

# Strategies and models for agricultural sustainability in developing Asian countries

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The green revolution of the 1960s and 1970s which resulted in dramatic yield increases in the developing Asian countries is now showing signs of fatigue in productivity gains. Intensive agriculture practiced without adherence to the scientific principles and ecological aspects has led to loss of soil health, and depletion of freshwater resources and agrobiodiversity. With progressive diversion of arable land for non-agricultural purposes, the challenge of feeding the growing population *without*, at the same time, annexing more forestland and depleting the rest of life is indeed daunting. Further, even with food availability through production/procurement, millions of marginal farming, fishing and landless rural families have very low or no access to food due to lack of income-generating livelihoods. Approximately 200 million rural women, children and men in India alone fall in this category. Under these circumstances, the evergreen revolution (pro-nature, pro-poor, pro-women and pro-employment/livelihood oriented ecoagriculture) under varied terms are proposed for achieving productivity in perpetuity. In the proposed 'biovillage paradigm', eco-friendly agriculture is promoted along with *on-* and *non-farm* eco-enterprises based on sustainable management of natural resources. Concurrently, the modern ICT-based village knowledge centres provide time- and locale-specific, demand-driven information needed for evergreen revolution and ecotechnologies. With a system of 'farm and marine production by masses', the twin goals of ecoagriculture and eco-livelihoods are addressed. The principles, strategies and models of these are briefly discussed in this paper.

**Keywords:** agricultural sustainability in developing countries; evergreen revolution; reconciling agriculture and ecosystems.

## 1. AGRICULTURAL SUSTAINABILITY

### (a) *Environment and population*

In the simplest sense, agricultural sustainability connotes the maintenance of the quantity, as well as the quality of agricultural produce over very long periods of time *without* signs of fatigue. Agriculture includes both crop and animal husbandry and fisheries to produce the food requirements of humankind. The farm animals also must get their share of feed and forage. Apart from good seeds, agricultural productivity depends on soil health, irrigation water quality and quantity, clean atmosphere of proper composition of carbon dioxide, nitrogen and oxygen, in addition to diverse micro-organisms, pollination insects, birds, earthworms, farm animals and other non-domesticated flora and fauna (Swaminathan 1983). Discussing the scenario of global agriculture, Swaminathan (1996a,b) has comprehensively addressed the scientific, technological, ecological, economic, social, gender and ethical dimensions of sustainable agriculture and food security. The domesticated crops and animals depend on ecosystem services for their productivity. So long as the ecosystems, particularly the ecological foundations such as soil, fresh water, biodiversity, renewable energy and atmosphere remain intact, agricultural sustainability (i.e. the quantity and quality or agricultural productivity over long periods of time) is not likely to be

adversely affected. The ecological footprint would remain within the population supporting capacity of the planet Earth. However, anthropogenic pressures on the environment are rising to the point of causing 'ecological overshoot' (Wackernagel *et al.* 1999, 2002) in many regions of the world. The human population, particularly in developing Asian and African countries, is growing at an exponential rate. There is also the coexistence of unsustainable life styles and unacceptable poverty. Consequently, humankind has been facing serious ecological and social problems: growing damage to basic life support systems of land, water, forests, biodiversity, oceans and the atmosphere. Further, global warming with consequent changes in temperature, precipitation and sea level as well as changes in the ozone layer leading to a higher concentration of ultraviolet radiation impinging on living organisms substantially enhances abiotic stress on all living beings including the beneficial microbes, crop plants and farm animals (Swaminathan 1990). The climate change-related natural disasters (e.g. heavy downpours causing floods alternating with long spells of drought, etc) have become frequent, and their destructive potential also seems to have increased (Emanuel 2005). These have obvious implications for sustainability of agriculture.

The social problems have arisen largely from the rich-poor divide, leading to the coexistence of unsustainable lifestyle on the part of approximately one billion people in the developed world, and unacceptable poverty of another billion, largely in the developing countries.

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Also, economic growth is taking place at the expense of employment, leading to jobless economic growth. A vicious downward spiral between accentuating poverty and environmental degradation is engulfing most of the developing countries of our planet. Under these circumstances, the Malthusian view that population increase beyond the Earth's carrying capacity would cause environmental degradation and outrun the growth of food production gains credence. However, it is also true that modern science and technology have so far thwarted the realization of Malthusian predictions (Trewavas 2002), despite the fact that the planet Earth now has over six billion people, a population approximately six times greater than in 1798, when Malthus wrote his *Essay on the principle of population*. The green revolution of the 1960s in India was one such example in which Mendelian genetics and plant breeding accelerated the cereal production at a rate higher than the population growth rate during 1965–2000 (Swaminathan 1993, 1996b, 1999). During the last 35 years (1965–2000), India's population has increased from approximately 450 million to just over 1000 million—an increase of 2.2-fold. The cereal production went up approximately from 75 Mt in 1965 to 207 Mt in 2005, just keeping ahead (approx. 2.8-fold increase) of the rate of population growth. However, since the mid-1980s, visible signs of degradation of the soil quality in the predominantly irrigated agricultural regions of India together with yield stagnation have started appearing. The yield plateau has not, however, been accompanied by a similar trend in the population growth; on the other hand, 17–18 million children are added annually and this raises questions on food security linked with agricultural sustainability. Two-thirds of India's agriculture is in rainfed areas and therefore agriculture is referred to as a 'gamble with monsoon'. In more recent years, monsoon has become even more erratic on account of possible climate change-induced vagaries. Occurrence of too much rain in a short time or of no rain at all over long periods, as also its unpredictable distribution pattern, adversely affects farming activities. Consequently, agricultural operations are not under human control to the extent desired. Therefore, the cost–risk–return structure of farming shapes farmers' decisions on the cropping pattern as well as investment on inputs.

**(b) Could the green revolution have been sustainable?**

India's dramatic gains in cereal production from the green revolution could have indeed become reasonably sustainable, had the successive Indian governments since 1968 heeded the 'precautionary principle' put forward by Swaminathan (1968) and also had the political will for implementing the population control measures through appropriate incentives for small families, quota of benefits for small families and quota for female children in higher education and employment (this would have also averted the social evil of selective infanticide of female foetuses and promoted still smaller families through highly educated women!). In the larger interest of livelihood and food security, the people and

the Government of India could have even legislated that the couples who got married after 1970 (the green revolution era) should avoid having more than *two* children. The point is that the population growth that has more than doubled since 1968 has greatly diluted the gains from green revolution in terms of *per capita* availability of cereal grains. However, this picture is complicated by lack of access to food by over 200 million Indians. Much has already been said about the paradox of 'mountains of grains on the one hand, and millions of hungry people' on the other (Swaminathan 2004a). Even in this context, containing the population growth must be accorded highest priority.

The precautionary principle put forward by Swaminathan (1968), who has been cited by the Nobel laureate Dr Norman Borlaug as the major architect of India's green revolution, is worth being reproduced here: 'Exploitative agriculture offers great dangers if carried out with only an immediate profit or production motive. The emerging exploitative farming community in India should become aware of this. Intensive cultivation of land without conservation of soil fertility and soil structure would lead, ultimately, to the springing up of deserts. Irrigation without arrangements for drainage would result in soils getting alkaline or saline. Indiscriminate use of pesticides, fungicides and herbicides could cause adverse changes in biological balance as well as lead to an increase in the incidence of cancer and other diseases, through the toxic residues present in the grains or other edible parts. Unscientific tapping of underground water will lead to the rapid exhaustion of this wonderful capital resource left to us through ages of natural farming. The rapid replacement of numerous locally adapted varieties with one or two high-yielding strains in large contiguous areas would result in the spread of serious diseases capable of wiping out entire crops, as happened prior to the Irish potato famine of 1854 and the Bengal rice famine in 1942. Therefore, the initiation of exploitative agriculture without a proper understanding of the various consequences of every change introduced into traditional agriculture, and without first building up a proper scientific and training base to sustain it may only lead us, in the long run, into an era of agricultural disaster rather than one of agricultural prosperity'.

