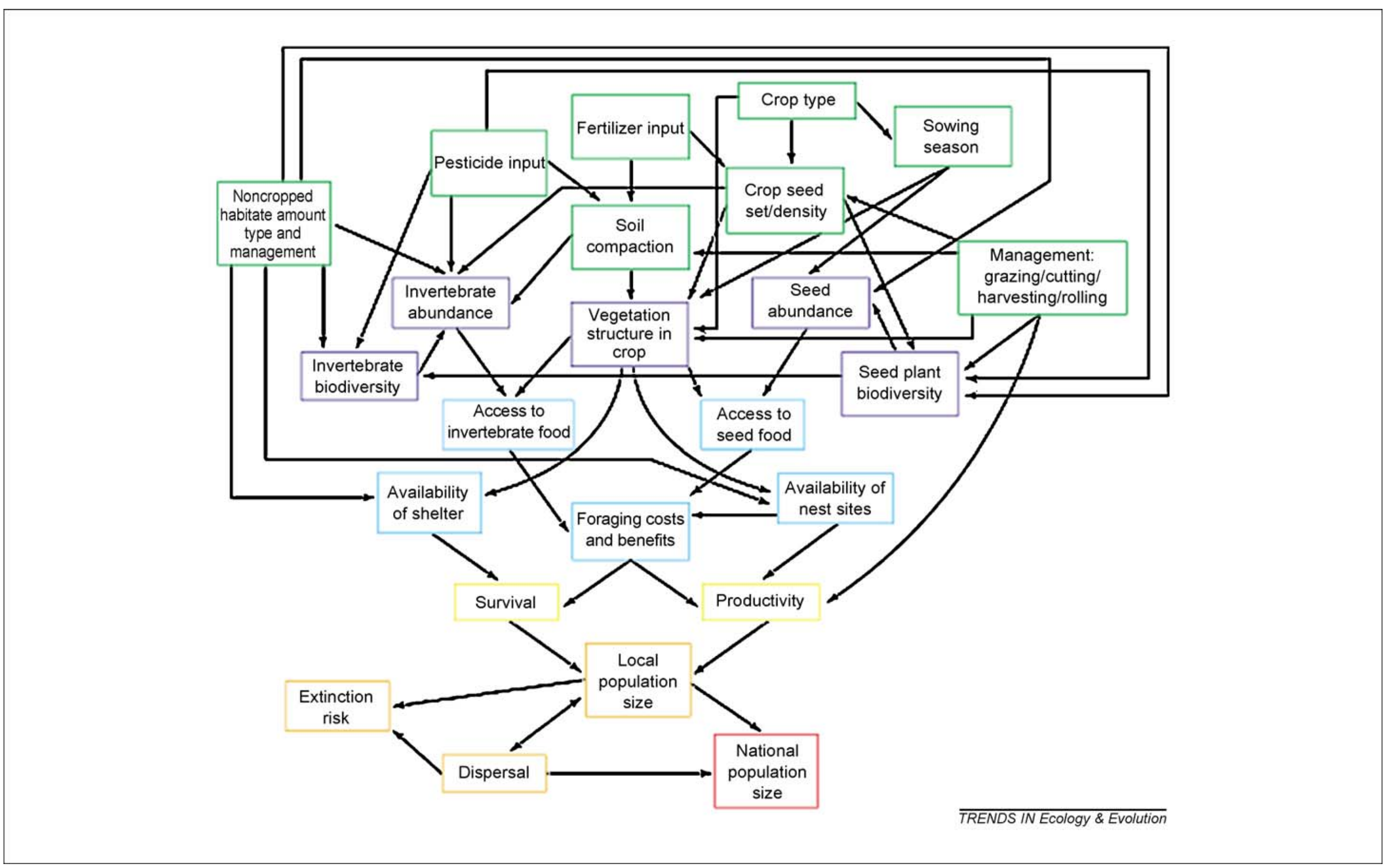

FIG. 3

The multivariate and interacting nature of farming practices and some of the routes by which farming practice impacts on farmland birds. Arrows indicate known routes by which farming practices (green boxes) indirectly (dark-blue boxes) or directly (light-blue boxes) affect farmland bird demography (yellow boxes), and therefore local population dynamics (orange boxes) and finally total population size (red box). The goal of manipulating farming practice is to impact on population size. Rather than identifying key routes through this web to change in a piece-wise fashion (e.g. insecticide usage), we suggest that management designed to increase habitat heterogeneity is likely to benefit the organisms in such a way as to meet the management goals. The rate at which the birds will feed is determined both by the amount of food (abundance) and its accessibility (access) within the habitat. From [89].

efficiency and spinach yield. The study was carried out at an organically managed arable farm in the Netherlands.

Elements of organic/ecological farming which could be adopted by farmers using modern agricultural technology

As was elaborated in the first part of this article [1] and its preceding text in the Handbook of IP methods [33], there exist controversial views about biodiversity in general and in agriculture in particular. This topic has also been covered more broadly for biodiversity as a whole by the author [34,35], here we concentrate on the case of agro-biodiversity. Biodiversity within the production field cannot be the solution, although the results of the British Farm Scale Experiments suggest that this is basically a good thing. Yet there are reasons of doubt: because some weeds provide toxic substances to the harvest, an old problem in agriculture, it cannot therefore be the goal of such experiments to enhance biodiversity within production fields. For more extensive crucial comments about the British experiments, see [36,37] – these experiments are actually asking the wrong questions.

The case of agro-biodiversity, new insights

In many publications about agro-biodiversity, it is hardly questioned whether biodiversity *per se* is a good thing. It is just assumed that we need to strive for as much biodiversity as possible, sometimes at the cost of simple production rules. This is why the following subchapters will try to produce a fresh and more pragmatic look at biodiversity in agriculture.

Nature's fields: ancient wild crop relatives often grew in monodominant stands

Species and genetic diversity within any agricultural field will inevitably be more limited than in a natural or semi-natural ecosystem. Surprisingly enough, many of the crops growing in farming systems all over the world have traits of ancestral parents, which lived originally in natural monocultures [38]. This is, after all, most probably the reason why our ancestral farmers chose those major crops. There are many examples of natural monocultures, such as the classic stands of Kelp, *Macrocystis pyrifera*, already analysed by Darwin [39] and, more relevant to agriculture, it has now been recognised by agro-ecologists that simple, monodominant vegetation exists throughout nature in a wide variety of circumstances. Indeed, [40] reporting [41,42] use the term 'natural monocultures' in analogy with crops. Such monodominant stands might be extensive. As one example out of many, Harlan recorded that for the blue grama grass (*Bouteloua gracilis*): 'stands are often continuous and cover many thousands of square kilometres of the high plains of central USA.' It is of utmost importance for the sustainability of agriculture to determine how these extensive, monodominant and natural grassland communities persist and when and if we might expect their collapse.

