SUSTAINABLE AGRICULTURE

D.M. Hegde[1] and S.N. Sudhakara Babu[2]

[1] Ex Director, ICAR-Indian Institute of Oilseeds Research, Hyderabad
[C-108, SMR Vinay Galaxy, Hoodi Circle, ITPL Road, Mahadevapura, Bengaluru560048]

[2] Principal Scientist (Agronomy), ICAR-Indian Institute of Oilseeds Research, Hyderabad

Sustainability refers to the perpetual ability and is a systems issue. Sustainability as a goal seeks permanence for an activity or a system where a system is a conglomeration of different elements, components, subsystems, or constituents knit together into an integrated whole that help in the system's organization and maintenance of its integrity (Von Bertalanffy, 1968). A sustainable system is one that survives or persists through emerging stresses and shocks owing to the interactive nature of its components (Costanza and Palten, 1995). Sustainability does not mean that a system has an infinite life span, but a sustainable system is one that attains its expected life span consistent with temporal and spatial scale.

Agriculture is the lifeline for sustenance of life on earth. Agriculture encompasses every aspect of human survival by directly or indirectly connecting through the products consumed – from the air we breathe to the fossil fuels we depend. Sustainable agriculture development is a concept central to all future human endeavors. Agricultural sustainability in its broader sense means ecological sustainability. The transformation of agriculture from the situation of 'farming for subsistence' to 'farming for profits' with the backing of technological advancements in improved crop and animal varieties, fertilizers, pesticides, irrigation and mechanization has resulted in meeting the expected demand of goods and services from agriculture, but with disregard to their negative impacts of decline in resource base both in quantity and quality. The need for bothering about agricultural sustainability is an awakening of twentieth century wherein the technological developments in agriculture, industry and infrastructure for human comfort is falling short of support systems and resources to match the steep increase in human population with enhanced life expectancy and economic growth. From the thinking of human beings as external to the ecosystem to the knowledge about finiteness of earth's resources and human beings as part of the ecosystem is the prime driver to assess the sustainability and carrying capacity of ecosystem in general and agriculture in particular to sustain anthropogenic interests. Advances in the science of ecology in the 1970s highlighted the interaction and interdependence of the natural resources of land, water, air, and biodiversity and the life support systems they provided for our ecosystem and their capacity to provide life support, though vast, are not infinite and are only conditionally renewable. In its study, *The Limits to Growth* (Meadows *et al.*, 1972), the Club of Rome advocated calling a halt to further economic growth to serve the planet. Lester Brown and Paul Ehrlich, among others, became strong critics of uncontrolled population growth and its role in environmental degradation and advocated drastic deceleration in its rate (Brown and Kane, 1994; Ehrlich, 1968; Ehrlich and Ehrlich, 1990). The International Union for Conservation of Natural Resources (now the World Conservation Union; IUCN *et al.*, 1980) made it clear that human survival and development were inextricably linked to the conservation of the natural resources of our ecosystem. The United Nations World Commission on Environment and Development (WCED) in, Norway in 1987 reiterated in principle the concerns of the Club of Rome and the IUCN with a more positive and pragmatic prescription for future development.

Our Common Future (also known as the Brundtland Commission Report) defined sustainable development as “development that meets the needs of the present without compromising the ability of future generations to meet their own needs with a process in which the exploitation of resources, the direction of investments, the orientation of technological development, and institutional change are all in harmony and endorse both the current and future potential to meet human needs and operations (WCED, 1987). The report alerted the world community to the severe degradation of the environment, especially in the industrialized countries. This degradation was not sustainable because the global ecosystem’s capacity to provide resources and absorb wastes is finite, and so unlimited growth could jeopardize the chances of future generations realizing their needs.

By 1990s, environmental degradation, which had started escalating in the early 1960s in the developed nations as a result of industrialization and intense agricultural operations, had spread to very large areas of the globe, including the developing countries (Raman, 2006). It became evident that the widespread and large scale plundering of natural resources could aggregate and cascade into severe, technologically irreversible, and permanent impairment globally and at places far removed from the site of the original pillaging. There were clear indications that human economic activities were exceeding the source and sink limits of the global ecosystem.

The gravity of sustainability of present day life style of people on earth was assessed by Tim De Chant (2012) in terms of ecological footprint expressed as number of square miles that is approximately equal to the number of earth’s resources required to maintain the *status quo* of life style (sustainability) (Fig 1). It was found that China need just 1.1 earth’s resource, Bangladesh and Costa Rica would require 1.4 times earth’s resources While India and Nepal need double the earth’s resources, Uganda and France need 2.5 earth resources, USA need 4.1 earths and UAE need 5.4 earth’s resources.