The precautionary principle largely remained only in the print; unfortunately, the green revolution was practised keeping in view only the short-term yield gains and commercial goals. The ecological concerns were not given any discernible attention. No concerted action was ever taken towards arresting the progressive degradation of soil health, exhaustion of fresh water resources, depletion of biodiversity, etc. Consequently, the productivity has started declining. The greed-oriented wheat–rice rotation in the green revolution areas of Punjab and Haryana has been largely responsible for the deterioration of soil quality and depletion of groundwater. Neither pulses nor *Sesbania rostrata* which can fix soil nitrogen were included in the rice–wheat rotation. The result is that these regions which have been granaries of India are slowly disintegrating into food insecure regions (MSSRF & WFP 2001, 2002, 2004; Bose 2004).

In retrospect, it could be argued that the science-based green revolution could have been sustainable, had the precautionary principles been implemented, and if the necessary steps had been taken for maintenance of the quality of soil and water; further, the prophylactic measures taken should have been such that these did not exert toxic residual effects on non-target sources and organisms. The ecosystem that supports agriculture, whether in the form of subsistence farming or intensive farming, is essentially composed of finite entities. Therefore, the consumers of the products of this system must also be finite. The developing countries, particularly India with its great spiritual and scientific attainments, should not let the gains of green revolution slip away. The green revolution could indeed have been managed as a sustainable eco-friendly agriculture. On the other hand, it was transformed into an 'exploitative agriculture' which in turn led to ecological degradation, social disintegration and accentuation of economic and gender divides. In hindsight, it is evident that despite the note of caution (Swaminathan 1968), the bulk of the scientific, administrative, political, farming communities and the media, as also the general public, had been too delirious with the newly found agricultural gains through green revolution to worry about precautionary principles; further, they did not realize that massive chemical inputs of fertilizers and pesticides and flooding the soil in the name of irrigation *without* adequate drainage would erode the physical and ecological foundations of productive agriculture. The increased grain output also created a fallacy that once food shortage is eliminated, the food security for each and every Indian would be naturally ensured. It turned out that food security at the national level does not ensure the same at the individual level in households. The point is that green revolution effectively puts an end to 'famine of food', but *not* to 'famine of livelihood' that was becoming intense due to human numbers exceeding the population supporting capacity of the ecosystems (Swaminathan 1999, 1996a, 2004a).

### (c) *Ecological footprint and agricultural sustainability*

An appraisal of the human ecological footprint will help in evolving models and strategies for sustainable agriculture. The 'ecological footprint' is a resource management tool that measures how much area of land and water a human population requires to produce the resources it consumes and to absorb the wastes it generates, under prevailing technology. Every action of humans impacts the planet's ecosystems and we depend on the ecological assets to survive. The depletion of these undermines the well being of people; livelihoods disappear, resource conflicts emerge, land becomes barren, etc. As the numbers of consumers (i.e. population growth) increase and/or their lifestyles become extravagant/wasteful, the ecological deficit increases and nature's capacity to meet basic human needs reduces (Wackernagel *et al.* 1999).

The intelligence and creative capacity of humans have unfortunately led to largely deleterious impact on the planet's ecosystems. The initiation of farming *ca* 10 000 years ago, and the domestication of plants and

animals led to the establishment of permanent settlements. Freedom from hunting and gathering provided more leisure for pursuit of intellectual activities—music, sculpture, arts and literature, science and culture, etc. At the same time, permanent settlements also led to increase in human population. It is believed (Clarke 2006, <http://www.energybulletin.net/16237.html>) that the human population on the planet was approximately 300 million around 1000 BC and had gone up to 800 million at the time of the Industrial Revolution in 1750. During the last 250 years, the industrial revolution has not only changed the lifestyles of humans successively from one generation to another, but also accelerated the depletion of Earth's natural resources (e.g. fossil fuels, biodiversity). More importantly, the planet Earth was also increasingly loaded with synthetic products and waste by-products, some of which are resistant to nature's method of degradation; hence, these persist as pollutants. Since the beginning of the era of industrial revolution, the global human population growth has registered approximately eightfold increase with an annual addition of 70–80 million new mouths to feed. Impacts of anthropogenic pressure, agricultural activities and industrial progress have resulted in an imbalance between the human demand and nature's capacity to provide at the local, national or global level. It is regarded as 'growth beyond an area's carrying capacity, leading to crash'. Wackernagel *et al.* (2002) have tracked the ecological overshoot of the human economy. Their analyses and accounts included six human activities that require biologically productive space: (i) growing of crops for food, animal feed, fibre, oil and rubber; (ii) grazing animals for meat, hide, wool and milk; (iii) harvesting timbers for wood, fibre and fuel; (iv) marine and freshwater fishing; (v) accommodating infrastructure for housing, transportation, industrial production and hydroelectric power; and (vi) burning fossil fuel. In each category and for each year of the 40-year time series, both human demand and Earth's existing capacity to provide were calculated. For these analyses, the authors have used the Food and Agriculture Organization (FAO) data (1999, 2000) on cropland, grazing pastures, natural forests and plantations which exist worldwide. These data were used to calculate the human demand on the production of food and other goods, together with absorption of wastes. The accounts arrived at indicate that human demand may well have exceeded the biosphere's regenerative capacity since the 1980s. The surmise was that humanity's load corresponded to 70% of the capacity of the global biosphere in 1961, and grew to 120% in 1999. In the same year, global environmental impacts of agricultural expansion and need for sustainable practices became the major focus (Tillman 1999).

It must also be emphasized that the purpose of these global accounts is not merely to measure human demand on productivity, but to offer a tool for measuring the potential effect of remedial measures. For instance, these can be used to calculate the probable effect of various technological breakthroughs. Emerging ecotechnologies producing renewable energy or mimicking biological processes are promising candidates for such calculations. For example, Von Weizacker *et al.* (1997) have shown

how, by using appropriate technology, resource consumption for ground transportation and housing can be reduced by a factor of four, while still maintaining the same level of service. The M.S. Swaminathan Research Foundation (MSSRF) has developed a 'biovillage paradigm' which has twin goals: (i) sustainable resource management and (ii) developing ecotechnologies that are *pro-nature, pro-poor, pro-women and pro-livelihood* oriented to combat the famine of livelihoods and the resulting food insecurity (Swaminathan 1999). He has discussed how *on-farm* eco-enterprises such as production of oyster mushrooms from paddy straw, vermicompost from used straw waste, goat rearing based on biomass from fodder plantations on wastelands, aquaculture in community ponds, dairying based on fodder from fodder banks, broiler production based on local feed resources and production of hybrid vegetable seeds would contribute to sustainable agriculture. The details are found elsewhere (Swaminathan 1996a,b, 2001a, 2002, 2004a, 2005b). These are briefly discussed in §5 in the context of linking sustainable agriculture with food security of the rural poor in the developing countries. In a way, these seem to fulfil the urgent need to usher in an *Ecological Revolution* as sequel to the *Agriculture Revolution* and the *Industrial Revolution* to save humanity and a planet Earth which are at a crossroads (Clarke 2006).

## 2. PRESENT GLOBAL CONCERNS ON POPULATION GROWTH AND FOOD SECURITY

The global population of approximately 6.0 billion in 2000 is projected to reach approximately 7.9 billion in 2025 (United Nations 2002, [www.un.org](http://www.un.org)). Much of the increase in the population growth will also take place in the developing countries particularly in China and India in Asia, and also in most countries of Africa. Correspondingly, an as yet undetermined area of arable land would be diverted for housing, industries, schools and hospitals. The water scarcity is also spreading (Falkenmark 1997). The forest area is encroached for agricultural and developmental activities, thereby depleting the biodiversity. Several already endangered species are becoming extinct.