More examples are given in Wood and Lenne [43]; here we cite a few more cases. Wild species: *Picea abies*, *Spartina townsendii*, *Pteridium aquilinum*, various species of Bamboos, *Arundinaria* ssp. [44]. Also the related *Phragmites communis* grows in large monodominant stands, which contain large clones. They renew after some decades over seeds (just like the large tropical Bamboos do in amazingly regular periods), which causes temporary local breakdowns of the populations. Still other ancestral cultivars are cited extensively [38]. *Sorghum*, the wild variety *verticilliflorum*, is the most widely distributed feral complex of the genus, with a broad climatic plasticity, extending almost continuously east of 20° east longitude from the South African coast to 10° north latitude. It overlaps along its northern and northwestern borders with var. *aethiopicum* and var. *arundinaceum*, again hybridising extensively. It grows over extensive areas of tall grass savannah in the Sudan [38]. Typically enough, [45] found a remarkably narrow genetic basis for the variety *verticilliflorum* in their analysis. Wild rice: *Oryza coarctata* is reported in Bengal as growing in simple, oligodiverse pioneer stands of temporarily flooded riverbanks [46]; Harlan ascribed *Oryza* [47] to monodominant populations and illustrated harvests from dense stands of wild rice in Africa (*Oryza barthii*, the progenitor of the African cultivated rice, *Oryza glaberrima*). *O. barthii* was harvested wild on a massive scale and was a local staple crop across Africa from the southern Sudan to the Atlantic. Grain yields of wild rice stands in Africa and Asia could exceed 0.6 tonnes/ha – an indication of the stand density of wild rice [48].

Botanists and plant collectors have repeatedly and emphatically noted the existence of dense stands of wild relatives of wheat [38]. For example, in the Near East, massive stands of wild wheat cover many square kilometres [49]. 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 wheat under traditional management [50]. Wild Einkorn occurs in massive stands as high as 2000 m altitude in south-eastern Turkey and Iran [51]. 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 [52]. Wild wheat was also recorded to grow in Turkey and Syria in natural, rather pure stands with a density of 300 m^{-2} [53].

Agro-biodiversity and food webs of insects

In a recent notable paper Macfadyen *et al.* [54], were able to show in extensive field studies, focusing on the food web and its ecosystem services, instead of using traditional biodiversity descriptors, that things are a bit more complex than expected. Although organic farms support greater levels of biodiversity on all three trophic levels, as shown in metastudies [55,56], these systems provide greater levels of natural pest control and therefore also greater resistance towards the invasion of alien herbivores, because more parasitoids attack herbivores. However they also predict [54], as a consequence of higher species richness, a lower *connectance* and therefore a lower robustness of organic farms to species loss [57].

Extreme population dynamics of agricultural systems

It is amazing to see that there are entomologists who wonder about the slightest detail in insect population shifts and foodwebs to satisfy their effort to find negative effects of transgenic crops on non-target insects, and in so doing often forget some basics about experimentation. This has recently happened again with a paper from lab entomologists [58], which has been refuted justifiably on multiple grounds by an important consortium [59]. Here only one important reason is mentioned: feeding experiments have been done in the past [60,61] with low quality prey, but when healthy preys are used, the lacewings have proven extremely high tolerance for the Bt proteins [62,63]. Given here as a typical controversy on experimental details, some of the main influences are completely forgotten; just imagine the mass extinction effects which happen with certitude, if you change the cropping system, often from year to year. Interestingly enough, there is literature on the detrimental effects of crop rotation against pest insects [64], but it is difficult to find fieldwork data on non-target insects.

Agricultural ecosystems can be dynamic in terms of species diversity over time as a result of management practices. This is often not understood by ecologists who involve themselves in biosafety issues related to transgenics. They still think in ecosystem categories close (or seemingly close) to nature. Biodiversity in agricultural settings can be considered to be important at a country level in areas where the proportion of land allocated to agriculture is high: see Ammann in [65]. This is the case in continental Europe for example, where 45% of the land is dedicated to arable and permanent crops or permanent pasture. In the UK, this figure is even higher, at 70%. Consequently, biodiversity has been heavily influenced by human for centuries, and changes in agrobiological management will influence biodiversity in such countries overall. Innovative thinking about how to enhance biodiversity in general, coupled with bold action, is crucial in dealing with the loss of biodiversity.

Centres of crop biodiversity

Centres of biodiversity are a controversial matter, and even the definition of centres of crop biodiversity is still debated. Harlan [66] proposed a theory that agriculture originated independently in three different areas and that in each case there was a system composed of a centre of origin and a noncentre, in which activities of domestication were dispersed over a span of 5–10,000 km. One system was in the Near East (the Fertile Crescent) with a noncentre in Africa; another centre is north Chinese and a noncentre in S.E. Asia and the south Pacific, with the third system including a Central American centre and a South American noncentre. He suggests that the centres and the noncentres interacted with each other.

There is a widespread view that centres of crop origin should not be touched by modern breeding because the biodiversity treasures are so fragile that these centres should stay free of modern breeding – rather like museums. It is an error to assume that regions of high biodiversity are particularly susceptible to invasive processes. On the contrary, there are studies showing that high biodiversity means more stability against invasive species, as well as against genetic introgression [67–69] and most recently by [54] commented on above. The introduction of new predators and pathogens has caused well-documented extinctions of long-term resident species, particularly in spatially restricted environments such as islands and lakes. One of the (in)famous cases of extinction of an endemic rare moth is documented from Hawaii; it was caused by a failed attempt at biological control [70,71]. However, there are surprisingly few instances of extinction of resident species that can be attributed to competition from new species. This suggests either that competition-driven extinctions take longer to occur than those caused by predation or that biological invasions are much more likely to be threaten species through inter-trophic than through intra-trophic interactions [72]. This also fits well with agricultural experience, which builds on much faster ecological processes.

Selected proposals for improving high technology agriculture related to biodiversity

Biodiversity and agricultural landscapes

High potential to enhance biodiversity considerably can be seen at the level of regional landscapes [73,74], and with the help of remote sensing methods it should be possible to plan for much better biodiversity management in agriculture [75]. This is also a good point for organic farming in marginal regions, such as the Norwegian Sognefjord. An analysis has shown the positive influence of small-scale organic farming in this region [76]. Some of the more important papers demonstrate the intensive research activities on the relationship between landscapes and biodiversity [76–87]. A bibliography, containing a total of more than 300 papers dealing with the impact of ecological agriculture on landscapes and *vice versa* can be found in [88]. There is a great deal of potential in restructuring landscape in regions with a high yielding industrial agricultural production. In a thoughtful multivariate scheme Benton *et al.* [89] show the highly complex interactions between farmland activities and the diversity of bird species.

Now that many of the biodiversity myths related to agriculture are clarified, it is becoming obvious that one of the priorities in fostering biodiversity in agriculture is to take better care of the landscape structure, and this is where high tech agriculture can learn from organic and integrated farming. But there are other ways and means to cope with the demand of enhancing biodiversity in high tech agriculture.

More biodiversity through mixed cropping

Mixed cropping systems have been proposed for a variety of agricultural management systems. The bibliography coming from Web of Science reaches nearly 300 items and many papers offer a wide variety of options. There is no reason why modern cropping system with industrial automatisation could not cope with some specific mixed cropping systems. Mixed cropping offers advantages in pest management and soil fertility [90–92], but is also subject to limitations, such as the fight against the maize stem borer [93], yet under low pest pressure a system of maize–bean intercropping in Ethiopia seems to be successful [94].

