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Sustainable Agriculture: An Update

by

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[1] This is a revised and extended version of a contribution which appeared in *The Handbook of Sustainable Development* in 2007. This is a draft for the 2nd edition of this book to be published by Edward Elgar. It is being edited by G. Atkinson, S, Dietz, E Neumayer and M. Agarwala. Compared to the earlier version, it contains an extension of the section on organic agriculture, a new section on GM crops, and a rewritten conclusion.

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The *Economics, Environment and Ecology* set of working papers addresses issues involving environmental and ecological economics. It was preceded by a similar set of papers on *Biodiversity Conservation* and for a time, there was also a parallel series on *Animal Health Economics*, both of which were related to projects funded by ACIAR, the Australian Centre for International Agricultural Research. Working papers in *Economics, Environment and Ecology* are produced in the School of Economics at The University of Queensland and since 2011, have become associated with the Risk and Sustainable Management Group in this school.

Production of the *Economics Ecology and Environment* series and two additional sets were initiated by Professor Clem Tisdell. The other two sets are *Economic Theory, Applications and Issues* and *Social Economics, Policy and Development*. A full list of all papers in each set can be accessed at the following website:
http://www.uq.edu.au/economics/PDF/staff/Clem_Tisdell_WorkingPapers.pdf

For further information about the above, contact Clem Tisdell, Email: c.tisdell@economics.uq.edu.au

In addition, the following working papers are produced with the Risk and Sustainable Management Group and are available at the website indicated. *Murray-Darling Basin Program, Risk and Uncertainty Program, Australian Public Policy Program, Climate Change Program* :http://www.uq.edu.au/rsmg/working-papers-rsmg

For further information about these papers, contact Professor John Quiggin, Email: j.quiggin@uq.edu.au

Sustainable Agriculture: An Update

ABSTRACT

Provides some background on concerns about the sustainability of agriculture, outlines and discusses views about what constitutes sustainable agriculture and contrasts the sustainability of modern industrialised agriculture with that of traditional agriculture. Then the question is considered (taking into account the available evidence) whether organic agriculture is more sustainable than non-organic agriculture. Barriers to switching from non-organic to organic agriculture are mentioned. The development of agriculture usually has a serious negative impact on wild biodiversity. Whether or not more intensive agriculture would reduce the negative ecological footprint is unclear but many scientists believe it will do this. Globally, there has been a rapid expansion in the area planted with GM crops. Reasons are given why yields and returns from these crops may not be sustained, and why they may result in genetic losses liable to jeopardise sustainable development. Nevertheless, agriculturalists may still have an incentive to adopt unsustainable agroecosystems for reasons outlined. While genetic losses may be a threat to the long-term sustainability of agriculture, increasing scarcity of natural resources used in agriculture, such as water, and climate change may be more immediate challenges to the sustainability of agricultural production.

Keywords: biodiversity loss, genetically modified crops, industrialised modern agriculture, organic agriculture, sustainable agriculture, sustainable development.

JEL Classification: Q01, Q16, Q57.

Sustainable Agriculture: An Update

1. Introduction

Humans today are mostly dependent on agriculture for food, a necessity for their survival. This may explain why so much recent attention has been given to the question of whether agriculture, particularly modern agriculture, can maintain its current levels of production and those predicted for the near future. Furthermore, in the broader debate about conditions needed for sustainable development, there are concerns that the negative environmental spillovers arising from agriculture, especially modern or industrialised agriculture, will result in economic growth that cannot last (cf. Robertson and Swinton, 2005). Agricultural development also has changed and is altering the global pool of genetic resources in objectionable ways to many (e.g. loss of valued wildlife) and in a manner that may eventually undermine the sustainability of agricultural production itself.

Concerns about the ability of agriculture to provide sustainably for the needs of human populations are by no means new. For example, T.R. Malthus (1798) argued that, because of the law of diminishing marginal productivity, agriculture would be limited in its ability to feed an ever-increasing population. Later writers, such as David Ricardo (1817), argued that, with technical or scientific progress and sufficient capital investment in agriculture, the Malthusian problem would not be a real issue. Engels (1959) dismissed the Malthusian view passionately saying that ‘nothing is impossible to science’. However, in recent times, doubts have arisen about whether intensive agriculture based on high inputs of capital and high use of resources external to farms, and relying on ‘modern’ science, is really sustainable. It is claimed that application of modern industrialised methods that have produced much agricultural growth are bringing about environmental changes (and in some instances, social changes) that will undermine that growth eventually and depress that level of agricultural production (Conway, 1998; Altieri, 2000, 2004).