Concomitant with population growth exceeding the carrying capacity of a given region, the compulsion to produce more food and fibre for a unit area of land and per drop of water also greatly intensifies. This is essentially intensification of agricultural production. Such an approach in the long run results in the degradation of soil health and subsequently reduction in crop productivity. Brown & Kane (1994) have brought out the imbalance between the growing demand for food grains fuelled by both population growth and rising affluence and the future growth in grain production, in the light of various constraints, most importantly water scarcity and a diminishing response of grain yields to fertilizers. In addition, with an annual population growth at approximately 70–80 million, the non-farm claims on both cropland and water are bound to be substantial. After 2 years, Brown (1996) analysed the two major threats to food security. One is the accelerated pace of doubling of the world population. The other is the progressive depletion of

oceanic resources and the slowing down of the rapid growth in grain harvest. He has also pointed out that the formula of combining more and more fertilizer with ever higher yielding varieties to increase the grain harvest is no longer working well. Global warming leading to sea level rise and climate change are now known to be real new threats. Small island developing countries, and the developing countries with large coastline such as India would suffer serious set back to agriculture and fisheries. As these problems and handicaps seem insurmountable, it is natural to look for powerful technologies to come to the rescue. For nearly two decades, hopes were raised that modern biotechnology would help in ushering in the second green revolution. It is now evident, as has also been pointed out by Duvick (1994), that it cannot produce sharp upward swings in yield potential, especially in wheat and rice. Their use particularly in genetic shielding of crop plants against biotic and abiotic stresses is, however, well proven. Brown (1996) concludes that biotechnology is not a magic wand that can be waved at food scarcity to make it go away.

The question at this point is whether agricultural yield sustainability to meet the needs of approximately 7.5 billion people by 2030 *without* causing depletion of existing biodiversity and exhaustion of non-renewable resources is at all feasible, and if so, what the pathways are. The best option is the evergreen revolution discussed below.

## 3. TRANSFORMING THE GREEN REVOLUTION INTO AN EVERGREEN REVOLUTION

The green revolution was essentially commodity-centred (Swaminathan 1996a, 2004b). Results and products of laboratory research were taken to the farmers' fields in a 'top-down' manner. The cost of external inputs as well as their affordability by the resource-poor marginal farmers was not one of the concerns. Even more importantly, the long-term negative impact of intensive use of inorganic chemicals and machines on the ecological foundations of agriculture was not addressed. Slowly but steadily, the production gains during the 1960s and 1970s increasingly became the very cause of transformation of the green revolution into the 'greed' revolution. Neglect of groundwater management, agrobiodiversity and soil health started eroding the prospects of achieving productivity in perpetuity. It became clear that environmental impacts of agricultural expansion warrant sustainable and efficient practices (Tillman 1999).

However, by no means, was the green revolution the sole cause of degradation of the natural resources of our planet. While Swaminathan (1968) drew attention to the harmful impact of exploitative agriculture on soil, water and biodiversity, the U.N. conference on the 'Human Environment', 4 years later in 1972, in Stockholm, addressed how human activities were rapidly exhausting the natural resources of the planet. It recognized that ecological degradations and poverty are mutually reinforcing. The accelerated pace of damage to basic life support systems of land, water, forests, biodiversity and atmosphere naturally lead to

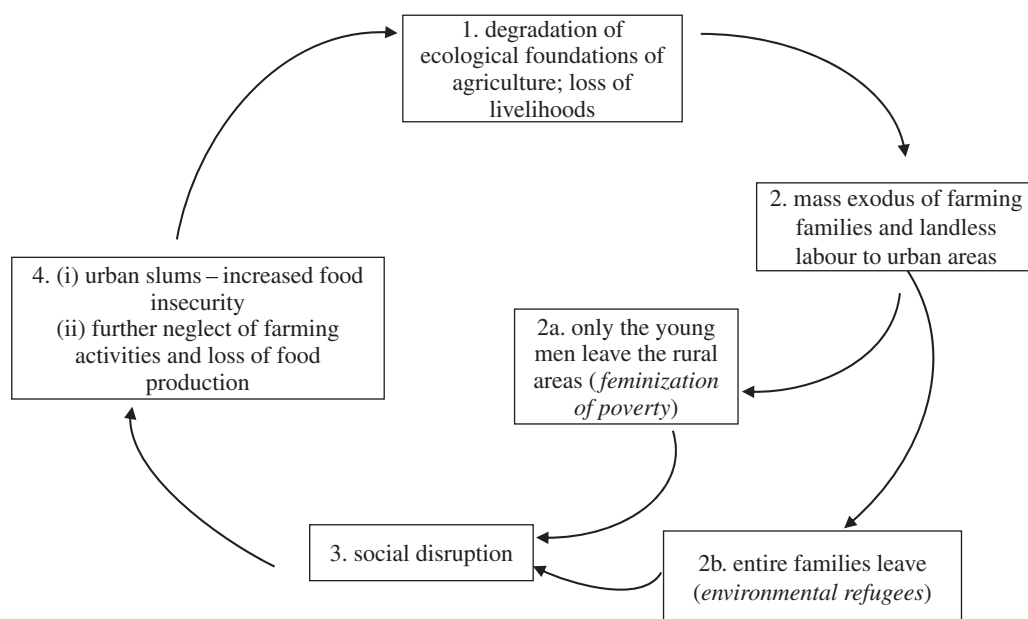


Figure 1. Ecological degradation leading to famine of livelihoods, social disintegration and food insecurity.

increasing poverty as well as social and gender inequity. As stated earlier, rapid growth in population resulted in reduced *per capita* availability of land and water. Further, explosive technological development coupled with high rates of unemployment accentuates the misery of jobless economic growth. The World Commission on Environment and Development (WCED 1987) report aptly titled, 'Our Common Future' is a reminder that notwithstanding political and geographical frontiers, our life on this planet is ecologically entwined. Several global agreements relating to climate, biodiversity, oceans, desertification and toxic wastes provide a framework for sustainable future to humankind. The U.N. Conference on Environment and Development (UNCED) in 1992, in Rio de Janeiro resulted in adopting Agenda 21 for reconciling environment and development. The priority is to break the vicious spiral between environmental degradation and poverty. When the largely illiterate, unskilled, resource-poor farming, fishing families lose much of the natural resource base, they migrate to the cities to eke out a living. Myers (2002) refers to them as 'environmental refugees' and describes varied aspects of the social problem. When only the able-bodied young men migrate to the urban areas, the young women are compelled to take over the responsibility of management of the subsistence farming and seasonal labour. The women of farm families become the household heads who have no or only meagre income. That results in 'feminization of poverty'. The term, the feminization of poverty originated from the US debates about single mothers and welfare, dating from the 1970s. The feminization of poverty has been linked to firstly, a perceived increase in the proportion of female-headed households (FHHs) and secondly, the rise of female participation in low-return sector activities. Today, the term has come to be used to mean three distinct things: (i) that women have a higher incidence of poverty than men, (ii) that their poverty is more severe than that of men, and (iii) that there is a trend to greater poverty among women, particularly associated with rising rates of FHHs.

Marcoux (1997) has discussed these basic aspects of the feminization of poverty having implications for sustainable development.

Further, the mass exodus of farming families to the urban areas leads to mushrooming of urban slums and civic problems. Ecological degradation leading to economic problems and then to social disintegration is widely witnessed. These are depicted in figure 1.

The management of the deleterious consequences of the human-induced changes in climate will be a major challenge in the twenty-first century. The global warming due to increasing concentrations of green house gases (GHG) has begun to cause sea level rise and an increase in hydro-meteorological natural disasters (UNEP/GRID Arendal 2005; [http://maps.grida.no/go/graphic/scenarios\\_of\\_sea\\_level\\_rise](http://maps.grida.no/go/graphic/scenarios_of_sea_level_rise)). The frequent occurrences of severe downpours leading to floods, cyclones alternated with long periods of drought particularly exert a devastating effect on agriculture. In many developing countries, agriculture has always been a 'gamble with monsoon', and the present climate change makes it even more so. The economic and livelihood crises created by failed crops in many parts of India have led to large numbers of suicides among the farmers caught in debt trap. The climate change-induced natural disasters could aggravate the poverty and miseries of these farmers.