Varietal mixture of genes and seeds

Also on a microscale of seed production, biodiversity could play a new role. Precision Biotechnology could also mean a combination of resistance genes, achieved either through gene stacking [95–97] or by taking up the idea of artificial gene clusters [98]. This has been the accepted strategy up to now. But this goal of introducing more biodiversity in the fields could be achieved in a much simpler way. Other than complex gene stacking, it would be easier to create a seed mix in which each seed contains a single resistance and the appropriate mixture could be adapted to the local pest situation. This would considerably lower selection pressure [99] and would create a situation, which comes closer to nature, where we encounter many genomes within a square mile and dozens of different resistance genes. Varietal mixtures have been proposed by several authors [100–103].

More biodiversity in the food web including non-target insects by reducing pesticide use with transgenic crops

If we refrain from heavy pesticide use, beneficial insects will come back – as they do in Bt maize fields, [104–107] and adapt to GMOs. Much has been written on agricultural biodiversity; foremost the book of Wood and Lenne [43] should be mentioned here, a refreshing mix of modern agriculture and independent views on biodiversity. Each chapter, written by some of the best experts in the field, deserves to be taken up in the future debate on agriculture and biodiversity. The chapter on traditional management written by [108] provides a very enlightening summary. Of course those management details have to be carefully selected for modern agriculture and where necessary also to be adapted. As a catalogue of ideas the tables in this article serve well.

There are also comparative data available on long-term development, with organic and conventional agriculture. The results show positive trends towards more biodiversity, when conventional farms are converted into organic farms, but the influence of local management habits and also a changing landscape are very important [109] and high technology farming could again learn.

On the wish list: more crop biodiversity

Another important aspect has been covered by the recently published book of Gressel [110] with an interesting theme: a proactive review on orphan crops, their present day deficiencies (the 'glass ceiling') and how biotechnology methods could greatly enhance them, so that they could be commercialised in future. It is especially fascinating to see how the author blends modern molecular biology with a deep insight into agriculture and its forgotten crops. This is an important boundary line, where organic/ecological farming can meet and create considerable synergy. Even within crops with a seemingly low reputation, like the herbicide tolerant soybeans, trends regarding diversity are positive, because a report from Iowa shows [111]: recently there are more than 700 nematode resistant soybean traits registered, the majority of them herbicide tolerant.

Plant breeding revisited

Plant breeding has gone through dynamic developments, from marker assisted breeding to transgenesis, with steadily improved methods up to the latest development of the zinc-finger enzyme assisted targeted insertion of transgenes in complex organisms [3,4]. The development is so rapid that it is necessary here to make some additional remarks related to the paragraph in the first of the articles dealing with the topic of organotransgenesis [1]: according to the descriptions of the new technology, it will be even more difficult for breeders of new organic crops to refuse zinc-finger transgenesis, because it is very likely to be that the transcriptomic disturbances will be even smaller in future – compared to the clumsy and tedious methods of conventional breeding. This does not mean that there is no value in the development of conventional breeding methodologies for organic crops. It is obvious that high technology breeding of new crops can also learn from the newly developed organic breeding strategies.

In a recent and comprehensive paper, a consortium lead by Wolfe *et al.* [112] gives an account of breeding crops for organic farming. Many of the characteristics required in new varieties are common to both conventional and organic agriculture, but there are also a number, mostly of complex nature, that must have a higher priority in organic farming. Characters that are important for the farming system and crop rotation, weed competition and adaptation to arbuscular mycorrhizas have a higher priority. To rationalise the long enduring selection process, it is necessary to focus on simultaneous selection processes such as weed competition, nutrient uptake and disease/pest resistance. It seems that the trend to ban any kind of *in vitro* breeding technology is unfortunately growing and therefore anticipated, including marker assisted breeding, which will deprive the organic community from modern and very efficient tools with which to achieve the genomic breeding goals. This way, the slowdown process cannot be stopped and the difficulties will grow with the need to cope with a considerably higher diversity of environmental factors, which does not favour centralised breeding. The real force of breeding for organic crops comes from the strong link to social structures, as promoted by a variety of breeding programmes, such as those on Sorghum in Western Africa by researchers from Wageningen [113], explicitly enforcing participative working strategies including traditional knowledge. These thoughts and strategies could well also be taken up by breeding programmes using unrestrained all modern DNA related manipulation methods.

Final remarks on the improvement list related to biodiversity

This cannot be the place to give a comprehensive list of possible improvements, which are compatible with high technology agriculture, which would fill dozens of pages and could also well be the intellectual engine for a long-term research programme. Rather, the reader is referred to some books written to improve agricultural biodiversity – most of the chapters cited below do not envisage improving high technology agriculture *per se*, indeed most of the authors see themselves in opposition to it. In the eyes of the author this is at least questionable and it would be much more fruitful to find opportunities for collaboration and creation of synergy.

There are several books and reports, as well as numerous peer reviewed journal articles, dealing with all aspects of ecological agriculture. The authors provide proposals on how to enhance sustainability, how to preserve biodiversity and what can be done so that traditional knowledge with all its treasures does not vanish. There are a majority of authors who really do not lose the focus of the developing world and its dramatic problems, but they avoid topics like modern breeding among others [114–117]. Scherr and McNeely [116] and in particular also Wood and Lenne [43] offer highly interesting chapters on the science and practice of ecoagriculture. It is impressive for the reader to learn about various schemes of integrated farming systems, and some are really integrative and especially strong on the side of analysing social dynamics, history and economy, topics sometimes forgotten by conservationists and certainly by proponents of high technology agriculture. By contrast, it is striking to see, with a few notable exceptions, that modern breeding technology and in most cases also high technology management methods like remote sensing, GIS supported systems are often only briefly mentioned. In Scherr and McNeely [116] even a meticulous search does not reveal a single sentence on genetically engineered crops and the otherwise extensive keyword index does not contain such words. By contrast, it is rewarding to see in the same book a treatment on remote sensing [32], stating that this is an important instrument in the landscape planning of ecoagriculture (GIS-based decision support). Nevertheless, the scarcity of such treatments provokes the serious question about bias against modern agricultural technology. The same can be said of the IAASTD report. In a rebuttal to a letter to *Science* [118] attacking the views of Fedoroff [119], the author [120] commented about the IAASDD report [121]:

> ***"Mitchell referred to the IAASTD report to degrade the importance of transgenic crops, but this report does not meet scientific review standards and comes to questionable negative conclusions about biotechnology in agriculture: "Information [about GM crops] can be anecdotal and contradictory, and uncertainty on benefits and harms is unavoidable." Such biased judgment ignores thousands of high quality science papers; it is not surprising that most renowned experts left the IAASTD panel before the final report was published".***

The good thing about all those publications on ecoagriculture is to see with an open mind that transgenic crops and all high technology practices, even the first generation transgenic crops, could very well fit into ecoagriculture and, *vice versa*, that ecoagricultural strategies could very well be introduced into high tech agriculture. The possible positive role of biotechnology related to ecology and conservation was stated as early as 1996 [122]. It is a fact which has been repetitiously stated with solid justification: present day commercialised transgenic crops are not inherently scale dependent, which means they can, with some adaptation in management, very well be integrated into small-scale farming – which has been shown with success in India and China with Bt cotton [123–125].

As summary and synthesis of both features on organotransgenics in New Biotechnology, a statement of sustainability is presented. It is, as one can infer from both texts, not written in a defensive way. On the contrary, the view is clear: we can only achieve the goals of sustainability successfully if we are ready for progress, changing the world and the course of evolution, thus producing the best outcome for biodiversity, humanity and our planet.