There are many different views of what constitutes agricultural sustainability and about the necessary conditions to attain it. Therefore, in this chapter, a brief outline and discussion of contemporary concepts of agricultural sustainability follows and the concepts mainly used in this chapter are stated. The sustainability of modern (industrialised) agriculture compared to traditional agriculture is then examined and this is followed by a discussion of whether organic agriculture is likely to be more sustainable than non-organic agriculture. Subsequently, given the large global area now allocated to the growing of genetically modified crops and the rapid increase in this area, attention is given to the possible consequences of this development for the sustainability of agriculture. Its consequences for the stock of biodiversity also receive special consideration. This leads on to a discussion of the relationship between agricultural development and wild biodiversity conservation, examination of the broad issues raised in this essay, and conclusions.

2. Concepts of Sustainable Agriculture

Consideration of concepts is important because they determine the focus of scientific enquiry. In relation to sustainable agriculture, we need to consider the following questions: What constitutes sustainable agriculture? Can it be achieved? If so, how can it be achieved? Is it desirable?

Several concepts of sustainable agriculture exist in the literature, most of which have been reviewed by Christen (1996). Christen (1996) claims, as a result of his review, that sustainable agriculture should have the following attributes: (1) ensure intergenerational equity; (2) preserve the resource base of agriculture and obviate adverse environmental externalities; (3) protect biological diversity; (4) guarantee the economic viability of agriculture, enhance job opportunities in farming and preserve local rural communities; (5) produce sufficient quality food for society; and (6) contribute to globally sustainable development.

Whether or not it is desirable for agriculture to possess all these attributes can certainly be debated. Few of these objectives may be absolutely desirable. For example, should rural communities be sustained at any cost? Furthermore, it may be impossible to fulfil all these desired objectives simultaneously. Consequently, some formulations of the desired sustainability attributes of agriculture may constitute little more than a pipe dream.

In this essay, the main focus will be on the maintenance or sustainability of agricultural product (or yields) as an indicator of sustainable agriculture and particular attention will be given to whether modern industrial-type agricultural systems are less sustainable than traditional agricultural systems.

At the outset, it should be recognised that sustainability of yields is only one valued attribute of the performance of agricultural systems. In comparing systems, many other attributes can also count such as the level of the yields or returns and the income distributional consequences of the farming system (cf. Conway, 1998, p.174). Furthermore, whether a particular agricultural system continues to be adopted can be expected to depend not only on biophysical factors but also on its social consequences.

Even if differences in the sustainability of yields is the sole basis for choosing one agricultural system rather than another, anomalies can arise, as illustrated in Figure 1, and as discussed more generally by Tisdell (1999a) in relation to sustainable development. In Figure 1, the curves marked 1, 2, 3 and 4 show the performance of four alternative agricultural techniques over time for a finite relevant time-period. Only systems 1 and 2 exhibit sustainability of yields. However, system 4 is superior to both of these because it results in greater yields in every period. From some perspectives, it is even possible that system 3 is socially preferable to systems 1 or 2 (Tisdell, 1999a).

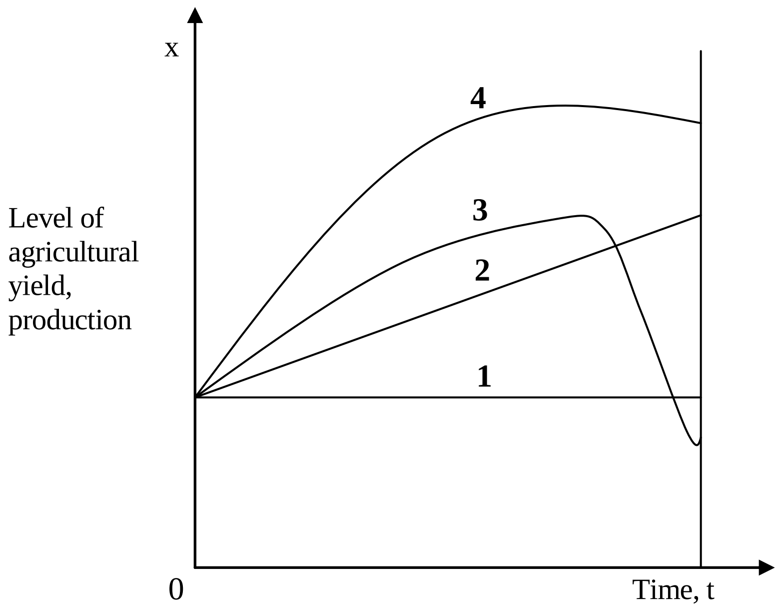

Figure 1. Comparisons of some agricultural yield patterns – agricultural sustainability is not an absolute virtue.