Under these circumstances, the intensification of agriculture to meet the future demands for commodities needs to be made keeping in view the avoidance of further expansion on to marginal lands, forest areas or fragile ecosystems. Also the increased use of external inputs and development of specialized production and farming systems tend to increase vulnerability to environmental stresses and market fluctuations. There is, therefore, a need to intensify agriculture by diversifying the production systems for maximum efficiency in the use of local resources, while minimizing environmental and economic risks. In order to combat the 'famine of livelihood', on- and non-farm entrepreneurial activities for income generation should also be included. It is

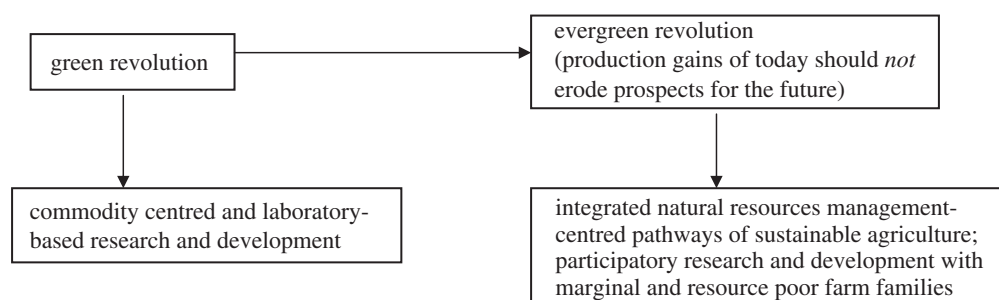


Figure 2. Paradigm shift: adding the dimension of environmental sustainability.

precisely for these reasons that the evergreen revolution is founded on the principles of environmental and social sustainability and economic viability.

With particular reference to a highly populated developing country, India, Swaminathan (1996b) observes that its 110 million farming families with small farms of an average of approximately 1.5 ha must produce more if they are to have marketable surplus. In fact, Swaminathan (1996b, 1999) has put forward the concept of *evergreen revolution* as follows: 'What nations with small farms and resource-poor farmers need is the enhancement of productivity in perpetuity, without associated ecological or social harm. The green revolution should become an evergreen revolution rooted in the principles of ecology, economics and social and gender equity'. While many have quoted him, Swaminathan (2004b) has specifically acknowledged that E.O. Wilson in his book 'Future of life' has even refined the concept of evergreen revolution further. Wilson (2002) wrote; 'The problem before us is how to feed billions of new mouths over the next several decades and save the rest of life at the same time without being trapped in a Faustian bargain that threatens freedom and security. The benefits must come from an evergreen revolution. The aim of this new thrust is to lift food production well above the level attained by the green revolution of the 1960s, using technology and regulatory policy more advanced and even safer than those now in existence'.

#### 4. PATHWAYS TO THE EVERGREEN REVOLUTION: PRODUCTIVITY IN PERPETUITY

##### (a) *Basic principles*

In making efforts for establishing a system of agricultural productivity in perpetuity, the two statements to be kept in view are the following: (i) 'the global agriculture is at a crossroads from the ecological, economic and ethical stand points. The challenge lies in converting the potential now available for higher production into an opportunity to develop agricultural research and development and food distribution strategies, which can make hunger a problem of the past' and (ii) 'if the existence of human beings as an independent species is equated to a 24 hour day (Lord 1962), then we have been farmers for only about seven minutes. Even during those seven minutes, we have practised market-oriented agriculture for only a few seconds' (Swaminathan 1996b, 1999).

The point being emphasized is that a single-track approach for enhancing productivity and market gains is now known to destroy the very foundation of sustainable agriculture. The experience gained over

the past four decades with the green revolution has just exemplified the above statements. There are essential differences in the research methodology and development between the green revolution and the evergreen revolution. In the green revolution, technologies were based upon a crop-centred research as in rice research or wheat research, etc. The soil was then rather indiscriminately saturated with mineral fertilizers as were deemed essential for the crops under cultivation; unfortunately, this was widely practised with utter disregard to the needs of the soil to maintain its structural and biological integrity. Flooding the soil without adequate drainage resulted in enhanced salinity or alkalinity. Consequently, the goals of production gains in the short term eroded the prospects of the same for the future. The evergreen revolution, on the other hand, involves not just one or two crops only, but a comprehensive farming systems' approach covering land, water, biodiversity and integrated natural resources management. Soil care and water management receive particular attention. The farm animals (cows, bullocks and milk buffaloes) provide dung and urine to enrich the soil, while crop residues and fodder form the bulk of the feed for these animals. Instead of just one or two crops, judicious rotation of cereals, millets, oil seeds and leguminous pulses is proposed. Further, it is recognized that site-specific changes in the edaphic and/or climatic conditions would necessitate a wider 'participatory' than a top-down research and development programme. The small farm holders with severe resource constraints would constantly need urgent solutions on crop and animal husbandry, soil and water management, conservation of traditional varieties and precious germ plasm of landraces, post-harvest processing, and marketing their crop and animal produces with reasonable profit. The modern information and communication technology has emerged as the most relevant technology in support of the evergreen revolution. Swaminathan (2003, 2004a-c) has elaborated the technology, planning and management needs for the paradigm shift from green to evergreen revolution (figure 2).

##### (b) *Pathways and terminologies*

In the initial stages of agricultural practice in India and several other developing countries, the cultivation together with crop and animal husbandry were largely eco-friendly. The farm yard manure was the major external input. Wooden ploughs drawn by bullocks tilled the soil; weeding was manually done. Yields were not as high as of the present day, but the agricultural practices were eco-friendly. It was during the middle of

the nineteenth century that Justus von Liebig in Germany discovered that plants feed on nitrogen compounds and carbon dioxide derived from the air, as well as minerals in the soil. He then invented nitrogen-based fertilizer. Nearly a century later, Muller (1939; <http://www.britannica.com/eb/article-9054225>) tested a compound, dichlorodiphenyltrichloroethane (DDT) and found it as an 'ideal' insecticide. The German chemist Othmar Zeidler had first synthesized this compound in 1874, but had failed to realize its value as an insecticide. Then, a series of chemical fertilizers providing nitrogen, phosphorous and potassium to the soil and chemical pesticides to protect crop plants against insect pests were synthesized. While the immediate benefits of these chemical agents were indeed quite impressive, their long-term harmful effects on soil and other non-target organisms came to be understood only after much damage to ecosystems had already been done. Carson (1962) has vividly described the terribly deleterious effects of DDT, dieldrin and heptachlor on wildlife populations. During the last couple of decades, there has been a growing campaign against the use of chemical pesticides in agriculture to protect crop plants. However, their use in small quantities in the integrated pest management (IPM) schedule is likely to continue for a long time, particularly in the highly populated developing countries like India and China.

In the context of the developing countries, particularly India and China, with a very large population, that is also still growing, Swaminathan (1996a,b; 1999; 2002) has recommended *integrated farming systems* (IFS) as the framework for creating more food and livelihood (income). He has elaborated as to how the IFS, when properly designed and practised, would ensure ecologically, economically and socially sustainable agricultural production. The seven essential constituents of the IFS are soil health care, water harvesting and management, crop and pest management, energy management, post-harvest management, choice of crop and animal components and information, skills, organization, management and marketing empowerment. There are also widely accepted broad approaches to develop each of these. For instance, soil health care that is most fundamental to sustainable intensification essentially requires the inclusion of stem-nodulating legumes like *S. rostrata*, incorporation of *Azolla*, blue green algae and legumes in the crop rotation sequence. There are, however, site-specific and resource-driven variations not only in the major inputs (e.g. effective microorganisms, vermicompost, biofertilizer, etc.) but also in their relative proportions to make up the total amount of particular nutrients required. These aspects are closely linked with integrated nutrient management (INM).

Water harvesting and management is of utmost importance especially to countries and regions with largely monsoon-dependent agriculture. Community-centred rainwater harvesting and management has been set up by the MSSRF in a few semi-arid regions of India. Community-based agrobiodiversity-conservation, rain water harvesting and management and fodder management through a system of community banks (i.e. banks with a difference; Swaminathan 2001a-c, 2002) help in

linking sustainable agriculture with livelihood. Emphasis is placed on *on-farm* water use efficiency and on techniques such as drip irrigation, which optimize the benefits from the available water. Genetic shielding of rice and other water-thirsty crops with drought-resistant genes from *Prosopis juliflora* is yet another aspect of sustaining agriculture in the numerous small farms of the developing countries.