Final remarks about sustainability

An intelligent scheme of sustainability (among others [126]) has been coined by Mendel Biotechnology, combining elements of social/environment to 'Bearable', social/economic to 'Equitable' and economic/environment to 'Viable', and where all three elements of social/environment/economic overlap, sustainability resides (http://www.mendelbio.com/sustainability/index.php). A convincing way forward for the understanding and the practice of agricultural sustainability is described by Nash *et al.* [127]. Using the notation and software tools for the Unified Modeling Language (UML), a complete model of all identified data-flows was created. Individual data-streams relating to particular source or product datasets were then extracted from this model. These data-streams present a practical application of the model in identifying the benefit that might be obtained from a particular gathered dataset (e.g. yield data) or in identifying the data that must be gathered to generate a particular product dataset (e.g. sustainability indicators).

For some years, the author has tested in debates of numerous events a sustainability scheme, which is somehow similar to the one by Mendel Biotechnology. It concentrates more on the essential activities of humanity with the goal to solve the urgent global problems on how to feed the ever-growing number of hungry people.

If we want to aim at a more sustainable world, it needs more than defensive measures usually advocated. Sustainable development has been defined in many ways, but the most frequently quoted definition is from *Our Common Future*, also known as the Brundtland Report [128]:

> ***Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs. It contains within it two key concepts:***
>
> - the concept of *needs*, in particular the essential needs of the world's poor, to which overriding priority should be given and
> - the idea of *limitations* imposed by the state of technology and social organization on the environment's ability to meet present and future needs.

Sustainability is usually understood as a definition with a rather defensive spirit, but taken in its original content, then the words envision uncompromisingly the way forward – asking not only for conservation, but also for *development* and *management* of patterns of *production* and *consumption*.

The declaration of the OECD, authored by Yokoi [129], catalogues a range of concrete measures and rules to achieve a more sustainable agriculture. It is remarkable that the proposed indicators do not distinguish between farming with or without transgenic crops.

The scheme in Fig. 4 meets those needs and asks for an intransigent view of the future. The three-column model has been chosen with care, and as one can see:

- *The most important column to the left is agriculture*. It demands 'to foster renewable resources, knowledge based agriculture' [130] and with some additions [131–133]. The rather provocative phrase *Organic Precision Biotechnology Agriculture* is now coined; a shorter one might be 'Organotransgenic' Agriculture, but the most elegant term 'Orgenic' [134] is unfortunately already lost to other purposes. By no means does this mean to suggest that the mistakes of organic farming or exaggerated industrialisation of production should be included; those mistakes in organic farming are dealt with fully in my previous article in New Biotechnology [133]. The most dramatic mistakes in organic farming are the low yield, documented in many long term monitoring experiments and the eco-imperialist attitude towards farmers of the developing world [135–138,167,168]. On the positive side is some pioneering work in developing recycling loops in agriculture [139–145] and also in better landscape management [76–87,146–149]. (For further documentation, see the previous paragraph on landscape management and organic farming.) To balance local production against global trade will not be easy, because the equilibrium between the demands and perils of pressure to produce for global trading and local food production must be found. The economic basis should be important, but local social networking and life need to be taken into account as well.
- *Middle column: socio-ethics*: It is of utmost importance to reach greater equity, especially in these difficult times of the credit crunch 2009. It will be imperative to reduce the huge agricultural subsidies paid to the farmers in the developed world, a kind of protectionism that needs to be questioned. Access to global markets is important, but should not hamper local food production and social structures in the developing world. The myth that developing countries are in the tight grip of multinationals can be debunked with some publications [150–156]. A new creative capitalism – a novel discussion which would have been totally utopic before the global economic crisis – needs our attention. It will be a demanding process to reconcile traditional knowledge with modern science; the intellectual property (IP) system is up to now completely unilateral, and no wonder because it has been created by the developed world. In the IP handbook of Krattiger *et al.* (accessible over the Internet), there are

FIG. 4
View of a future Sustainable World, original K. Ammann 5.4.2009.

numerous contributions offering innovative solutions to reconcile this contrast; the author also contributed and offered some solutions [33]. This contribution made it clear that we need not only a big boost in breeding science, but also a new focus on emerging fields in science: biomimetics (formerly bionics) could be a promising area of research, where high technology equipment is certainly helpful, but not indispensable, and agriculture needs new research goals for new production lines. Hygroscopic mechanisms are offered within the plant kingdom and also abundantly with insects, but the details, often functioning for 200 years beyond the organismal death, need clarification; maybe in some future days we will be able to use the adiabatic moisture differences of our daily climate fluctuations to produce power.

- *Right column on evolution*: The most audacious third column questions our view of evolution in both the biological and the general sense of the word. Evolution deplorably still contains – often not consciously – some elements of creationism [157] – and this not only with opponents of gene splicing. It will be important to emancipate these views and make clear that for many years we have taken human evolution into our own hands through modern medicine, and we need to deal with the problems *and* prospects of a new evolutionary view. Modern breeding has the potential to enlighten the population, if done in an ethically acceptable way and if communicated properly. The tasks will grow over the coming decades and in many fields of science we are already now heavily dependent on calculation power; therefore, let us make sure that mathematical algorithms can be translated into useful artificial intelligence in the service of mankind. We need the help of all new and emerging technologies (of course regulated in a sensible way) to enhance food production and the livelihood of mankind. The statement 'only one planet' is at the same time a reminder to precaution, but appeals also to our responsibility to take evolution as a whole into our own hands. This can only be achieved if we have a close and conscious look at the cultural side of human evolution as a whole with all its consequences for ourselves. This will be another string of thoughts in a next feature on 'Darwin and beyond', the development of the evolutionary theory after Darwin on all levels, from the molecules to culture; it will need historical and philosophical scrutiny, going far beyond the usual disputes on technologies [158,159].

Some closing words: Agriculture is at the centre of this text, and rightly so, since we have the urgent task of feeding a *billion hungry people*, and there is no time for sterile sophisticated bickering on whether some hypothetical negative effects could emerge decades from now, because by then hundreds of millions of people would have died of hunger and disease. The case of the golden rice is symbolic for the situation of mankind: we can develop it as fast as we can, unhampered by over-regulation – or we might tolerate hundreds of thousands of children dying every year from pro-vitamin A deficiency. It is no coincidence that this article closes with some references essential for the Golden Rice debate [160–166]. Actually the solution would be extremely simple and its unconditional support would honour all institutions of the United Nations, including the Convention of Biodiversity that has created the Cartagena Protocol on Biosafety. Human beings should be part of any risk assessment in technology: this is a request with enormous ethical implications.