The greatest challenges for sustaining the present status and to meet the necessities of future generations are the diminishing carrying capacity of the ecosystem services of our planet in all its ecologies. Indications of dangers are loud and clear through the effects of climate change manifestations. Humans were appropriating more than 40% of all the net primary product of terrestrial photosynthesis (Vitousek *et al*., 1986). Almost 40% of crop land had been degraded in less than four decades, and almost 25 billion tonnes of top soil was being lost to erosion every year. Severe depletion of fossil fuel and water shortages in many countries became a cause for worry. Clear indications of anthropogenic climate change led to the constitution of the Intergovernmental Panel on Climate Change (IPCC) in 1988 to study the problem. All these factors, combined with excessive loss of biodiversity, signaled an obvious threat to agricultural production and the life-support systems provided by nature. Uncontrolled population growth and asymmetric economic growth and environmental degradation also subverted the socio-economic system and imposed various kinds of socio-economic stress arising from glaring inequalities in empowerment, standards of living, health, livelihood opportunities, food security and so on. The danger of these developing into threat to regional and global security and peace became a cause for concern.

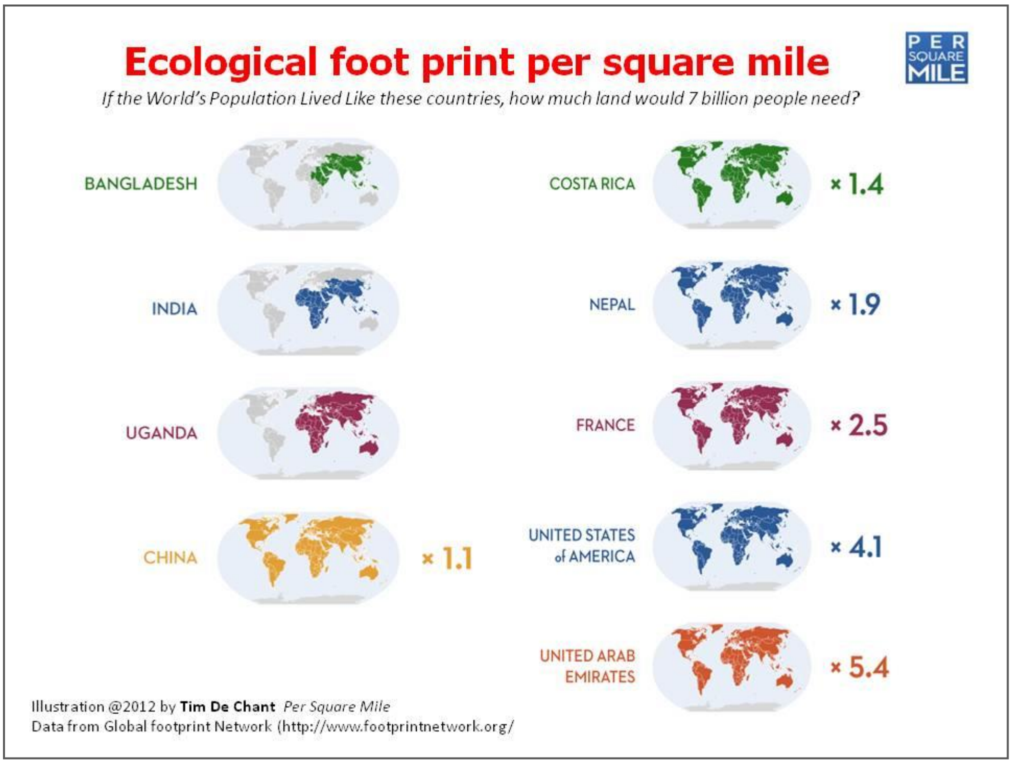

Fig 1. Ecological footprint per square mile (Tim De Chant, 2012)

The Brundtland Commission, therefore, advocated an alternate paradigm of all round, sustainable development that ensured economic growth coupled with the safety of the biophysical environment, social equality and harmony so that minimum standards of living became a prerogative of all people. Sustainable development thus can be looked upon as harmonious re-conciliation of economic growth, environmental safety, and the social well-being of all communities around the world in a mutually reciprocal and reinforcing way and within environmental limits of our planet. Sustainable development has been widely accepted as a concept that must be central to all future human endeavors. In very simple terms, the concept can be said to combine two basic notions: economic development and ecological sustainability (Braat, 1991). If a system or an activity fails to include these two notions, it does not represent sustainable development.

Historical Perspective

Ever since the concept of sustainable development was highlighted as a paradigm for intergenerational equity by WCED, the topic of sustainable agriculture has come to occupy center stage. However, the credit for first understanding and articulating the importance of sustainability in agriculture should go to a Roman landowner, Marcus Terentius Varro, of the first century BC. According to Varro, agriculture is a science which teaches us what crops are to be planted on each kind of soil and what operations are to be carried on in order that the land may produce the highest yield in perpetuity (Conway, 1997). This is probably the most elegant and succinct description of the concept of sustainable agriculture yet given and forms the core of most-later expositions of this topic.