INM and IPM are the two major components of IFS (Swaminathan 2002, 2004a). From the biological aspect of soil fertility management, INM seeks tight nutrient cycling with synchrony between demand of crops and nutrient release within the soil while minimizing loss of nutrients through leaching, runoff, volatilization and immobilization. It is a strategy that incorporates both organic and inorganic plant nutrients to attain higher crop productivity, prevent soil degradation and thereby help meet the future food supply needs. In the context of promoting sustainable agriculture in the developing countries, it relies on judicious application of both organic and inorganic nutrients, providing pathways to increase nutrient availability to plants, while minimizing soil degradation. The INM and IPM require close interaction between scientists with their modern scientific inputs and the traditional farmers with their ecological prudence and practical experience of soil management. Hence, both these require a 'bottom-up' or *participatory approach*. The precise composition of the INM and IPM will depend on the components of the farming system as well as on the agro-ecological and soil conditions of the area.

The integration of cultural, physical, mechanical, biological and chemical measures to manage crop pests below the *economic injury level* (EIL) is called *IPM* (<http://www.pestinfo.ca/main/session/lang/EN/ns/22/doc/32>). The IPM is effective for controlling pests of various kinds, namely sucking pests (aphids, mealy bugs and leaf hoppers), leaf caterpillars (shoot and fruit borers) and internal feeders and stored products pests. The cultural and mechanical methods consist of cultivating insect resistant/tolerant crops, using trap crops that are highly preferred/susceptible so that the main crop is spared. Light traps and pheromone traps (pheromones are chemical substances secreted by adult insects (mostly female) for attracting the members of the opposite sex of its own species) to lure and trap help in reducing mating and egg laying. The biological methods involve the use of living agents (insects and micro-organisms) to manage the destructive species. They are categorized as parasitoids, predators and pathogens. The parasitoids are parasite-like, but almost the same size as their hosts and kills the host during development. They are often described in terms of the host stages(s) within which they develop. For example, there are egg parasitoids, larvae parasitoids, pupae parasitoids and a few species that parasitize adult insects. Parasitoids are host-specific, laying their eggs on or onto a single developmental stage of only a few closely related host species.

The MSSRF has developed an eco-enterprise, for landless women, of culturing the egg parasitoid *Trichogramma chilonis* which effectively controls *Helicoverpa armigera*, and several other stem and

fruit borers (Subashini *et al.* 2003). The integration of cultural, physical, mechanical and biological methods of pest management is quite effective in most situations; furthermore, these are all eco-friendly. The production of biopesticides (e.g. *Trichogramma*) by the landless, incomeless rural women is indeed a pro-nature, pro-poor, pro-women and pro-livelihood oriented eco-enterprise. Even a small increase in income generation for these landless women enhances their access to food, and hence the food security.

Several pathways/approaches towards an evergreen revolution have been proposed and have been engaging the attention since the time of arousal of ecological consciousness in agriculture first by Swaminathan (1968), and then the U.N. Conference on Human Environment in 1972, in Stockholm. Hence, it is significant that the International Federation of Organic Agriculture Movements (IFOAM) was also started on November 5, 1972, in Versailles, France. The initiative came from the late Roland Chevriot, President of *Nature et Progres* (French farmers organization). The IFOAM was supposed to act as a much needed counter to what was already then perceived as the disastrous impact of 'chemically-based' agriculture on the environment and peasant societies. The federation also had the task to demonstrate the global relevance of organic agriculture as part of the solutions (<http://en.wikipedia.org/wiki/IFOAM>). The IFOAM has defined organic agriculture as all agricultural systems that promote the environmentally, socially and economically sound production of food and fibres (IFOAM—[http://www.ifoam.org/about\\_ifoam/principles/index.html](http://www.ifoam.org/about_ifoam/principles/index.html)). Essentially, four principles govern the identification of organic agriculture. The first is the *principle of health*, which emphasizes that health of all living systems and organisms from the smallest in the soil to human beings are mutually dependent. The second is the *ecological principle* which stipulates that organic agriculture should be based on living ecological systems and cycles, should work with them and help sustain them. The third is the *principle of fairness* directing that the organic agriculture should be built upon relationships that ensure fairness, equity, respect, justice in the human-human relations and between humans and other living beings. It insists that animals are provided with conditions and opportunities of life that accord with their physiology, innate behavioural characteristics and well being. In fact, the dictum is that organic production systems should be constrained by the animal's needs and not the other way around. Improvement of quality and quantity of animal products through modern scientific tools and technologies which adversely affect the integrity of the animals is just *not* acceptable in organic farming. A case of unethical violation of animal welfare has been the use of modern rDNA technology to produce leaner meat in the 'Beltsville pigs' (Pursel & Rexroad 1993). These pigs contained human growth hormone genes to accelerate growth, but suffered health problems, such as lameness, ulcers, cardiac diseases and reproductive problems (Rollin 1997). For broiler chickens, which gain approximately 2 kg in 40–50 days, the muscles and gut grow faster but skeleton and cardiovascular system do not keep up, leading to leg problems and heart failure

(Kesavan & Swaminathan 2005). The administration of recombinant-bovine somatotropin (r-BST) to lactating cows to enhance milk production is also unethical. Jarvis (1996) has pointed out that gearing the cows with r-BST to produce more milk leads to higher demands on their physiology, and if adequate nutrition is lacking, negative effects are observed on fertility, with other health problems, especially mastitis and ketosis. Several papers presented at the 15th IFOAM Organic World Congress (21–23, 2005, Adelaide, South Australia) deal with animal husbandry and welfare. Straughan (2000) had earlier emphasized that there is no reason to believe that animals lack sentience or the capacity to experience pain and pleasure and that they are mere automata. He has also discussed *telos*—the way of living exhibited by an animal whose fulfilment results in happiness or whose thwarting results in psychological depression. Free moving pigs and fowls are certainly happier than those with restricted mobility in the pigsties and pens, respectively. For these considerations, organic approach ensures a better physiological and psychological health for the farm animals. The fourth is the *principle of care* which stipulates that organic agriculture should be managed in a precautionary and responsible manner to protect the health and well being of present and future generations and the environment. Here, the precautionary approach for decision making recognizes that, even when the best scientific knowledge is used, there is often a lack of knowledge with regard to future consequence and to the plurality of values and preferences of those who might be affected. The emphasis is on precaution and responsibility and not on risk assessment which is considered as a narrow notion based on narrow scientific or economic appraisal. However, it does not permit use of any chemical agents (i.e. fertilizers, pesticides, etc) or transgenic crops in the schedule of organic farming. Further, the organic certification is a rigorous one and, consequently, even a very slight deviation from or compromise with the stipulations in the production of organic foods results in their outright rejection. In many countries, certification is a serious matter of legislation and commercial use of the word 'organic' outside of the certification framework is illegal.

However, the question is whether organic agriculture, that certainly is ecologically sustainable, could provide yield increases commensurate with the demands of the population growth (Tillman *et al.* 2002). Trewavas (2002) is of the view that organic farming is no more sustainable than the fish-farming that produces high-value smoked salmon to a few rich consumers. The yields probably remain unchanged in the organically grown apples (Reganold *et al.* 2001). There have been as yet unsubstantiated views that crop varieties genetically equipped for high yields (i.e. dwarf and semi-dwarf) through high responsiveness to mineral fertilizers would not be suitable for organic agriculture. What this means is the need for *selection* of traditional varieties to suit locale-specific organic agriculture. At present, there are no convincing data to argue that organic farming, as has been defined by the IFOAM, could help in accelerating the crop productivity to meet the demands of India and China. This statement is made based on the fact that



productivity aspect in organic agriculture has not received noticeable attention although over 150 papers on various aspects in over 20 sessions had been presented at the First Scientific Conference of the International Society of Organic Agriculture Research (ISO FAR) on Researching Sustainable Systems held during 21–23, September 2005 in Adelaide, South Australia. The emphasis is clearly on quality of the agricultural produce and shaping sustainable systems.

McNeely & Scherr (2003) have suggested *ecoagriculture* as a strategy to feed the world and save wild biodiversity. Their analyses of the most recent global data on agricultural systems and wildlife habitats revealed that the scale of agriculture's impacts on ecosystems was indeed immense. It even seemed that with farming all the efforts at biodiversity conservation, in the critical protected areas, especially in the 'biodiversity hotspots' would be futile. Fortunately, they have discovered the potential for coexistence of agricultural systems and ecosystems based on new scientific understanding and the new resource management systems being developed in different parts of the world. They coined the term *ecoagriculture* to reflect such systems. For some time, a growing number of innovative agriculturists and environmentalists have been trying out different methods to tackle the *agriculture-income-wild biodiversity* challenge. Researchers, farmers and community planners with diverse perspectives have begun working together to develop land-use systems managed for both agricultural production and conservation of wild biodiversity and other ecosystem services. An ever-increasing realization of the fatigue of the green revolution, degradation of the soil and water and loss of biodiversity led to the integration of ecological concerns and principles into modern agricultural research and technology development. Lessons from indigenous agricultural technologies and practices were given a serious consideration from the point of promoting sustainable production. For instance, the role of soil micro-organisms, pollinator insects and nitrogen-fixing plant species suddenly received recognition and respect.