Figure 1 makes it clear that sustainability of agricultural yields or production is not an absolute virtue. However, that does not mean that sustainability is unimportant. It can be a private and social folly to obtain considerable short-term benefit while ignoring or inadequately considering the long-term consequences of current actions. There is a danger that modern economies will do just that for reasons outlined in the literature about sustainable development that has evolved in recent times.

3. Sustainability of Modern Industrialised Agriculture versus Traditional Agriculture

Conway (1985, 1987) and Altieri (1995) have argued that traditional agricultural systems are likely to be more sustainable than modern industrialised agricultural systems. However, both modern and 'traditional' systems can be diverse and agricultural systems are still evolving. Therefore, while the above observation seems to hold broadly, it needs some qualification as, for example, pointed out by Pretty (1998). For instance, although slash-and-burn or shifting agriculture (and early forms of agriculture) can be relatively sustainable, when rotation cycles are sufficiently shortened, yields decline and it no longer remains sustainable (Ramakrishnan, 1992).

Methods for undertaking modern agriculture can vary. Technologies are available that can increase the sustainability of yields in modern agriculture compared to widely used methods. These include intercropping, appropriate crop rotations, agroforestry, sylvo-pastures, green manuring, conservation tillage (low or no tillage), biological control of pests rather than by the use of pesticides, and integrated pest management (Conway, 1998, p.170; Conway and Barbier, 1990). These technologies, however, are not dominant in modern agriculture and do not replicate traditional agroecosystems.

Altieri (2004, p.35) estimates that 10-15% of all land under cultivation in the developing world is still cultivated using traditional cultivation methods. These are a result of a complex co-evolutionary process between natural and social systems. They are usually place-specific and well adapted to local conditions. Altieri's estimates also indicate that a very low percentage of cultivated land globally is cultivated using traditional methods.

On the whole, most modern industrialised agricultural systems differ significantly from those adopted in traditional agriculture. Traditional agroecosystems are, as a rule, characterised by several features that help maintain yields. These include high species numbers (considerable biodiversity); use of local varieties of crops of wild plants and animals well adapted to local conditions; maintenance of closed cycles of materials and little waste because of effective recycling practices; pest control through natural levels of external inputs; pest control through natural biological interdependencies; high structural diversity in space (intercropping) and in time (crop rotations) and a high degree of adaptation to local microenvironments (cf. Altieri, 2004; Gliessman, 1998). They tend also to be labour-intensive and have evolved as a result of local knowledge.

Modern industrialised agrosystems usually lack most of the attributes associated by Altieri (2004) and others with traditional agrosystems. They are characterised by use of few species on the farm (often only one farmed species); use of varieties of crops not developed locally to suit local conditions (for example, varieties developed by companies, often multinational ones, specialising in plant breeding), the presence of monoculture, and relatively open cycles resulting in considerable imports of materials to farms as well as substantial exports of materials from them in the form of products and wastes.

The openness of most modern industrialised agricultural systems compared to the relatively closed cycles of most traditional and organic agricultural systems creates sustainability problems for modern agriculture. Potential obstacles to sustaining yields from modern agriculture include the following.

1. Possible lack of future availability of many external inputs, such as fossil fuels and some types of fertilizer, because global stocks are finite and they are exhaustible and non-renewable (Ewel, 1999).

2. Reduced soil fertility due to long-term use of chemical fertilisers, e.g. increased acidity of the soil, and impoverishment of soil structure due to frequent cultivation and lack of return of organic matter to the soil to provide humus (Ewel *et al*., 1991). Frequent cultivation and lack of intercropping may also encourage soil erosion eventually reducing soil depth so much that yields fall.

3. The widespread use of chemical pesticides and herbicides in modern agriculture can create sustainability problems. For example, resistance of pests to pesticides tends to develop in the long term. Furthermore, some pesticides and weedicides have adverse impacts on soil flora and fauna which can negatively impact on farm productivity.

4. Given the urbanised structure of modern societies (and the fact that the degree of urbanisation is continuing to rise, especially in developing countries) large amounts of produce sent by farms to urban areas deplete or ‘mine’ soils on farms. Little of the wastes from off-farm consumption is recycled to farms, mainly because of the high transport and collection costs involved in their return to agricultural land. This large exported surplus of modern agriculture entices agriculture into the high use of artificial external inputs. Therefore, growing urbanisation may create a major barrier to the development of

sustainable agriculture in modern times and makes it difficult, if not impossible, to return to traditional agroecosystems.