Agriculture marked the beginning of the manipulation of nature by humans. Agricultural development from the stage of nomadic agriculture to settled agriculture; technology enabled vertical improvement in productivity, economic aspect of agriculture for trade; urbanization, globalization and specialization for economic supremacy; excessive dependence on off-farm resources has gradually eroded the sustainability that was characterized by the strength of diversity and inter-dependence of farm resources. To meet the diametrically opposite ends of development (economic) and sustainability (ecological) to be addressed simultaneously, require re-engineering the present model of agricultural development (Sudhakara Babu, 2016). The evolution of the concept of agricultural sustainability, as it stands today can best be understood by tracing the coevolution of agricultural practices and production systems with human needs and ingenuity. Subsistence agriculture was practised for almost 6000 years of the preindustrial era, from 8000 to 2000 BC, without much disruption of nature. The shifting cultivation practised in the early days and the traditional agricultural systems of the ancient civilizations of India, China, the middle-East, and so on were durable for thousands of years and provided adequate yield to support the low level of population that existed at that time. Franklin King, a professor at the University of Wisconsin in the early 20th century, wrote a landmark book, *Farmers of Forty Centuries* (King, 1911), on how the integrated use of soil nutrient recycling, animal manure, and agricultural residues maintained the productivity of the traditional agricultural systems of the orient for thousands of years.

Historical perspective of sustainable agriculture has been reviewed extensively and succinctly presented by Raman (2006) as briefly excerpted in this article. A steep increase in population to 500 million during the period 2000 BC to AD 1500 required the expansion of agricultural activities and intensification of agricultural practices. This forced the extension of cultivation to vulnerable areas such as hills, wetlands, and drained swamps. The adoption of new innovations in the form of animal power, heavy ploughs, terrace formation and an expanded crop portfolio (use of legumes, crop rotations, etc.) known collectively as the Norfolk Revolution, after changes in East Anglia, England, during the 1700s, became widespread during this period. Agricultural intensification led to processes of degradation of natural resources like soil erosion, water-logging and salinization in several areas. The earliest recorded instance of flawed management of the natural resources of soil and water leading to a failed agricultural system can be traced to Sumeria in central Asia during 4000 to 2000 BC. Salinization, arising from faulty irrigation practices without drainage, resulted in the gradual destruction of an evolved irrigated agricultural system and brought to an end the advanced Sumerian civilization and its thriving agriculture. Disasters of the Sumerian type were repeated in several other areas of the world, leading to the destruction of more civilizations, such as the Mayan civilization in South America, the Harappan civilization in the Indus Valley, and the Chinese, Roman and Greek civilizations, owing to factors including drought, soil erosion, climate change, and water-logging. The demise of ancient civilizations primarily due to failed agricultural systems confirms that sustainability of agriculture is a *sine qua non* for the perpetuation of human civilization. According to Holmberg *et al*. (1991), sustainable agriculture is not a luxury. When an agricultural resource base erodes past a certain point, the civilization it has supported collapses. There is nothing like a post-agricultural society.

During the period 1500 to 1825 AD, the global population doubled to one billion and agriculture turned from a subsistence base to a commercial one. Great strides were made in crop production management such as tillage and crop rotation including legumes. Simultaneously, Industrial Revolution also swept across Europe. Rapid population growth, industrial and agricultural revolutions interacted in complex ways to hamper agricultural growth as there was shift in favour of industrial activities and urbanization. The famine like situation in England during 1794 to 1800 due to poor harvests, inadequate food availability and high prices for agricultural commodities, prompted Malthus to write his famous

Essay on the Principle of Population, in which he articulated the fear that mismatch between the productive capacity of the land and increasing population could lead to famines and death on a large scale (Malthus, 1798). This is the earliest record of such concern about the limited capacity of the natural resource of land to balance agricultural production and population growth.

The century from 1825 to 1927 ushered in an era of hope in the form of discovery of a whole series of scientific principles of crop production that helped to forestall the Malthusian prophecy coming true and became the foundation for the spectacular growth of agriculture in later times. This marked the beginning of the period of the triumph of human ingenuity over nature that has continued to feed the world since, despite more than six-fold growth in population. Rapid technological advances during the period 1927 to 1960, based on scientific principles of the previous century, helped human kind to make great strides in agricultural production and productivity. Wilcox (1936) lucidly documented the efforts and progress made in the field of crop nutrition through the works of Mitscherlich and Liebig that was accepted as science of Agrobiology, and provided quantitative (mathematical) relationship between plant growth and growth factors, and their limits of response individually and in relation to other factors. This has promoted use of manure and nutrients for increasing plant growth and yield. The world population reached the 3 billion mark by 1960. The period from beginning of 19^{th} century until 1950 saw large-scale expansion of the area for agricultural production owing to the availability of fossil fuels and the adoption of mechanization in the industrialized countries. The golden era for agriculture continued from 1960 to 1975 in the developed countries, where science and technology were fully exploited to maximize agricultural productivity. The phenomenal increase in the populations of developing countries during this period subsistence oriented traditional agriculture could not meet the demand and rightly provided unlimited opportunities to the developed countries to export agricultural commodities to them. Agriculture thus became a major productivity and profit oriented economic enterprise in the United States and Western Europe.