References

1 Ammann, K. (2008) Feature: integrated farming: why organic farmers should use transgenic crops. *New Biotechnol*. 25, 101–107
2 Batte, M.T. and Arnholt, M.W. (2003) Precision farming adoption and use in Ohio: case studies of six leading-edge adopters. *Comput. Electron. Agric*. 38, 125–139
3 Shukla, V.K. *et al.* (2009) Precise genome modification in the crop species *Zea mays* using zinc-finger nucleases. *Nature* advanced online publication
4 Townsend, J.A. *et al.* (2009) High-frequency modification of plant genes using engineered zinc-finger nucleases. *Nature* advanced online publication
5 Paszkowski, J. *et al.* (1988) Gene targeting in plants. *EMBO J*. 7, 4021–4026
6 Paszkowski, J. *et al.* (1984) Direct gene-transfer to plants. *EMBO J*. 3, 2717–2722
7 Sai, M. and Rao, P.V.N. (2008) Utilization of Resourcesat-1 data for improved crop discrimination. *Int. J. Appl. Earth Observ. Geoinform*. 10, 206–210
8 James, C. (2009) *Global Status of Commercialized Biotech/GM Crops: 2008, Brief 39, Executive Summary*. ISAAA p. 20
9 Christy, C.D. (2008) Real-time measurement of soil attributes using on-the-go near infrared reflectance spectroscopy. *Comput. Electron. Agric*. 61, 10–19
10 Multivariate correlation of deposition data of 8 different air pollutants to lichen data in a small town in Switzerland. Ammann, K. *et al*. eds), 1987.In Int. Assoc. Aerobiol.
11 Herzig, R. *et al.* (1989) Passive biomonitoring with lichens as a part of an integrated biological measuring system for monitoring air-pollution in Switzerland. *Int. J. Environ. Anal. Chem*. 35, 43–57
12 Liebendorfer, L. *et al.* (1988) Evaluation and calibration of the Swiss lichen-indication-method with important air-pollutants. *Staub Reinhalt Luft* 48, 233–238
13 Taylor, J.A. *et al.* (2007) Establishing management classes for broadacre agricultural production. *Agron. J*. 99, 1366–1376
14 Florin, M.J. *et al.* (2009) Quantification and comparison of wheat yield variation across space and time. *Eur. J. Agron*. 30, 212–219
15 Kitchen, N.R. (2008) Emerging technologies for real-time and integrated agriculture decisions. *Comput. Electron. Agric*. 61, 1–3
16 Lamb, D.W. *et al.* (2008) Improving pathways to adoption: putting the right Ps in precision agriculture. *Comput. Electron. Agric*. 61, 4–9
17 Gartner, C. (2008) *Hype Cycles for Emerging Technologies, The Wave of the Future? Or Just Hype? Gartner Hype Cycles Show the Difference*. Gartner Inc. p. 35
18 Guyer, D.E. *et al.* (1993) Application of machine vision to shape-analysis in leaf and plant-identification. *Trans. ASAE* 36, 163–171
19 Sogaard, H.T. (2005) Weed classification by active shape models. *Biosyst. Eng*. 91, 271–281
20 Woebbecke, D.M. *et al.* (1995) Shape-features for identifying young weeds using image-analysis. *Trans. ASAE* 38, 271–281
21 Franz, E. *et al.* (1991) The use of local spectral properties of leaves as an aid for identifying weed seedlings in digital images. *Trans. ASAE* 34, 682–687
22 Chi, Y.T. *et al.* (2003) Leaf shape modeling and analysis using geometric descriptors derived from Bezier curves. *Trans. ASAE* 46, 175–185
23 Guyer, D.E. *et al.* (1986) Machine vision and image-processing for plant-identification. *Trans. ASAE* 29, 1500–1507
24 Ishak, A.J. *et al.* (2009) Weed image classification using Gabor wavelet and gradient field distribution. *Comput. Electron. Agric*. 66, 53–61
25 Slaughter, D.C. *et al.* (2008) Autonomous robotic weed control systems: a review. *Comput. Electron. Agric*. 61, 63–78
26 Sudduth, K.A. *et al.* (2008) Field comparison of two prototype soil strength profile sensors. *Comput. Electron. Agric*. 61, 20–31
27 Drummond, S.T. *et al.* (1999) Combine harvest area determination by vector processing of GPS position data. *Trans. ASAE* 42, 1221–1227
28 Ehlert, D. (2002) Advanced throughput measurement in forage harvesters. *Biosyst. Eng*. 83, 47–53
29 Pelletier, G. and Upadhyaya, S.K. (1999) Development of a tomato load/yield monitor. *Comput. Electron. Agric*. 23, 103–117
30 Reyniers, M. *et al.* (2002) Precision farming through variable fertilizer application by automated detailed tracking of in-seasonal crop properties. *Proc. Int. Soc. Opt. Eng*. 4542, 36–46
31 Whitney, J.D. *et al.* (1999) Precision farming applications in Florida citrus. *Appl. Eng. Agric*. 15, 399–403
32 Dushku, A. *et al.* (2007) *Farming with Nature: The Science and Practice of Ecoagriculture*. Island Press pp. 250–64
33 Ammann, K. (2006) Reconciling traditional knowledge with modern agriculture: a guide for building bridges. In *Intellectual Property Management in Health and Agricultural Innovation: A Handbook of Best Practices* (Krattiger, A., Mahoney, R.T.L., Nelsen, L., eds), pp. 1539–1559, MIHR, PIPRA
34 Ammann, K. (2009) Biodiversity and GM crops. In *Environmental Impact of Genetically Modified/*

Novel Crops (Ferry, N. and Gatehouse, A.M.R., eds), p. 28, CAB International

35 Ammann, K. (2007) The needs for plant biodiversity: the general case, foreword. In *Genetic Glass Ceilings, Transgenics for Crop Biodiversity* (Gressel, J., ed.), The Johns Hopkins University Press pp. X–X10

36 Ammann, K. (2005) Effects of biotechnology on biodiversity: herbicide-tolerant and insect-resistant GM crops. *Trend Biotechnol.* 23, 388–394

37 Chassy, B. *et al.* (2003) UK field-scale evaluations answer wrong questions. *Nat. Biotechnol.* 21, 1429–1430

38 Wood, D. and Lenne, J. (2001) Nature's fields: a neglected model for increasing food production. *Outlook Agric.* 30, 161–170

39 Darwin, C. (1845) *Journal of Researches into the Natural History and Geology of the Countries Visited During the Voyage of H.M.S. Beagle Round the World.* John Murray

40 Fedoroff, N.V. and Cohen, J.E. (1999) Plants and population: Is there time? *Proc. Natl. Acad. Sci. U. S. A.* 96, 5903–5907

41 Janzen, D. (1999) Gardenification of tropical conserved wildlands: multitasking, multicropping, and multiusers. *Proc. Nat. Acad. Sci. U. S. A.* 96, 5987–5994

42 Janzen, D. (1998) Gardenification of wildland nature and the human footprint. *Science* 279, 1312–1313

43 Wood, D. and Lenne, J. (1999) Agrobiodiversity and natural biodiversity: some parallels. In *Agrobiodiversity, Characterization, Utilization and Management* (Wood, D. and Lenne, J., eds), pp. 425–445, CABI

44 Gagnon, P.R. and Platt, W.J. (2008) Multiple disturbances accelerate clonal growth in a potentially monodominant bamboo. *Ecology* 89, 612–618

45 Ayana, A. *et al.* (2000) Genetic variation in wild sorghum (*Sorghum bicolor* ssp *verticilliflorum* (L.) Moench) germplasm from Ethiopia assessed by random amplified polymorphic DNA (RAPD). *Hereditas* 132, 249–254