5. Modern agriculture is often a source of unfavourable environmental externalities or spillovers. This is because of its open-cycle character and the type of cultivation and husbandry practices adopted. It can pollute shared water bodies, cause salting or water logging of soils over extensive areas and seriously disrupt hydrological cycles. Furthermore, the uncoordinated use of shared water bodies by agriculturalists can threaten the maintenance of their production. This can happen, for instance, if farmers initially use water from underground aquifers at a rate faster than their rate of recharge.

Modern agriculture is associated with an overall global reduction in crop varieties and breeds of livestock. This is a result of: (1) growing globalisation (the extension of free market systems geographically and easier access to knowledge globally); and (2) the development of food production technologies and methods that allow increased artificial manipulation of micro-environments in primary food production; and (3) more widespread trade that reduces dependence of local agriculture on local material inputs (Tisdell, 2003). Market extension encourages greater specialisation in agricultural production by farmers and the adoption of specialised breeds of livestock or varieties of crops and results in path dependence, as pointed out by Tisdell (2003). Consequently, agricultural production systems become more specialised. This reduces the scope for their co-evolution at the local rural level and agricultural innovations have primarily become dependent on large specialist corporations supplying inputs to farms and/or marketing farm produce (Heffernan, 2000).

The change in the organisational structure of agriculture involving greater dependence on external inputs supplied by large corporations tends to reinforce the dependence pattern. Sellers of agricultural inputs focus their efforts and research on ways to sell greater external inputs to agriculturalists. Scientific research on non-traded inputs and products is liable to be neglected. Local knowledge of farmers may be lost and local development of agroecological systems may cease or be curtailed. These factors, as well as advertisements and other means of marketing, may bias the agricultural development path in favour of open-cycles. In addition, urban 'bias' (Lipton, 1977) in agricultural production to serve urban areas grows as urbanisation gains momentum. Government policies may encourage agricultural production for sale to urban areas (or even international export) rather than for subsistence (cf. Kiriti and Tisdell, 2003).

Table 1 summarises those attributes of modern agriculture that are liable to make it less sustainable than traditional agriculture. It is based on the representative typology adopted, for example, by Altieri (2004). It raises the question of why has there been such a swing to modern industrialised agriculture even though it lacks many sustainability properties.

However, before discussing this, let us briefly consider the sustainability of organic agriculture compared to non-organic agriculture.

Table 1 Typical attributes of modern industrialised agriculture and of traditional subsistence agriculture.

Modern Agriculture	**Traditional Agriculture**
1. High level of external inputs. Low level of self-sufficiency	1. Low level or no external inputs. High degree of self-sufficiency
2. Open-cycle agrosystems. Encouraged by market extension and urbanisation	2. Closed cycle agro-systems. No or little marketing
3. Loss of agricultural biodiversity. Loss of co-evolution	3. Retention of agricultural biodiversity. Evolution of genetic material by co-evolution
4. High degree of export of wastes resulting in adverse externalities – pollution.	4. Low degree of export of wastes. Low external impacts
5. Significant reduction in on-farm natural resources due to export of products and 'wastes'	5. Little reduction in on-farm natural resources
6. Dominance of monocultures and specialised forms of agricultural production	6. Mixed systems of agriculture production e.g. polyculture.
7. Market-dominated. Increasingly dominated by global markets	7. Subsistence or semi-subsistence use dominates

4. The Sustainability of Organic versus Non-organic Agriculture

The demand for organic agricultural produce has increased in more developed countries (Lampkin and Padel, 1994). Reasons for this include the following.

1. Organic produce is widely believed to be healthier than food produced by non-organic agricultural systems.

2. A high degree of sustainability is attributed to organic agriculture compared with agroecosystems that extensively use chemicals, such as pesticides and artificial fertilisers.

3. Organic agriculture is believed to be more environmentally friendly than modern agriculture, including less threatening to wildlife.

However, varied organic agroecosystems are possible and not all replicate traditional farming systems. For example, organic agriculture can depend on fossil fuels for energy and on high import of organic material to farms. There may be a high degree of specialisation in farm production and significant agricultural biodiversity loss. The use of some organic materials can pose health risks unless appropriate care is taken; for example, the use of human excreta as fertiliser. Wildlife may be threatened by habitat change, although the degree of change may be less than with industrialised modern agriculture.

Some forms of organic agriculture, for example, cattle and sheep grazing in parts of Australia involve extensive land use. Nevertheless, such land-uses have been implicated in loss of wild species and significant habitat changes (Tisdell, 2002, p.91).