Agriculture and Ecosystem

Agricultural intensification relying heavily on external inputs caused remarkable improvement in productivity but led to the decline in sustenance on long term and shown trends of declining soil quality and environmental issues for human health. By the late 1970s, U.S. agriculture was suffering the consequences of severe land degradation as a result of erosion, depletion of soil organic matter, loss of biological activity, salinization from excessive use of fertilizers and water, and severe environmental pollution owing to agricultural runoff. Agriculture became the largest non-point source of pollution, with nitrate and pesticide residues polluting even ground water adversely affecting the health of the ecosystem. The safety and health of livestock and humans were threatened by the indiscriminate use of pesticides and antibiotics in livestock, which flooded the food chain. High yielding monoculture not only led to large scale erosion of genetic resources but also resulted in the proliferation of new pests and pesticide resistant strains and the need for new pesticides and higher doses. Agriculture had become environmentally unsafe and provoked strong reaction from environmentalists in the 1970s, who called for closer-to-nature models of agriculture. The major breakthrough in creating public awareness by Rachel Carson (1964) documented in *Silent Spring* against the ill effects of pesticides (DDT) on environment and health caused for incorporating environmental concerns of sustainability of modern technologies. The basic philosophy of these models was one of using natural processes and local materials as opposed to the external synthetic inputs of industrial agriculture.

The theory of agro-ecology, which developed into an accepted scientific discipline around the 1970s, sought to highlight the possibility of a scientific yet durable agricultural production paradigm based on a synergistic relationship with natural resources and processes. The most noteworthy contribution to sustainable agriculture came from the system of regenerating/alternate agriculture, which evolved in parallel with industrial agriculture in the United States. It combined judiciously and selectively the products of newer technologies (such as improved crop cultivars, mechanization, and soil testing to allow the measured addition of fertilizers) with natural processes (nutrient cycling, pest control, crop production, and so on) to conserve resources and prevent pollution. This was the real birth of a science-based paradigm of sustainable agriculture. The credit for coining the term sustainable agriculture in 1970 should go to Eva Balfour, who was a proponent of the alternate agriculture model and believed strongly in the need for harmony with nature. Robert Rodale was another pioneer of regenerative agriculture who believed in observing natural soil processes to ensure perpetual productivity (Rodale, 1983; Harwood, 1990).

Sustainable Development and Sustainable Agriculture

The concept of sustainable development became an appropriate basis for defining future development goals for agriculture. Although Brundtland Commission Report mainly targeted the environmental damage caused by intense industrialization, it made explicit references to deficiencies in world agricultural systems and also the need for a new holistic approach. The report advocated agricultural systems that focus as much attention on people as they do on technology, as much on resources as on production, as much on the long-term as on the short-term. This was the harbinger of a new paradigm of sustainable agriculture.

Sustainable agriculture was quickly acknowledged as the most important component of sustainable development. International organizations such as Food and Agriculture Organization (FAO), the World Bank, and the Consultative Group on International Agricultural Research (CGIAR) made sustainability the basic objective to be pursued in all their future programmes in agriculture.

Sustainable Agriculture: Definitions

"Sustainable agriculture is the successful management of resources for agriculture to satisfy changing human needs, while maintaining or enhancing the quality of the environment and conserving natural resources" CGIAR/TAC, 1988.

The CGIAR definition does not include the economic and social aspects of sustainable agriculture overtly because CGIAR's mandate was focused on improving production and productivity.

The American Society of Agronomy in 1989 adopted a more holistic view of sustainable agriculture and came up with the following definition:

"A sustainable agriculture is one that over the long-term, enhances environmental quality and the resource base on which agriculture depends; provides for basic human food and fiber needs, is economically viable; and enhances the quality of life for farmers and society as a whole". ASA, 1989. Sustainable agriculture thus operates within the bounds of physical and biological resources on the one hand and socio-economic viability and quality on the other.

The definition by G.K. Douglas (1984) formulated little earlier captures the essence of sustainable agriculture in its totality. “Sustainability must be regarded as long-term food sufficiency which requires that agricultural systems be more ecologically based and do not destroy their natural base. Sustainability as stewardship means that agricultural systems are based on a conscious ethics regarding humankind’s relationship to future generations and to other species in nature. Sustainability as a community means that agricultural systems are equitable. Agricultural systems cannot be sustained if there is gross misdistribution of land, wealth and power. Social tensions and upheavals in many parts of the world are often manipulations of such inequalities”.

Another definition by Mac Rae *et al*. (1990) argues that, Sustainable agriculture is both a philosophy and a system of farming. It is rooted in a set of values that reflects an awareness of both ecological and social realities and a commitment to respond appropriately to that awareness. It emphasizes design and management procedures that work with natural processes to conserve all resources and minimize waste and environmental damage while maintaining and improving farm productivity”.