46 Prain, D. (1903) *Flora of the Sundribuns.*

47 Harlan, J.R. (1989) Wild-grass harvesting in the Sahara and Sub-Sahara of Africa. In *Foraging and Farming: The Evolution of Plant Exploitation* (Harris, D.R. and Hillman, G.C., eds), pp. 79–98, Unwin Hyman

48 Evans, L.T. (1998) *Feeding the Ten Billion: Plants and Population Growth.* Cambridge University Press

49 Harlan, J.R. (1992) *Crops and Man* (2nd edn), American Society of Agronomy

50 Hillmann, G. (1996) Late Pleistocene changes in wild food plants available to huntergatherers of the northern Fertile Crescent: possible preludes to cereal cultivation. In *The Origin and Spread of Agriculture and Pastoralism in Eurasia* (Harris, D.R., ed.), pp. 159–203, University College Press

51 Harlan, J. and Zohary, D. (1966) Distribution of wild wheats and barley. *Science* 153, 1074–1080

52 Nevo, E. (1998) Genetic diversity in wild cereals: regional and local studies and their bearing on conservation ex situ and in situ. *Genet. Resour. Crop Evol.* 45, 355–370

53 Anderson, P.C. (1998) History of harvesting and threshing techniques for cereals in the prehistoric Near East. In *The Origins of Agriculture and Crop Domestication* (Damania, A.B., Valkoun, J., Willcox, G., Qualset, C.O., eds), pp. 145–159, ICARDA

54 Macfadyen, S. *et al.* (2009) Do differences in food web structure between organic and conventional farms affect the ecosystem service of pest control? *Ecol. Lett.* 12, 229–238

55 Bengtsson, J. *et al.* (2005) The effects of organic agriculture on biodiversity and abundance: a meta-analysis. *J. Appl. Ecol.* 42, 261–269

56 Hole, D.G. *et al.* (2005) Does organic farming benefit biodiversity? *Biol. Conserv.* 122, 113–130

57 Lafferty, K.D. *et al.* (2008) Parasites in food webs: the ultimate missing links. *Ecol. Lett.* 11, 533–546

58 Lovei, G.L. *et al.* (2009) Transgenic insecticidal crops and natural enemies: a detailed review of laboratory studies. *Environ. Entomol.* 38, 293–306

59 Shelton, A. *et al.* (2009) Setting the record straight: a rebuttal to an erroneous analysis on transgenic insecticidal crops and natural enemies. *Transgenic Res.* 18, 317–322 open access

60 Hilbeck, A. *et al.* (1998) Effects of transgenic *Bacillus thuringiensis* corn-fed prey on mortality and development time of immature *Chrysoperla carnea* (Neuroptera: Chrysopidae). *Environ. Entomol.* 27, 480–487

61 Hilbeck, A. *et al.* (1998) Impact of *Bacillus thuringiensis* – insecticides on population dynamics and egg predation of the Colorado potato beetle in North Carolina potato plantings. *Biocontrol* 43, 65–75

62 Dutton, A. *et al.* (2002) Uptake of Bt-toxin by herbivores feeding on transgenic maize and consequences for the predator *Chrysoperla carnea*. *Ecol. Entomol.* 27, 441–447

63 Romeis, J. *et al.* (2004) *Bacillus thuringiensis* toxin (Cry1Ab) has no direct effect on larvae of the green lacewing *Chrysoperla carnea* (Stephens) (Neuroptera: Chrysopidae). *J. Insect Physiol.* 50, 175–183

64 Landis, D.A. *et al.* (2000) Habitat management to conserve natural enemies of arthropod pests in agriculture. *Annu. Rev. Entomol.* 45, 175–201

65 Wolfenbarger, L.L. *et al.* (2004) GE crops: balancing predictions of promise and peril. *Front. Ecol. Environ.* 2, 154–160

66 Harlan, J.R. (1971) Agricultural origins – centers and noncenters. *Science* 174, 468

67 Tilman, D. *et al.* (2005) Diversity, productivity and temporal stability in the economies of humans and nature. *J. Environ. Econ. Manage.* 49, 405–426

68 Whitham, T.G. *et al.* (1999) Plant hybrid zones affect biodiversity: tools for a genetic-based understanding of community structure. *Ecology* 80, 416–428

69 Morris, W.F. *et al.* (1994) Do barren zones and pollen traps reduce gene escape from transgenic crops. *Ecol. Appl.* 4, 157–165

70 Henneman, M.L. and Memmott, J. (2001) Infiltration of a Hawaiian Community by introduced biological control agents. *Science* 293, 1314–1316

71 Howarth, F.G. (1991) Environmental impacts of classical biological-control. *Annu. Rev. Entomol.* 36, 485–509

72 Davis, M.A. (2003) Biotic globalization: does competition from introduced species threaten biodiversity? *Bioscience* 53, 481–489

73 Dollaker, A. (2006) Conserving biodiversity alongside agricultural profitability through integrated R&D approaches and responsible use of crop protection products. *Pflanzenschutz-Nachrichten Bayer* 59, 117–134

74 Dollaker, A. and Rhodes, C. (2007) Integrating crop productivity and biodiversity conservation pilot initiatives developed by Bayer Crop Science, in Weed Science in Time of Transition. *Crop Sci.* 26, 408–416

75 Mucher, C.A. *et al.* (2000) Land cover characterization and change detection for environmental monitoring of pan-Europe. *Int. J. Remote Sens.* 21, 1159–1181

76 Clemetsen, M. and van Laar, J. (2000) The contribution of organic agriculture to landscape quality in the Sogn og Fjordane region of Western Norway. *Agric. Ecosyst. Environ.* 77, 125–141

77 Belfrage, K. *et al.* (2005) The effects of farm size and organic farming on diversity of birds, pollinators, and plants in a Swedish landscape. *Ambio* 34, 582–588

78 Boutin, C. *et al.* (2008) Plant diversity in crop fields and woody hedgerows of organic and conventional farms in contrasting landscapes. *Agric. Ecosyst. Environ.* 123, 185–193

79 Filser, J. *et al.* (2002) Long-term dynamics and interrelationships of soil Collembola and microorganisms in an arable landscape following land use change. *Geoderma* 105, 201–221

80 Hendriks, K. *et al.* (2000) The appearance of agriculture: an assessment of the quality of landscape of both organic and conventional horticultural farms in West Friesland. *Agric. Ecosyst. Environ.* 77, 157–175

81 Jan Stobbelaar, D. and van Mansvelt, J.D. (2000) The process of landscape evaluation: introduction to the 2nd special AGEE issue of the concerted action: the landscape and nature production capacity of organic/sustainable types of agriculture. *Agric. Ecosyst. Environ.* 77, 1–15

82 Kuiper, J. (2000) A checklist approach to evaluate the contribution of organic farms to landscape quality. *Agric. Ecosyst. Environ.* 77, 143–156

83 MacNaeidhe, F.S. and Culleton, N. (2000) The application of parameters designed to measure nature conservation and landscape development on Irish farms. *Agric. Ecosyst. Environ.* 77, 65–78

84 Norton, L. *et al.* (2009) Consequences of organic and non-organic farming practices for field, farm and landscape complexity. *Agric. Ecosyst. Environ.* 129, 221–227