The *ecoagriculture* is considered even superior to organic agriculture in the sense that the former does not lay emphasis on ecosystem function and *wild* biodiversity conservation. The *ecoagriculture* increases agricultural production and simultaneously restores biodiversity and other ecosystems functions, in a landscape or ecosystem management context. McNeely & Scherr (2003) have suggested six strategies for *ecoagriculture*. These are briefly as follows: (i) creation of biodiversity reserves that also benefit local farming communities. An example of what has already been done in this regard by the MSSRF is in Wayanad, Kerala, India. There, the MSSRF has developed a 'model' farm that cultivates several spices (black pepper, ginger, turmeric and cardamon), vanilla, coffee, several medicinal plants, tuber crops (*Dioscorea* species), jack fruit trees and several wild but economically useful tree species (*Syzygium travancorium* and *Cinnamomum malabattrum*) and also maintains a few farm animals. The farming principle includes the low external input sustainable agriculture (LEISA).

Rainwater harvesting and management and soil health care are integral parts of the system. The crop pests are largely controlled (but not completely eliminated) by a traditional practice. It involves the use of crude extracts of *Lobelia nicotianae foliae* and 'Panchkarya' (a mixture of cow dung, urine, 'ghee' milk and curd). The 'ghee' is made from melting unsalted butter in a pan over a low flame. The farm manure and 'vermicompost' (that is the compost of digested farm waste by earthworms which also pulverize the soil) are extensively used to enhance the soil organic matter, particularly the humus. The economic viability is ensured through regular income from composite culture of medicinal, agricultural and plantation crops and farm animals. From the biodiversity point of view, the shift from the usual monoculture to polyculture ensures that a wider spectrum of species of insects, birds, small mammals and reptiles make use of the habitat. The inclusion of honeybees (apiculture) provides additional income from honey and also helps in pollination of vanilla; where adequate water is available, edible and ornamental fish culture is also included. (ii) The second strategy is the development of habitat networks with agriculture in non-farmed areas. This involves the integration of agricultural landscapes in many non-farmed areas with high-quality habitat for wild species that are compatible with farming. For example, the traditional farmers provide facilities for barn owls to contain destructive rodents. (iii) The third strategy is the reduction or even reversal of the conversion of wild lands into agriculture by increasing farm productivity. (iv) The fourth strategy is to minimize agricultural pollution through more resource-efficient methods of managing nutrients, pests and waste. This is a basic principle governing all the approaches towards sustainable agriculture, conservation of biodiversity and health and welfare of all the rural women, children and men constituting especially the farming families. (v) The fifth strategy is the modification of the management of soil, water and vegetation resources, in order to enhance the habitat quality in and around farms. An excellent example is the community-managed gene, seed, grain, water and fodder bank set up in the 'biodiversity-rich hotspots' in Orissa, India by the MSSRF. Swaminathan (2000a,b, 2001a) has described the concept of promoting a community-led integrated gene management system to achieve sustainable development and food security. The Koraput region of Orissa is largely inhabited by tribals and is also the centre of origin of cultivated rice. The tribal women are also credited with the selection and conservation of the precious genes in the form of hundreds of landraces and indigenous varieties. Their landraces have been used in scientific plant breeding for valuable 'genes' without, of course, any recognition or economic benefit accorded to them. These tribals who have rendered valuable service towards conservation and food security have been living in abject poverty. The MSSRF, therefore, initiated a programme of *ex situ* and *in situ* activities to strengthen the conservation traditions of the tribal communities (particularly the women) and also open up avenues for providing recognition and economic benefit to them. The conservation approach practised and advocated by

the MSSRF includes *in situ* on-farm and *ex situ* gene bank conservation. The *in situ*-participatory conservation has an important feature of the involvement of traditional conservers, integration of conservation with a *community gene-seed-grain bank continuum* and establishment of an economic stake in conservation using participatory plant selection, value addition and market linkages. The *in situ* conservation becomes sustainable when the communities are able to link conservation with economic or cultural stakes. The knowledge system established and the genetic enrichment achieved under the *in situ* conservation are of profound significance to future agriculture. The *ex situ* community gene bank set up by the MSSRF is distinct on few accounts from the widely practised *ex situ* conservation. The accessions in the *ex situ* gene bank are deposited by farming communities, who had evolved and conserved these accessions, with trusteeship entrusted with MSSRF. This gene bank located at the MSSRF, Chennai is a medium-term storage facility maintained at 4°C and 25% RH. A duplicate sample of each accession is also stored in the long-term storage at the National Gene Bank as an additional safeguard. The accessions belonging to major food crops are notable for agronomic potential under different biotic and abiotic stresses. They are accessible, subject to Indian laws, by any party with *prior informed consent* of the community which has developed that accession. The MSSRF facilitates such access through mutually agreed terms and material transfer agreement. Accessions have a detailed digitalized database called *Farmer's Right Information System (FRIS)*. This includes the traditional knowledge associated with each accession, their passport data, nationality and internationally accepted scientific descriptors. This database is devised to establish the intellectual property rights of farmers on their variety.

MSSRF also takes proactive actions in influencing national and global policies on conservation and rights of communities. Back in 1990, prior to the conclusion of the *Convention on Biological Diversity (CBD)*, MSSRF through a Keystone Dialogue held in Chennai developed a framework for recognizing and rewarding farmers and traditional communities engaged in conservation through benefit sharing and other means. These concepts were taken forward by the CBD through its Articles 8 (j), 15 and 16.

The community conservation being undertaken by the MSSRF at Jeypore in Orissa was adjudged for the first *Equator Initiative* award instituted by the UNDP in partnership with IDRC, IUCN, BrasilConnects, the Government of Canada and the United Nations Foundation. The Equator Initiative is a global movement committed to identifying and supporting *innovative partnerships that reduce poverty through conservation and sustainable use of biodiversity*. In addition, the *Protection of Plant Varieties and Farmers' Right Act, 2001 (PPVFR-2001)* of India recognizes farmer as cultivator, conserver and breeder. Accordingly, it allows farmers the right to register farmers' variety, right to receive reward and recognition for conservation of agrobiodiversity, right to receive benefit sharing from a new commercial variety developed by using farmers' variety and right to

re-sow, exchange, share or sell farm saved seeds. (vi) The sixth strategy is the modification of the farming systems to mimic natural ecosystems. Economically useful trees, shrubs and perennial grasses are integrated into farm in ways that mimic the natural vegetative structure and ecological functions to create suitable habitat niches for wildlife. In nutshell, ecoagriculture involves developing mutually reinforcing relationships between agricultural productivity and conservation of nature (Kesavan & Swaminathan 2006). Thus, the ecoagriculture involves concurrent action plans towards *agricultural growth, poverty alleviation and biodiversity conservation*. In the conventional approach, these three goals seldom complemented one another. In fact, agricultural growth and biodiversity conservation were erroneously regarded as mutually exclusive.