Any definition of sustainability must recognize its multiple dimensions: physical, economic, ecological, social, cultural and ethical. Sustainability can be defined only in the boundaries of a system’s framework, that is, after specification of what is to be sustained. Choosing the boundary is difficult because agricultural systems operate at multiple levels: soil-plant system, cropping system or farming system, agro-ecosystem and so on to higher regional, national, and global levels (Lynam, 1994). The level chosen thus also defines the spatial scale of operation for the definition. Decisions at the farm level have impacts at the agro-ecosystem and higher levels and *vice versa*. The linkages between agricultural systems at different levels of hierarchy (spatial scales) are important (Rao, 2002).

While there are differences in emphasis among the definitions, they are generally concerned with the need for agricultural practices to be economically viable to meet human needs for food, to be environmentally positive, and to be concerned with quality of life.

Agriculture is not linked to any particular technological practice since the objectives of sustainability can be achieved in a number of different ways as opposed to the exclusive domain of organic farming. The buffering capacity of agriculture to adapt to the changes in the resource base/demands over time qualifies as sustainable. The role of technology in aiding this process is the need of time conducive to sustainability. The principles of conservation, complementarities and rejuvenation of resources are the guiding principles for development of sustainable agricultural technologies as per the dynamics of demands of society and environment.

Rao (2002) outlined the determinants of framework of sustainable agriculture as:

1. The food demand of the growing population and economy (sustainability goals), and the supply limits set by carrying capacities of the agro-ecosystem (system capacities),
2. The trade-offs between agricultural productivity and quality of the natural resource base in different regions/agro-ecosystems as assessed by trends in suitable sustainability indicators, (Are the levels and growth of production sustainable?), and

3. Emerging technologies and improved management strategies that can shift the tradeoffs towards improving both sustainability and productivity. (Can prospects for long term sustainability be improved with new technologies and management?)

The framework is to be applied at two levels: the crop production system level and the agro-ecosystem level. For agriculture to be sustainable, it must be profitable in the short term. Thus two level perspectives - the short term and long term - are also needed. The sustainability indicators of profitability and social concerns based on income generation and distribution are effective in the short term compared to the ecosystem health indicators, which require a longer time to take effect The analytical framework is complete when the systems at different hierarchical levels are linked in a scheme that permits the three questions above to be asked and answered at each level.

The more the developments in science, the more clarity emerges about the intricate relationship and balance between myriad factors both biotic and abiotic, in influencing the outputs of agriculture. A systems perspective is therefore essential for understanding sustainability. An emphasis on the system allows a larger and more thorough view of the consequences of farming practices on both human communities and the environment. A systems approach to understand and decipher the concerns of sustainability require inter and multi-disciplinary efforts in research and education. The concerns and involvement of various stakeholders *viz*., farmers, farm workers, consumers, policy makers and others as consumers and managers is essential to develop sustainable agricultural practices.

Making the transition to sustainable agriculture is a process and is continuous. In short term, for farmers, the transition to sustainable agriculture normally requires adoption of efficient methods and products of resource use, reliance on on-farm resources, science based farming, niche areas farming for market oriented agriculture, value addition, etc. Family economics and personal goals influence the degree of adoption of technology. In long term, the objectives of soil health monitoring, infrastructure development, minimizing losses, insurance against natural calamities, credit and market policies, etc would align with the broad objectives of sustainability. As understood from the intricate relationships of factors, each improvement at individual level can bring about multiplier effects on interdependent factors towards sustainability just as opposed to the present crisis of unsustainable situation for lack of corrective actions.

Components of Sustainable Agriculture

Human development, economic development, and social development are considered the most crucial areas for the attainment of sustainable development in the course of the next two generations (NRC, 1999). Food security is at the core of human development, which includes several other parameters such as health, education, shelter, longevity and basic amenities. Declining per capita arable land and water and necessity for achieving higher agricultural productivity to meet the growing demands, the green revolution technologies of sixties – HYVs, fertilizers, pesticides have been used indiscriminately. Realizing the negative impacts of continuous reliance on such technologies with advancements in science and technology, sustainable development strategies are developed for sustainable agriculture with due care for the factors that are impacted by agriculture, such as productivity, ecological safety, economic viability, and social responsibility and equity. If a system is not ecologically sustainable, it cannot persist in the long run and cannot be productive and profitable. Similarly, if a system is not productive and profitable, it cannot be sustained economically no matter how ecologically sound. Social acceptability, harmony and equality are critical to the sustainability of agriculture or any other human development system.