85 Rossi, R. and Nota, D. (2000) Nature and landscape production potentials of organic types of agriculture: a check of evaluation criteria and parameters in two Tuscan farm-landscapes. *Agric. Ecosyst. Environ.* 77, 53–64

86 Schellhorn, N.A. *et al.* (2008) Managing ecosystem services in broadacre landscapes: what are the appropriate spatial scales? *Aust. J. Exp. Agric.* 48, 1549–1559

87 Stobbelaar, D.J. *et al.* (2000) Landscape quality on organic farms in the Messara valley, Crete: organic farms as components in the landscape. *Agric. Ecosyst. Environ.* 77, 79–93

88 Ammann, K. (2009) *Bibliography on the relationship between ecological agriculture and landscape.* Istanbul 5. April 2009

89 Benton, T.G. *et al.* (2003) Farmland biodiversity: is habitat heterogeneity the key? *Trends Ecol. Evol.* 18, 182–188

90 Wolfe, M.S. (2000) Crop strength through diversity. *Nature* 406, 681–682

91 Zhu, Y.Y. *et al.* (2000) Genetic diversity and disease control in rice. *Nature* 406, 718–722

92 Zhu, Y.Y. *et al.* (2003) Conserving traditional rice varieties through management for crop diversity. *Bioscience* 53, 158–162

93 Songa, J.M. *et al.* (2007) The role of intercropping different cereal species in controlling lepidopteran stemborers on maize in Kenya. *J. Appl. Entomol.* 131, 40–49

94 Belay, D. *et al.* (2009) The profitability of maize–haricot bean intercropping techniques to control maize stem borers under low pest densities in Ethiopia. *Phytoparasitica* 37, 43–50

95 Taverniers, I. *et al.* (2008) Gene stacking in transgenic plants: towards compliance between definitions, terminology, and detection within the EU regulatory framework. *Environ. Biosafety Res.* 7 10.1051/ebr:2008018

96 Halpin, C. (2005) Gene stacking in transgenic plants – the challenge for 21st century plant biotechnology. *Plant Biotechnol. J.* 3, 141–155

97 Gressel, J. *et al.* (2007) Approaches to and successes in developing transgenically enhanced mycoherbicides. In *Novel Biotechnologies for Biocontrol Agent Enhancement and Management.* pp. 297–305

98 Thomson, J.M. *et al.* (2002) Artificial gene-clusters engineered into plants using a vector system based on intron- and intein-encoded endonucleases. *In Vitro Cell. Dev. Biol. Plant* 38, 537–542

99 Ammann, K. (1999) *Towards Precision Biotechnology.* Center for International Development at Harvard University (CID) Available from: http://www.botanischergarten.ch/Precision-Biotechnology/Ammann-Towards-Precision-Biotech-1999.pdf

100 Smithson, J.B. and Lenne, J.M. (1996) Varietal mixtures: a viable strategy for sustainable productivity in subsistence agriculture. *Ann. Appl. Biol.* 128, 127–158

101 Gold, C.S. *et al.* (1989) Effects of cassava varietal mixtures on the whiteflies *Aleurotrachelus-socialis* and *Trialeurodes-variabilis* in Colombia. *Entomol. Exp. Appl.* 53, 195–202

102 Gold, C.S. *et al.* (1990) Effects of intercropping and varietal mixtures on the cassava hornworm, *Erinnyis-ello* L (Lepidoptera, Sphingidae), and the stem-borer, *Chilomima-clarkei* (Amsel) (Lepidoptera, Pyralidae), in Colombia. *Trop. Pest Manage.* 36, 362–367

103 Murphy, K.M. *et al.* (2007) Evidence of varietal adaptation to organic farming systems. *Field Crop Res.* 102, 172–177

104 Candolfi, M.P. *et al.* (2004) A faunistic approach to assess potential side-effects of genetically modified Bt-corn on non-target arthropods under field conditions. *Biocontrol Sci. Technol.* 14, 129–170

105 Marvier, M. *et al.* (2007) Meta-analysis of effects of Bt cotton and maize on nontarget invertebrates. *Science* 316, 1475–1477

106 Wolfenbarger, L.L. *et al.* (2008) Bt Crop effects on functional guilds of non-target arthropods: a meta-analysis. *PLoS ONE* 3, e2118

107 Naranjo, S.E. (2009) Impacts of Bt crops on non-target invertebrates and insecticide use patterns. 23 pp.

108 Thurston, H.D. *et al.* (1999) Traditional management of agrobiodiversity. In *Agrobiodiversity, Characterization, Utilization and Management* (Wood, D. and Lenne, J., eds), pp. 211–243, CABI

109 Taylor, M.E. and Morecroft, M.D. (2009) Effects of agri-environment schemes in a long-term ecological time series. *Agric. Ecosyst. Environ.* 130, 9–15

110 Gressel, J. (2007) *Genetic Glass Ceilings, Transgenics for Crop Biodiversity.* The Johns Hopkins University Press

111 Tylka, G.L. (2002) *Soybean Cyst Nematode Resistant Varieties for Iowa.* Iowa State University Ext Publ Pm-1649, pp. 1–26

112 Wolfe, M.S. *et al.* (2008) Developments in breeding cereals for organic agriculture. 1st EUCARPIA Meeting of the Section Organic Plant Breeding and Low-Input Agriculture 2007. *Euphytica* 163, 323–346

113 Slingerland, M.A. *et al.* (2006) Fighting Fe deficiency malnutrition in West Africa: an interdisciplinary programme on a food chain approach. *NJAS-Wagen J Life Sci* 53, 253–279

114 Altieri, M. and Nicholls, C.I. (2004) *Biodiversity and Pest Management in Agroecosystems* (2nd edn), Haworth Press

115 Altieri, M.A. (2002) Agroecology: the science of natural resource management for poor farmers in marginal environments. *Agric. Ecosyst. Environ.* 93, 1–24

116 Scherr, S.J. and McNeely, J.A., eds) (2007) *Farming with Nature: The Science and Practice of Ecoagriculture*, Island Press

117 Thurston, H.D. (1991) *Sustainable Practices for Plant Disease Management in Traditional Farming Systems.* Westview Press p. 280

118 Mitchell, P. (2008) Doubts about GM crops. *Science* 321, 489

119 Fedoroff, N. (2008) Seeds of a perfect storm. *Science* 320, 425

120 Ammann, K. (2008) In defense of GM crops, response to P. Mitchell's letter 'Doubts about GM crops'. *Science* 322, 1465–1466

121 IAASTD. (2007) International Assessment of Agricultural Knowledge, Science and Technology for Development. http://www.agassessment.org/.