Yet another system of sustainable agriculture is the use of effective microorganism (EMs). Higa (1994) describes the fantastic benefits offered by EMs in solving agricultural, environmental and medical problems. The EMs not only eliminate the undesirable need to use agricultural chemicals and artificial fertilizers, but also enhance the crop yields to much higher levels than achievable with conventional farming methods. The health benefits to the producers and consumers and also the economic benefits are particularly noteworthy. He also cites the case of record-breaking rice production even in the abnormally cool summer of 1993 in Japan. The EM comes in four varieties which are numbered EM no. 1 through EM no. 4. Each type has distinct features and properties. EM no. 2 features mainly Gram-positive actinomyces; the major content of EM no. 3 is photosynthetic bacteria, and of EM no. 4, lactic bacteria and yeasts. EM no. 1 exhibits all the properties found in EM no. 2, no. 3 and no. 4. In other words, EM no. 1 is a composite mixture of all the three. Each of the four types is more appropriate to certain uses, the appropriateness of each depending on the activities of the dominant species of microorganisms in the mix. During the abnormally cool summer of 1993 in Japan, the EM no. 3 application led to more than normal rice production. The other features of the EM system of agriculture are that rice cultivation involved direct planting without any tilling and weeding. It cut the costs of agricultural chemicals and artificial fertilizers by one fifth. Untreated cow dung forms the bulk of the fertilizer. In the initial period (the first and second year), the yields were lower, but in the fourth year, the production level had even slightly surpassed the standard yield level of modern agriculture. Besides being benign to ecosystems, the EM agriculture improves the quality of fruits and reduces the cost of external inputs by approximately one-fifth. More importantly, the EM is credited with turning barren soil into rich, fertile land again, and therefore does away with the need for slash-and-burn farming technique. In the context of Brazil, where Amazon's tropical rainforests are presently destroyed at a rate of approximately 1.8 Mha a year, the EM technology proved useful to remedy the root causes of low productivity and regenerating the soil exhausted and impoverished by the use of artificial fertilizers and agricultural chemicals.

Table 1. Green revolution and evergreen revolution: pathways.

<i>green revolution</i> : commodity-centred increase in productivity	<i>evergreen revolution</i> : increasing productivity in perpetuity without associated ecological harm
(i) Change in plant architecture and harvest index.	(i) <i>Organic agriculture</i> : cultivation <i>without</i> any use of chemical inputs such as mineral fertilizers and chemical pesticides
(ii) Change in the physiological rhythm insensitive to photoperiodism	(ii) <i>Green agriculture</i> : cultivation with the help of integrated pest management, integrated nutrient supply and integrated natural resource management systems.
(iii) Lodging resistance	(iii) <i>Ecoagriculture</i> : based on conservation of soil, water and biodiversity and the application of traditional knowledge and ecological prudence
	(iv) <i>EM agriculture</i> : system of farming using <i>effective microorganisms</i> (EMs)
	(v) <i>White agriculture</i> : system of agriculture based on substantial use of microorganisms, particularly fungi
	(vi) <i>One-straw revolution</i> : system of natural farming without ploughing, chemical fertilizers, weeding and chemical pesticides and herbicides

Fukuoka (1978) has described a system of natural farming in his book entitled 'One-straw revolution'. Its four cardinal principles are: (i) *no* cultivation (no ploughing or turning the soil), (ii) *no* chemical fertilizer or prepared compost, (iii) *no* weeding by tillage or herbicides (weeds play a part in building soil fertility; they need to be controlled, but *not* eliminated), and (iv) *no* dependence on chemicals or poisonous pesticides. With reference to the first point (no cultivation), the author maintains that Earth cultivates itself naturally by means of the penetration of plant roots and the activity of microorganisms, small animals and earthworms. Left to itself, the soil maintains its fertility naturally in accordance with the orderly cycle of plant and animal life. Weeds are believed to play their part in building soil fertility and in balancing the biological community. Hence, they need to be there, but *under control* through straw mulch; a ground cover of white clover interplanted with the crops in a healthy environment is the solution for insect pests and diseases caused by viruses, bacteria and fungi. As far as yield is concerned, Fukuoka obtained 1650 pounds of a variety of glutinous rice per quarter acre (i.e. approx. 3 tonnes per acre or 7.4 tonnes per hectare). Unfortunately, no follow-up studies are available in the literature.

In recent times, the term *green agriculture* is in usage, particularly by China. It is a system of cultivation with the help of IPM, integrated nutrient supply and integrated natural management systems. Green agriculture does not exclude the use of minimum essential quantities of mineral and chemical fertilizers. [http://english.people.com.cn/english/200010/09/eng20001009\\_52142.html](http://english.people.com.cn/english/200010/09/eng20001009_52142.html).

*White agriculture* (Stevenson 2004) is a system of agriculture based on a substantial use of microorganisms, particularly fungi. The concept of white agriculture took shape in 1986 in China. *White* refers to the white-coated scientists and technicians performing high-tech processes to produce food directly from microorganisms or to use them to augment and improve green agriculture. The paradigm shift from green revolution to evergreen revolution as well as the various terminologies and pathways to achieve the same are given in table 1.

From the foregoing review, it is evident that several systems of natural farming ranging from organic farming with stringent stipulations to green agriculture

with some flexibility provide options. The future of agriculture in India and several other developing countries depends upon their ability to enhance the productivity of small holdings without damage to their long-term production potential. Transforming green revolution into an evergreen revolution using one or more of the several pathways described here will usher in a win-win situation for both farmers and ecosystems. Crop-livestock integration and introduction of stem-nodulating legumes or pulse crops in the rotation will facilitate the building up of soil fertility. Instead of placing the above-mentioned six approaches to sustainable agriculture in different compartments, it will be prudent to develop for each farm an evergreen revolution plan based on an appropriate mix of the different approaches which can ensure both ecological and economic sustainability.

It is also required of each country to modify the various systems of sustainable eco-friendly agriculture to suit the specific need of the region and the farming community. For instance, Swaminathan (2001b, 2004b) had proposed the introduction of *Bt*-gene into organic crops and vegetables to contain the heavy damage by insect borers (figure 3).

The point is that the available biological methods of pest control do not seem sufficiently efficient in the tropical and subtropical agriculture. Therefore, genetic shielding of crops in organic agriculture with *Bt* is not a bad idea at all, since it is now known to be environmentally benign and biologically safe for human consumption. Of course, more intensive studies to verify the biosafety are welcome. Similarly, the global warming-induced sea level rise is of enormous threat to coastal agriculture due to salinization of soil and freshwater sources. For instance, India with a coastline of approximately 7600 km cannot abandon the small scale farming operated by millions of resource-poor farming families. In order to sustain the coastal agriculture with rice as the major cereal crop, Swaminathan (1990) suggested the genetic shielding of the coastal cereal crops with salinity-tolerance genes from mangrove species. The MSSRF scientists have accordingly incorporated the salinity-tolerance genes from a mangrove species, *Avicennia marina* into rice. The transgenic rice under field trials is able to tolerate up to 150 mM of salt-induced stress (Mehta *et al.* 2005;

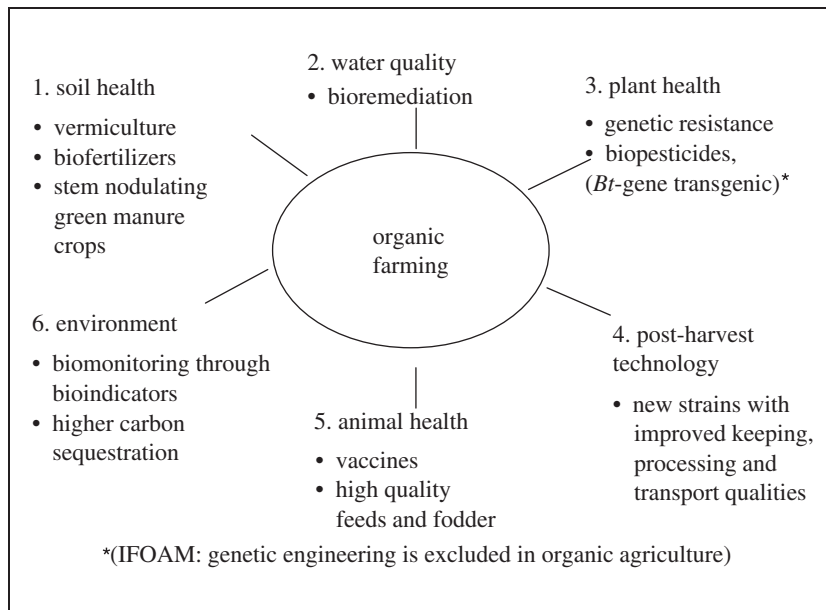


Figure 3. Biotechnology and organic agriculture.