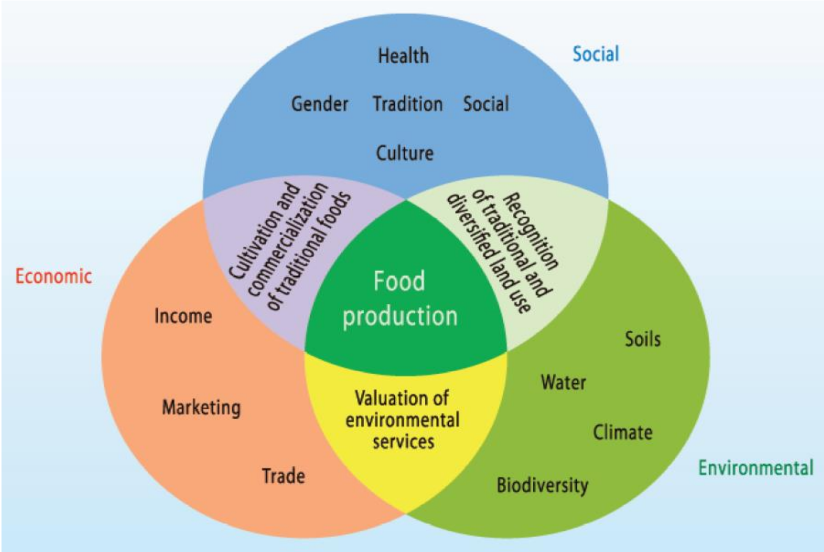

Fig 2. A generalized diagram showing interrelationships between basic components of sustainability (IFOAM)

Productivity: Vertical improvement in crop yield is inevitable under the ever declining per capita arable land. This is compounded by the competing demands for land and water from profitable ventures of industry and urbanization through special economic zones, further complexed due to practicing agriculture in sub-optimal agroecological conditions. The needs are compelling and resources are limiting. Sen (1981) developed the concept of 'entitlements' as a vehicle for access to food. Various types of entitlements made people food secure. This has led to the realization that maintaining productivity per unit area of land at sustainable yield that is within the productive capacity of the land is a basic condition for the sustainability of an agricultural production system. The twin challenges of decreasing *per capita* arable land and limits to intensification through the current practice of increasing external inputs have necessitated a search for newer, alternative paradigms for increasing both production and productivity with acceptable levels of adverse ecological and socio-economic impacts. This is the current concern in terms of the productivity component of sustainable agriculture.

Owing to the combined efforts at individual farmer, regional, and national levels, global food production has so far been sufficient to feed everyone if the food were distributed according to needs (Pinstrup, 2002), thus bringing in the equity issue of sustainability. This has been achieved mainly through productivity increases since the 1950s, through the intensification of agriculture by the land-saving technologies of high yielding varieties/breeds of crops and animals fertilizers, pest control chemicals, irrigation and time-and labour-saving machinery. Unbridled use of these external inputs in the last six decades has given rise to an unprecedented scale of environmental pollution; degradation of agricultural lands through erosion, salinization, water-logging, and so on; and economic challenges as a result of the increasing cost of purchased inputs.

It is very clear now that there are ecological, environmental, economic, and even social limits to intensification in many of these over-exploited areas, where lower rate of growth, lowering of factor productivity, and even yield declines are surfacing. In addition, the high cost of production and low profitability are threatening the sustainability of the levels of productivity of these intensive cultivation systems (Cassman *et al*., 1997; Ladha *et al*., 2003; Pingali *et al*., 1995).

Economic Viability: With growing needs of human development and comfort, the practice of agriculture has grown from "subsistence to profit" and from "local to global" in domain, directly affected and adjusted by the dynamics of market demand, modified by socio-economic-political compulsions. Although economic viability is directly linked to productivity, it is neither static nor stable as demand for farm products varies with the dynamics and specific needs of a human population and with the agricultural and non-agricultural policies of local, state and national governments. Economic profitability for the farmer is essential if agriculture is to be sustainable.

At the global level, countries may be guided by different sets of circumstances in setting the price of their agricultural products. Countries such as the United States and the nations of Western Europe, including the Netherlands, produce very much in excess of their own needs and turn agriculture into an export advantage. Hence, their policies are different from those of countries that need to import food. These countries offer huge subsidies to farmers to facilitate exports and to keep local food prices low. For countries such as India and China, where a large percentage of population is dependent on agriculture and where the share of agriculture in the national economy is disproportionately large, pricing policies have to be different to balance affordability for local people, export competitiveness and import rates for deficit commodities.

Ecological Viability: The modern methods of agriculture production of plants and animals with reliance on monocultures, improved plant types with high productivity potential that demand higher qualities of nutrients and water, powerful pesticides that aims to eradicate the pests (weeds, insects and weeds), modified production environment through poly houses for overcoming weather dependency of agriculture, mechanization etc., undoubtedly increased the yields and profits but caused lasting negative impact on soil and environment and biota. Increased greenhouse gas emissions, loss of diversity of crops, fauna and flora, development of pesticide resistance and resurgence, nutritional imbalance in produce due to specialty produce, displacement of cattle population, modified micro-climate affecting larger macro-climate in the region, associated infrastructure development of warehouse, cold storages, roads, transport, etc. is seriously impacting the regional/local ecological balance. Conservation and enhancement of the quality of the natural resources of land, water, air, and biodiversity to sustain biological productivity and ecosystem services is basic to sustainable agriculture. Maintaining the ecological viability of agricultural production systems is more complex than the sustainability of natural ecosystems, because an agro-ecosystem is a system of human intervention with mandatory goals.