While organic farming is likely to be more favourable to the conservation of wildlife than non-organic farming (for example, because it does not use chemical pesticides), that does not mean that organic farming is favourable to biodiversity in the wild. Organic agriculture usually involves major changes in natural habitat or, in the terminology of Swanson (1994, 1995), much land conversion. This is an important factor in reducing biodiversity in the wild. Furthermore, not all organic farmers are favourably disposed towards wildlife (McNeely and Scherr, 2003, p.91).

Opinions differ about the comparative level of yields from organic compared to conventional agriculture. Nevertheless, it is widely accepted that yields per hectare per year are lower for organic agriculture (Pretty, 2008, pp. 455-457; Pimental et al., 2005). In particular, these yields and returns tend to be lower during the transition period from conventional to organic agriculture (Pimentel et al., 2005, p.576) and this is a deterrent to switching to organic agriculture (Tisdell, 1999b, pp. 48-50; Wilson and Tisdell, 2001). A factor contributing to this is the use of green manure in some forms of organic agriculture. This tends to reduce the frequency with which saleable crops can be grown in a year compared to cropping using chemical fertilisers.

Pretty (2008, p.455) argues that because yields are lower for organic compared to conventional agriculture, it requires more land to produce the same amount of food as conventional agriculture and results in greater land conversion and loss of natural capital. However, the situation is complicated. It is true that organic agriculture does not eliminate all the negative effects of agriculture. For example, according to Pimental et al (2005, pp. 577-578), nitrate leaching can still be significant for organic agriculture. Nevertheless, organic agriculture does eliminate some of the adverse environmental spillovers from conventional agriculture, such as from pesticide use, and can have positive effects in improving soil biology and soil organic matter, both of which help maintain or increase natural or agricultural capital. It also might be noted that as non-renewable resources used in agriculture become scarcer and more expensive this will favour organic agriculture, even though it is labour-intensive.

5. Agriculture and the Conservation of Wild Biodiversity

Many conservationists favour protection of wild biodiversity as an ingredient of sustainability. Unfortunately, the development of agriculture, particularly modern agriculture, has reduced this biodiversity and threatens to reduce it even further (McNeely and Scherr, 2003, Ch.4; Pretty, 1998, pp.62-65; Tisdell, 1997).

The mechanisms by which agricultural expansion (especially of modern agriculture) does this are varied and complex. They include:

1. Land clearing and conversion which results in loss of habitat for many wild species (cf. Swanson, 1994, 1995).

2. Greater uniformity of habitat with loss of diversity in niches and loss of niches for wild species (Tisdell, 1999c, Ch.4).

3. Increased competition of agriculturalists with wild species for natural resources resulting in less availability of these resources to wild animals and/or the destruction of wild species by agriculturalists as pests.

4. Poisoning of wildlife as a side-effect of agricultural pesticide use.

5. The release of pollutants from farms that poison wildlife or alter their natural environments in an unfavourable way. For example, eutrophication of water bodies as a result of farm run-off of nutrients can lead to the demise of some wild species.

6. Hydrological changes brought about by modern farming can seriously affect wild biodiversity. For example, farm irrigation schemes can greatly reduce the level of flows and cyclical patterns of river flows and this can adversely affect species dependent on the previously natural rhythms, for example their breeding, and lead to loss of seasonal wetlands, and even permanent wetlands. Regeneration of the red river gum on the Murray River basin in Australia, for instance, is threatened by the fact that this river is heavily utilised for human use (mostly agricultural) and the variability of its flows has been much reduced. Red river gums are important for the survival of several Australian wildlife species. In addition, the breeding of several species of wild duck is hampered by reduced frequency of flooding. Or to give another example, removal of trees with the aim of increasing agricultural productivity (an aim not always realised in this case) often leads to the death of other trees and vegetation in areas subject to dryland salinity. Furthermore, streams and other water bodies in the area may become very saline. This can result in loss of native species as has occurred in parts of Western Australia.

Because agriculture (broadly defined) accounts for the use of such a large area of land globally (McNelly and Scherr, 2003, p.32; Tisdell, 2004) and, politically at least, large increases in protected areas are unlikely, maintenance of wild biodiversity is highly dependent on conservation of wildlife outside protected areas. With this in mind, McNeely and Scherr (2003, Ch.5) have advocated the development of ecoagriculture, this is the development of agriculture that is more favourable than currently to the protection of wild biodiversity and natural ecosystems. They outline policies that might be adopted to promote ecoagriculture. However, some of these policies may require more in-depth consideration. For example, they recommend increasing farm productivity as a means to reduce land conversion to agriculture and give a favourable impression of Green Revolution technology saying that it "almost certainly helped to slow land conversion in the developing world" (McNeely and Scherr, 2003, p.136). However, while it certainly helped to provide more food for people, it is by no means clear that it had positive consequences for wild biodiversity conservation.