122 Bull, A.T. (1996) Biotechnology for environmental quality: closing the circles. *Biodivers. Conserv.* 5, 1–25

123 Vitale, J. *et al.* (2008) The economic impacts of second generation Bt cotton in West Africa: empirical evidence from Burkina Faso. *Int. J. Biotechnol.* 10, 167–183

124 Herring, R.J. (2008) Whose numbers count? Probing discrepant evidence on transgenic cotton in the Warangal district of India. *Int. J. Multiple Res. Appr.* 2, 145–159

125 Gruere Guillaume, P. *et al.* (2008) *Bt Cotton and Farmer Suicides in India Reviewing the Evidence. IFPRI Discussion Paper 00808.* Environment and Production Technology Division

126 Illge, L. and Schwarze, R. (2009) A matter of opinion-How ecological and neoclassical environmental economists and think about sustainability and economics. *Ecological Economics* 68, 594–604

127 Nash, E. *et al.* (2009) Development of a model of data-flows for precision agriculture based on a collaborative research project. *Comput. Electron. Agric.* 66, 25–37

128 UN-Report-Common-Future, (1987) *Our Common Future, Chapter 2: Towards Sustainable Development.* United Nations, Geneva

129 Yokoi, Y. (2000) *Effects of Agricultural Activities on the Ecosystem.* OECD, Paris

130 Trewavas, A. (2008) The cult of the amateur in agriculture threatens food security. *Trends Biotechnol.* 26, 475–478

131 Swaminathan, M.S. (2001) Biotechnology, genetic modification, organic farming and nutrition security. *Phytomorphology* 51, 19–30

132 Ammann, K. (2007) Reconciling traditional knowledge with modern agriculture: a guide for building bridges. In *Intellectual Property Management in Health and Agricultural Innovation: A Handbook of Best Practices* (Krattiger, A., Mahoney, R.T.L., Nelsen, L., eds), pp. 1539–1559, MIHR, PIPRA

133 Ammann, K. (2008) Integrated farming: why organic farmers should use transgenic crops. *New Biotechnol.* 25, 101–107

134 Gressel, J. (2009) Organic Food. *Nat. Genet.* 41, 137

135 Paarlberg, R. (2000) Genetically modified crops in developing countries – promise or peril? *Environment* 42, 19–27

136 Paarlberg, R. (2009) The ethics of modern agriculture. *Society* 46, 4–8

137 Paarlberg, R.L. (2001) *The Politics of Precaution: Genetically Modified Crops in Developing Countries.* International Food Policy Research Institute

138 Paarlberg, R.L. (2002) The real threat to GM crops in poor countries: consumer and policy resistance to GM foods in rich countries. *Food Policy* 27, 247–250

139 Albihn, A., ed. (2001) *Recycling Biowaste – Human and Animal Health Problems*,

140 Ernst, W.G. (2002) Global equity and sustainable earth resource consumption requires super-efficient extraction-conservation-recycling and ubiquitous, inexpensive energy. *Int. Geol. Rev.* 44, 1072–1091

141 Granstedt, A. (2000) Reducing the nitrogen load to the Baltic Sea by increasing the efficiency of recycling within the agricultural system – experience of ecological agriculture in Sweden and Finland. *Landbauforschung Volkenrode* 50, 95–102

142 Granstedt, A. (2000) Increasing the efficiency of plant nutrient recycling within the agricultural system as a way of reducing the load to the environment experience from Sweden and Finland. *Agric. Ecosyst. Environ.* 80, 169–185

143 Kirchmann, H. *et al.* (2005) Recycling municipal wastes in the future: from organic to inorganic forms? *Soil Use Manage.* 21, 152–159

144 Korn, M. (1996) The dike pond concept: sustainable agriculture and nutrient recycling in China. *Ambio* 25, 6–13

145 Srivastava, R.C. *et al.* (2004) Integrated farming approach for runoff recycling systems in humid plateau areas of eastern India. *Agric. Water Manage.* 64, 197–212

146 Hadjigeorgiou, I. *et al.* (2005) Southern European grazing lands: production, environmental and landscape management aspects. *Livest. Prod. Sci.* 96, 51–59

147 Holst, H. (2001) Nature conservation and landscape management advice – the integration of nature conservation and landscape management into "goodfarming practice" as a future task. *Berichte Uber Landwirtschaft* 79, 552–564

148 Potts, S.G. *et al.* (2001) The utility of fundamental ecological research of plant–pollinator interactions as the basis for landscape management practices. Proc. 8th Int. Pollination Symposium, Pollination: Integrator of Crops and Native Plant Systems. *Acta Hortic.* 561, 141–152

149 Skar, M. *et al.* (2008) Diversity in a Norwegian agrarian landscape: Integrating biodiversity, cultural and social perspectives into landscape management. *Int. J. Biodivers. Sci. Manage.* 4, 15–31

150 Chrispeels, M.J. (2000) Biotechnology and the poor. *Plant Physiol.* 124, 3–6
151 Cohen, J.I. (2005) Poorer nations turn to publicly developed GM crops. *Nat. Biotechnol.* 23, 27–33
152 Cohen, J.I. and Galinat, W.C. (1984) Potential use of alien germplasm for maize improvement. *Crop Sci.* 24, 1011–1015
153 Cohen, J.I. and Paarlberg, R. (2004) Unlocking crop biotechnology in developing countries – a report from the field. *World Dev.* 32, 1563–1577
154 Dhlamini, Z. *et al.* (2005) *Status of Research and Application of Crop Technologies in Developing Countries, Preliminary Assessment.* FAO
155 Atkinson, R.C. (2003) Public sector collaboration for agricultural IP management. *Science* 302, 1152
156 Beachy, R.N. (2003) IP policies and serving the public. *Science* 299, 473
157 Mayr, E. (1991) The ideological resistance to Darwin theory of natural-selection. *Proc. Am. Philos. Soc.* 135, 123–139
158 Mesoudi, A. and Danielson, P. (2008) Ethics, evolution and culture. *Theory Biosci.* 127, 229–240
159 Azzone, G.F. (2008) The biological foundations of culture and morality. *Rendiconti Lincei-Scienze Fisiche E Naturali* 19, 189–204
160 Potrykus, I. (2003) Nutritionally enhanced rice to combat malnutrition disorders of the poor. *Nutr. Rev.* 61, S101–S104
161 Stein, A.J. *et al.* (2008) Genetic engineering for the poor: Golden Rice and public health in India. *World Dev.* 36, 144–158
162 Mayer, J.E. *et al.* (2008) Biofortified crops to alleviate micronutrient malnutrition. *Curr. Opin. Plant Biol.* 11, 166–170
163 Humphrey, J.H. *et al.* (1998) Neonatal vitamin A supplementation: effect on development and growth at 3 y of age. *Am. J. Clin. Nutr.* 68, 109–117
164 Depee, S. *et al.* (1995) Lack of improvement in vitamin-A status with increased consumption of dark-green leafy vegetables. *Lancet* 346, 75–81
165 Humphrey, J.H. *et al.* (1992) Vitamin-A deficiency and attributable mortality among under-5-year-olds. *Bull. World Health Organ.* 70, 225–232
166 Miller, H.I. (2009) A golden opportunity, squandered. *Trends Biotechnol.* 27, 129–130
167 Goulding, K.W.T. and Trewavas, A. (2009) Can Organic Agriculture Feed The World? In AgBioView Special Paper: AgbioWorld. http://www.agbioworld.org and http://www.botanischergarten.ch/Organic/Goulding-Can-Organic-Agriculture-Feed-2009.pdf
168 Greene, C. *et al.* (2009) Emerging Issues in the U.S. Organic Industry, U.S. Dept. of Agriculture, Economic Research Service. pp 36 EIB-55 (Report). http://www.botanischergarten.ch/Organic/Greene-USDA-Emerging-Issues-Organic-2009.pdf and http://www.ers.usda.gov/publications/eib55/eib55.pdf

Klaus Ammann
Sabanci University, Istanbul, Turkey