Conserving the production resource base and maintaining environmental safety and quality are the basic criteria for the ecological sustainability of agricultural production. Short-term biological productivity alone is not an indicator for ecological health or the integrity of the system. Ecological processes, to use a metaphor of the 'agriculture factory' (Vandermeer, 1992), need to be overhauled and serviced to remain fit for use through proper management techniques involving efficient use of inputs. Apart from guarding the resource base, this will also reduce environmental pollution and degradation and keep them within the absorptive capacity of the environment. Attributes such as soil quality, fertility balance, and other indicators of sustainability are manifestations of healthy ecological processes and of natural resources that have not had their physical, chemical or biological integrity compromised.

Agricultural systems operating on agro-ecological principles with reduced use of external inputs and non-renewable resources are more ecologically sound than those that depend predominantly on external inputs, which have the potential to damage resources, the environment, livestock, wild life, soil microorganisms, useful insects like pollinators and predators. Increasing biologically favourable inputs such as crop residues, manures, green manures, legumes, crop rotations, biological pest control, and minimum tillage facilitates better use of ecosystem services and enhances ecological soundness. A wide variety of farming practices developed at different times in different regions, such as organic farming, alternate farming, ecological farming, and biodynamics, represent a greater degree of ecological prudence and soundness in terms of resource conservation and environmental safety than modern systems. The human element in agriculture makes it somewhat subjective and value oriented. Agricultural systems have the imperative to sustain biological productivity as their primary goal. In addition, they have to fulfill other aspects of human welfare such as sustaining life-support services, adequate profitability, and social responsibility toward rural farming communities.

Social Acceptability: Social justice and equity, the fourth component of sustainability, is even more complex. It is more a phenomenon external to the farm and natural resources but of human values that impacts on the farming practices and level of adoption of technologies acceptable to the social norms in the farming community. It is also linked to the macroeconomic policies of the governments and countries to encourage or restrict adoption of particular technology or resource through curbs and promotions. It also encompasses a plethora of definable as well as vague parameters such as poverty, cultural factors, education, social capital, justice and equity, value systems, food security at the household, regional and national levels, livelihood opportunities, and government policies.

Broad differences exist depending on whether the farmer is predominantly a subsistence farmer or a commercial farmer. The acceptability or otherwise of a specific mode of cultivation also depends on the physical resources available. For example, poor farmers and farmers who own complex and risk-prone lands such as arid and semi-arid regions of India and Africa could not benefit from Green Revolution technology, which requires level, healthy soil with assured irrigation and other inputs such as fertilizer, pesticides, and tractors for timely crop operations. At times, the notion of social equality tends to include utopian ideas without taking into account their economic and ecological implications. The performance and status of sustainability under different agroecosystems are delineated by Gliessman (2005) (Table 1).

Table 1. Properties of natural ecosystems compared with modern and sustainable agroecosystems

Property	**Natural ecosystem**	**Modern agroecosystem**	**Sustainable agroecosystem**
Productivity	Medium	High	Medium (possibly high)
Species diversity	High	Low	Medium
Functional diversity	High	Low	Medium–high
Output stability	Medium	Low–medium	High
Biomass accumulation	High	Low	Medium–high
Nutrient recycling	Closed	Open	Semi-closed
Trophic relationships	Complex	Simple	Intermediate
Natural population regulation	High	Low	Medium–high

Resilience	High	Low	Medium
Dependence on external inputs	Low	High	Medium
Human displacement of ecological processes	Low	High	Low–medium
Sustainability	High	Low	High

Gliessman (2005).

Prioritization

All the components of sustainable agriculture together form the foundation of agricultural sustainability and need to be considered *in to to*. But, trade-offs and compromises are often necessary in the pragmatic pursuit of sustainability. Productivity and ecological soundness would take priority precedence among the elements from a global perspective, over economic and social viability, because food security is contingent on adequate *per capita* productivity. Permanence of productivity is dependent first and foremost on the ecological base for production. Unless this is kept in sound health, not only productivity but also other life-support functions will be affected. Sustainability is basically a resource issue. Ecological limits exist to biological productivity and hence to sustainable intensification of agricultural production systems. This is corroborated by the fact that a number of intensively cultivated systems are showing signs of yield fatigue or saturation. When humans try to tilt the balance too much in their own favour, a backlash occurs in the form of yield plateauing, a decrease in factor productivity, or even a decrease in yield. In extreme cases, even the life-support systems are in danger (Cassman and Harwood, 1995).