In fact, a difference in views appears to exist among conservationists about which forms of agriculture are most favourable to nature conservation. Some conservationists favour intensive agriculture and silviculture on the basis that this is highly productive compared to extensive agriculture or silviculture (FAO, 2003), whereas others favour the opposite policy.

Those favouring intensive agriculture or silviculture believe that, although major habitat change would occur in the farmed or plantation area, this will enable a larger land area to remain in a natural state than if extensive agriculture and silviculture is practiced and that this will conserve more biodiversity in the wild than otherwise. However, the situation appears to be quite complex and needs more intensive evaluation before coming to a firm policy conclusion.

6. GM Crops and Agricultural Sustainability

Despite concerns in several countries (particularly European nations) about the development and planting of genetically modified (GM) crops, the global area planted to such crops is now substantial and is increasing at a rapid rate. The global area planted with biotech crops in 2011 was estimated by James (2011, p.7) to be 160 million hectares, an increase of 12 million hectares on the figure from 2010. The global area planted with GM crops has increased every year since they were first planted in 1996. The USA accounts for the largest plantings of biotech crops (43% of the global area in 2011) followed by Brazil, Argentina, India and Canada, in that order (James, 2011). According to James (2011), the area planted with such crops in developing countries is increasing rapidly.

Presumably, the main reason why farmers plant GM crops rather than non-GM crops is that they believe that this will increase their net returns. In many cases also yields are expected to rise. While the planting of GM crops may increase yields and returns in the short to medium term, there is a risk that these will decline in the long-term.

The widespread adoption of GM crops could ultimately threaten agricultural sustainability, food security and sustainable development. Consequently, three matters will be explored here, namely (1) reasons why the returns and yields from GM crops can be unsustainable and/or lower than anticipated; (2) the possible negative effects of the introduction of GM crops on the conservation of the existing stock of genetic capital; and (3) the potential negative impact of this on the welfare of future generations. Consider each of these aspects in turn.

The level and the sustainability of returns and yields from GM crops

There are several reasons why returns from GM crops may be lower than anticipated by farmers and others and why the yields (and) returns from such crops may not be sustained in the long-term. First, those firms marketing GM seed are likely to be keen to emphasise the positive attributes of their produce. Farmers may consequently obtain a distorted picture of the benefits of growing GM crops and may have insufficient knowledge to make an independent rational choice about whether to grow a GM crop or a non-GM crop. Secondly, if a GM crop increases yields and reduces the per unit cost supplying a particular commodity, it will tend to reduce its price, other things being held constant. For example, the use of herbicide-resistant GM soya beans could have this effect in the short to medium term.

In addition to these factors, there are several biological reasons why the introduction of GM crops may result in a lower than anticipated economic benefit from GM crops and why this benefit may not be sustained. They include the following phenomena:

- When one of more attributes of an organism are favourably strengthened, this often results in the weakening of other desirable attributes. Thus genetic engineering (as well as selective breeding) often requires some trade-off between attributes. An economic problem is involved (Tisdell, 2009, pp. 346-348) and the economic benefit of GM crops will be exaggerated if losses in desirable characteristics are not fully accounted for. For example, it has been found that GM poplars in China which have been modified to reduce their lignin content (thereby, increasing their suitability for proper production) are more susceptible to wind damage and to attacks by some type of beetles (Lu, 2009).

- In some cases, scientists only come to know of negative side-effects of some GM crops once they are in use. For example, it has been found that some types of GM cotton produce exudates on their roots which makes them prone to fungal attach (Liu, 2009). This negative side-effect was unknown prior to their release.

- Another problem is that genetic modification of a crop to resist one pest can make it more vulnerable to attacks by other pests because inter-species competition is reduced. As a result, other pests are likely to expand their realized niches and the level of economic returns from the GM crop are likely to be lower than anticipated and to decline with the passage of time. Zhao et al. (2011) have found that secondary pest in Bt cotton have increased in China and pesticide use has not fallen.

- The ecological and economic fitness of a GM crop can decline in the long-term as a result of natural selection. For example, if the genetic modification is designed to control a particular pest, in the long-term the pest may evolve to resist the modification (Andow and Zwahlen, pp 203-206).