Prashant & Parida 2005). In view of the intensity and rapid spread of water scarcity, the MSSRF is presently engaged in transferring drought-resistance genes from *P. juliflora* to water-thirsty cereal like rice. The point is that with enormous population growth, and substantial increase in abiotic stress, new scientific methods need to be adopted for realizing the Roman farmer Varro's statement 'Sustainable agriculture involves increasing productivity in perpetuity'. These transgenic rice could still be organically cultivated in order to enhance soil health, biodiversity and socio-economic equities than for certification and export. In fact, Evans (2006) in his book entitled, 'A Hand to the Plough' cites Prof. M.S. Swaminathan who made a plea for a marriage between the scientist and the farmer in the field to ensure sustainable agricultural productivity and conservation of biodiversity: 'An intelligent integration of molecular and Mendelian breeding techniques will help to enhance the nutritive value of staples. By integrating pre-breeding in laboratories with participatory breeding in farmers' fields, it will be possible to breed location specific varieties and maintain diversity'.

### 5. SUSTAINABLE AGRICULTURE FOR LIVELIHOOD AND FOOD SECURITY IN THE DEVELOPING COUNTRIES

Analyses of the causes of food insecurity at the individual household levels in rural and urban India by MSSRF (MSSRF & WFP 2001, 2002, 2004) revealed that besides the *availability* of food (a function of food production or procurement through import), *access* (purchasing power arising mostly from livelihood security) and *absorption* (absorption of ingested food which is a function of clean drinking water) are very important. The paradigm of 'mountains of grains' in the government godowns and 'millions of hungry' in India is mainly due to famine of livelihood (Swaminathan 2001a, 2003). With over 200 million people, mostly in the rural areas, caught in a 'poverty trap' with an income of about a

US dollar per day, strategies to develop *on-* and *non-farm* livelihoods became a major mission of the MSSRF. Harnessing frontier technologies and blending them with the traditional wisdom and ecological prudence of the rural farming, fishing and tribal forest dwellers by the MSSRF resulted in ecotechnologies which are pro-nature, pro-poor, pro-women and pro-employment oriented. Often demystification of the laboratory-based technologies is the initial requirement. The examples are the production of (i) mushroom on rice straw, (ii) fish pickle, (iii) *Trichogramma* egg parasitoid, and (iv) file boards and paper from banana waste, etc. by the rural women, especially the landless women. The next step is the formation of self-help groups (SHGs) of women, men and both together. Training in the chosen ecotechnology for eco-enterprise is imparted through 'techniracy' (a term coined by Swaminathan (1972) to describe a pedagogic method of learning by doing). With this sort of technological empowerment, the largely illiterate, unskilled and resource-poor rural women and men are able to get a better control of their livelihood and food security. Swaminathan (1999, 2002, 2003, 2005a) has described how the 'biovillages' (bios = living) with their technical resource centres, called 'bio-centres', and microcredit facilities provided by several national banks and with forward market linkages are serving an effective and integrated pathway for sustainable agriculture, sustainable rural development, sustainable food security and sustainable conservation and use of biodiversity.

In the twenty-first century, knowledge is power and the various approaches towards evergreen revolution involve knowledge empowerment of the farming and fishing communities. This would also synergize the benefits of the ecotechnological empowerment of the rural communities. Hence, the MSSRF has taken advantage of the modern information and communication technology and provided internet connectivity. Wherever electricity was not available, solar power was used. In the remote case of absence of telephone connection, a wired-wireless hybrid technology was developed. More important than connectivity is the

provision of *time- and locale-specific information content* such as those on crop and animal husbandry, soil health, monsoon management, diversification of crops in case of monsoon failure keeping in view the edaphic conditions and market trends, adversaries on plant protection, veterinary aspects, health care of especially women and children, market prices, transport, schooling, employment, etc. The MSSRF's success and initiatives have led to the Government of India's Mission 2007 to transform all the 600 000 plus villages of India into knowledge centres. The year 2007 marks the 60th anniversary of India's independence. The point is that sustainable agriculture involves enlisting several technologies, and participatory approaches of the farmers, fishers, agricultural scientists, planners, environmentalists, policy makers, politicians, non-governmental organizations, media people and so on. In addition, community-based (i.e. decentralized) activities towards conservation of biodiversity, water and other renewable resources are also essential.

If the green revolution was top-down, the evergreen revolution is essentially bottom-up and *participatory*. Finally, the trade-related agreement on agriculture needs to be corrected in the sense that the trade should not only be *free* but also *fair*. The point is that the various approaches towards the evergreen agriculture necessarily involve 'production by masses'. The 'masses' here are the resource-poor farming families with small land holdings of approximately 0.5 to 2.0 ha. As against this mode of production, the very large farms, as in the USA, essentially focusing on monoculture of crops, vegetables and fruits with substantial inputs of technology, capital and subsidy, belong to the 'mass production' (factory farming) category. For instance, India occupies the first place in the world in milk production with annual production exceeding 90 Mt. Nearly 80 million women and 20 million men are involved in this enterprise. This is an example of 'production by masses'; in contrast, the USA produces approximately 70 Mt of milk employing only approximately 0.20 million men; this is an example of 'mass production'. It should also be noted that nearly 150 million cows and buffaloes are used to produce a little over 90 Mt of milk in India, whereas just 9.2 million dairy cattle in the USA produce approximately 70 Mt of milk. In the USA, the production technologies lead to a 'jobless economic growth', whereas in India the enterprises necessarily must lead to *job-led economic growth*. The agricultural commodities produced by 'factory farming' are often exported to the predominantly agricultural, developing countries. For example, the 'factory-farmed' apples and oranges from developed countries have been flooding every city including Chennai (Madras) in India and, consequently, the apples and oranges grown by thousands of small scale farmers in central and northern India are not able to compete in terms of uniformity of appearance and market price. Unable to sell the products of their small farms, these farmers get into a 'debt trap'. Another difference between industrialized countries and India is that while in the former, hardly 3% of the population are farmers, the rest being consumers; in India, farmer-consumers constitute

two-thirds of the population. Globalization is a factor with considerable influence on sustainable agriculture.

## 6. CONCLUSIONS

The green revolution of the 1960s and 1970s transformed the image of India from a 'begging bowl' to a 'bread basket'. An assessment of its impact over the last four decades reveals that it also served as a 'forestland saving agriculture'. Had not the productivity levels been substantially increased through the pathways of the green revolution, India would now need 80 million ha of more land to produce food grains at the present level (approx. 207 Mt). Notwithstanding such gains, the fact, however, remains that the green revolution, practised without adherence to scientific principles, has caused damage to the ecological foundations essential for sustainable advances in productivity; this in turn resulted in fatigue of the green revolution. Lessons drawn from the green revolution are that steps taken towards productivity enhancement should concurrently address the conservation and improvement of soil, water, biodiversity, atmosphere, renewable energy sources, etc. Keeping these in focus, the goal of the 'evergreen revolution' for achieving higher productivity in perpetuity was developed. What this means is a system of agriculture that involves sustainable management of natural resources and progressive enhancement of soil quality, biodiversity and productivity. Several farming systems that can help to produce more from the available land, water and labour resources *without* either ecological or social harm to trigger the evergreen revolution have been identified. These include organic agriculture, eco-agriculture, green agriculture, EMs-based agriculture, white agriculture and one-straw revolution.

Unlike the green revolution, the pathways of the evergreen revolution address concurrently the famine of food and the famine of livelihood. Thus, the sustainable agriculture is integrated with sustainable rural development through technological and knowledge empowerment of rural communities. Blending of frontier technologies with traditional wisdom and ecological prudence of rural women and men result in ecotechnologies with pro-nature, pro-poor and pro-women orientation. Training and capacity building enables the rural resource-poor farming, fishing and landless families to manage successfully the various on- and non-farm enterprises. Technological and knowledge empowerment of the rural communities fall within the domain of MSSRF's 'biovillages' and 'village knowledge centres', respectively.

It should thus be evident that realization of sustainable agriculture requires several facets of modern science blended with traditional wisdom, participation of farmers, scientists, planners, policy makers, etc., as well as market and trade linkages that are not only free but also fair. In addition, the developing countries particularly India and China should contain their population growth without further delay. Sustainable agriculture holds out hope for humankind and the planet Earth which are at a crossroads; it can succeed only if all the developed

and developing nations stand together for common good. Sustainable agriculture and development is for 'our common future'.

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