- Crops which have been modified genetically to be herbicide resistant provide a further example of the possible declining ecological and economic fitness of GM crops. The use of such crops can result in an increase in the long-term of herbicide-resistant weeds in these crops and as a result of cross pollination, the wild relatives of cultivated GM crops may become a serious weed. For example, GM rice is prone to cross-fertilise with wild rice and problems with wild rice as a weed in rice crops can increase (Lu and Fu, 2009).

The consequences of GM crops for the stock of genetic capital

One of the concerns which has been raised about the introduction of GM crops is that they may unfavourably alter the composition of genetic capital. These crops can result in loss of existing crop varieties as a result of their economic replacement by GM crops. To the extent that the introduction of GM crops leads to the extension and intensification of agriculture, this is likely to reduce biodiversity in the wild (compare Swanson, 1997). Furthermore, where cultivated GM crops have wild relatives, cross-fertilization may occur thereby altering the wild genetic stock (Andow and Zwahlen, 2006).

Opinions differ about the extent to which the presence of GM crops reduces biodiversity and threatens sustainable agriculture and sustainable development (Uphoff, 2007). In some cases, genetic engineering may save some types of crops from extinction. For example, the development of GM papaya so that it is resistant to the ring spot virus could be an example (Gonsalves et al., 2007). However, individual cases do not give much lead to the overall situation. It seems most realistic to consider the effects on biodiversity of the introduction of a new GM crop to be akin to the introduction of an exotic species (Wolfenberger and Phifer, 2000). Such introductions very often lead to a loss of existing biodiversity and as in the case of introduced domesticated organisms, the loss tends to be greater the higher are the economic returns from the use of GM organisms.

Nevertheless, it needs to be stressed that the introduction of GM crops is not the only contributor to losses in the existing genetic stock, including reduced agrobiodiversity. Other genetic developments of agricultural organisms have had similar effects, for example, seed varieties developed as part of the ‘Green Revolution’. In addition, socio-economic processes, such as market extension (Tisdell, 2003), have taken their toll on biodiversity conservation. Undoubtedly, considerable loss in agrobiodiversity was experienced prior to the release of GM organisms but there are concerns that

GMO releases will accelerate biodiversity losses and reduce the economic value of the remaining genetic capital.

The potential negative impact of GM crops on the welfare of future generations

There are concerns that if the use of GM crops reduces genetic diversity and if their fitness is not maintained, this will eventually result in agricultural production being lower than it need be and may threaten the welfare of future generations. Varieties of crops may be lost which would result in greater yields should the fitness of GM crops decline. Both inherited and natural genetic material may be permanently lost as a result of the widespread use of GM crops.

The threat to the welfare of future generations as a result of genetic erosion and reduced sustainability of agricultural production due to the introduction of GM crops is inadequately accounted for by economic development models which discount future levels of per capita utility or economic benefits (Tisdell, 2011). This potential problem is of greatest concern for the genetic modification of crops which are staples or which are a large or an important component in the consumption of agricultural commodities. Particularly given the high degree of uncertainty about ecological changes following the introduction of GM crops, determining optimal development paths by taking into account the possible trajectory of human welfare remains a daunting task.

7. Discussion

If the productivity of modern industrialised agriculture is unsustainable, why have such agroecosystems been so widely adopted and why do they continue to be adopted given private and social misgivings about them? Let us consider such a choice from the viewpoint of an individual agriculturalist and from a social perspective.

Agriculturalists may adopt modern industrialised agroecosystems for the following reasons:

1. They may be unaware of the degree to which these systems lack sustainability. Sellers of external agricultural inputs that contribute to this lack of sustainability have no incentive to inform potential buyers about this aspect.

2. High levels of present returns available in the short- to medium-term from modern agriculture may be attractive to farmers. They may, for example, discount their future returns at a high rate. The aim of many is to obtain funds to educate their children so they can earn higher incomes by leaving agriculture. Furthermore, if a higher return on funds can be obtained from investment of the capital tied up in an agricultural property by investing it elsewhere in the economy, there is an economic incentive to realise the capital (for example, by mining farm resources) and invest the capital elsewhere. (Clark, 1976).

3. Modern economies are cash-based economies. Farmers need to obtain cash to educate their children, obtain health services, obtain other non-agricultural commodities and pay government taxes. To do this, farmers must market produce. When market transaction costs and other factors are taken into account, the costs of using traditional methods of production to supply agricultural produce to markets may exceed that from the use of modern agricultural techniques. Market competition may make it uneconomical for farmers to use traditional techniques, even if modern techniques result in higher costs in the long-term (Tisdell, 1999b, p.48-53). The market itself becomes a barrier to the retention of traditional agricultural technologies.

4. Government policies appear to encourage the development of commercial agriculture via the nature of their extension services, information provision, the direction of agricultural research and, in some cases, subsidies for external inputs. This may partly reflect urban bias (Lipton, 1977) since urban populations depend on the agricultural surplus supplied by commercial agriculture.

5. In some societies, power relationships and entitlements in families may bias agricultural development in favour of commercial crops produced from modern agroecosystems. For instance, in some parts of Africa, husbands have control of cash earned from cash crops and control of crops by women is mostly restricted to subsistence crops (Kiriti and Tisdell, 2003, 2004).

6. Environmental spillovers from modern farming practices will be ignored by farmers in their private decisions unless their costs or benefits are internalised. Farm costs still do not reflect many of these externalities.

A second pertinent question is why do modern agrosystems have so much social support if they are unsustainable. Reasons may include the following: current generations may not be as much concerned about the fate of future generation as is sometimes imagined; their practical concern may extend to only two or three future generations (see, for example, Pearce, 1998, pp. 70-71). Or again, it may be widely believed that scientific advances will be able to address any agricultural sustainability problems that may arise in the future. Furthermore, special interest groups and governments may be myopic in their outlook.

The increasing dominance of economic liberalism based on market operations is likely to reinforce the dominant position of modern industrialised agriculture. Increasingly governments have vacated the area of agricultural R&D in favour of private corporations and have passed property rights legislation covering new plant varieties and transgenic material. These provide incentives to private industry to develop and market new genetic material. This is likely to increase the dependence of agriculture on external inputs and may further reduce agricultural biodiversity (Altieri, 1999). In a market system, suppliers of agricultural materials are interested in promoting open agricultural systems rather than closed ones. This is because the more closed an agricultural system, the fewer are the sales of agricultural suppliers.

8. Concluding comments

There are fears that modern agriculture is resulting in the irreversible loss of natural and heritage-type agricultural capital. Natural capital includes soil depth and quality as well as some of the natural genetic stock. Heritage agricultural capital includes crop varieties developed by genetic selection by humans (for example, heirloom crop varieties) and different breeds of domesticated animals. The myopic development of modern agriculture can irreversibly reduce the existing stock of both types of this capital. Hence, modern agricultural development is liable to reduce the range of fall-back agricultural options available to future generations when, and if, modern agricultural methods are no longer able to sustain yields. Consequently, the welfare of future generations is likely to be less than it would have been if the development of modern agriculture had taken greater account of the conservation of natural and heritage capital.

Note that addressing sustainability problems associated with agriculture is not just a matter of adopting appropriate policies to deal with negative environmental externalities and inappropriate use of common pool resources. Agricultural capital is being irreversibly lost independently if such economic failures. This loss can be a major contributor to lack of sustainability resulting from the process of agricultural development. Hediger and Knickel (2009, p.308) emphasised this point. The irreversible loss of this capital has its roots in the discounting of future net benefits and is compounded by the existence of ignorance and uncertainty. Some of the consequences of this for sustainable development are analysed in Tisdell (2011). Nevertheless, as mentioned above, the policy consequences of the above observations depend upon value judgements about how much weight should be given to the welfare of future generations.

Modern agricultural methods have resulted in large increases in agricultural production. Since 1960 growth in global food production has, on average outpaced global population growth (Hazell and Wood, 2008). There is nevertheless, no guarantee that this situation can be sustained. Apart from the types of sustainability problems mentioned above, increasing scarcity of resources utilized in agriculture, such as water, is likely to restrict growth in agricultural output (Pretty, 2008, pp. 449-450). Furthermore, increased agricultural output has been achieved at substantial environmental cost and has diminished the stock of some non-renewable agricultural capital. At present, the environmental costs of agricultural expansion are most apparent in developing countries. The area of land allocated to agriculture has shown a strong upward trend in developing countries since 1960 whereas this area has fallen somewhat in industrialised countries (see Pretty, 2008, Fig. 2(a), p. 449). A controversial example of loss of wild biodiversity as a consequence of agricultural extension in developing countries includes the conversion of tropical forests to oil palm plantations (Swarna Nantha and Tisdell, 2009). In addition, increased intensification of agriculture has occurred in most developing countries in this period. This is reflected, for example, in the increased per hectare application of artificial fertilizers and pesticides in these countries. This is a trend which first manifested itself as the Green Revolution procedure (Alauddin and Tisdell, 1991). A further major challenge for the sustainability of agricultural production in the onset of climate change (see, for example, Chapters 28 and 29 in this book). This has not been addressed in this chapter.

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