Economic viability will follow productivity and ecology because it is a strong mobilizer and enabler of agricultural productivity. Globally, except in small and remote pockets of the world, agriculture has metamorphosed from subsistence to a strong commercial and economic activity with a powerful profit motive. Adequate economic returns are required for agricultural sustainability because all human interventions cost money. Sustainable systems have to be economically viable either naturally or by human intervention. Since a healthy ecosystem is productive and profitable, farmers generally have a stake in adopting ecologically sound farming practices. However, conflicts arise between short-run interests of individuals and the long-term interests of communities and ultimately the whole of humanity. Economics has come to be such a dominant factor in agriculture that it has become the agent of destruction of ecological health, not only at the level of individuals but even at national levels. The widespread resource degradation and environmental pollution of intensive cultivation are a consequence of profit first priority. This can be countered through such policy measures as providing economic incentives to individuals to follow good practices in ways consistent with long-term societal interests.

Social acceptability, equity, and justice are undoubtedly very important and can not be negotiated or compromised. Agricultural systems need to benefit all humans, at least to the extent of providing their basic needs of food and other components of human development. Unfortunately, current food systems are quite harsh and unjust toward rural peasants and the poor, especially in the developing countries. This is not desirable situation and indicates a threat to agricultural sustainability. Agriculture is the creation of human society and it can also be destroyed by human society if proper safeguards are not put in place.

The absence of economic security and social justice is not sustainable over long periods and will result in social conflicts, which may lead to irreparable economic and ecological damage. Agriculture that fails to sustain a society will not be sustained by that society. Hence, socially responsible agriculture that meets basic human needs equitably and provides social equality is critical to the long-term sustainability of agriculture. It is up to the society at the global, national, regional, community, family, and individual levels to find answers to such problems. In this, both producers and consumers have equal stakes.

Agricultural systems need to be constantly monitored if they are to overcome the various types of stresses they develop, including social impacts on farmers and rural communities, economic strains on consumers and pressures on the environment. Destroying any one of the critical elements of the agrosystem will damage the other elements as well and essentially destroys the whole system. The risks arising from a lack of sustainability at one place can be counteracted elsewhere in the global agriculture system temporarily and to a limited extent. If the stress caused by one sub-system exceeds a certain threshold, however, the danger arises of subverting the whole system.

Agriculture in India

Analysing the growth of agriculture in India since independence through the achievements of green and yellow revolutions to the present state of yield stagnation, cost escalation, soil fertility degradation, build up of pest resistance and diversity, declining resource use efficiency of nutrients and water, etc. itself provides volumes of learning about the short term success and long term threats of sustainability (Sudhakara Babu, 2016). India is predominantly an agrarian economy, with agriculture even during 2013-14 contributing 14% of GDP with nearly 56% of the population engaged in agriculture. Until early part of 20^{th} century, traditional systems of agricultural production were pre-eminent, and durable. Many clues for modern scientific technology development are rooted in deciphering the causes for the traditional practices being followed over long period. However, with rapid increases in population, the modest productivity of traditional systems could no longer meet the food needs. Agriculture remained primitive due to lack of such enabling technologies as fertilizers, efficient cultivars, and pesticides, and also of proper policies. Food shortages were putting survival at stake until 1960s. In the mid-1960s, India faced extensive and protracted droughts in addition to its already precarious food situation. Severe famines were predicted by the Paddock brothers, William and Paul, in *Famines-1975*! for India along with many other countries. Total gloom prevailed during the early 1960s for agriculture in India. The country countered such desperate situations by setting up effective national agricultural systems to strengthen agricultural education, research and extension at an accelerated pace. The Indian Council of Agricultural Research (ICAR) established in July 1929, was reorganized in 1966 to unify agricultural research, education and extension in the country. It has evolved into a model for several developing countries to emulate. Generous and long-term financial help from international donor agencies such as the Ford Foundation and the Rockefeller Foundation and technical cooperation from several international research centres under CGIAR, which provided a tremendous boost to agricultural productivity during late sixties onwards. In addition, large numbers of State Agricultural Universities were established in different states of the country starting from Gobind Ballabh Pant University of Agriculture and Technology (GBPUA&T) in Uttar Pradesh, following the pattern of land grant colleagues in the United States, where teaching, research and extension in agriculture were integrated.

The introduction of dwarf varieties of wheat and rice with a high harvest index and high nutrient utilization efficiency, coupled with better agronomic inputs and practices, such as fertilizers, irrigation, and pesticides, increased productivity dramatically not only in India but also in many of the South and South-East Asian countries. Enlightened and enabling support in the form of the supply of inputs and policies by the governments of the day played a key role in the agricultural revolution that took place in different countries including India. These factors, along with active participation by the farmers, transferred them from food-deficit to food-sufficient and even food-surplus countries within a short span of time. William Gaud, the then Director of the United States Agency for International Development (USAID), christened this the "Green Revolution" in 1968, a phrase that has become widely written about in global agriculture. Agricultural production almost tripled from 1950 to 1975. The addition of one more billion people to the global population between 1975 and 1987, mostly in the developing countries, passed off without raising great concern about food security owing to the widespread benefits of the Green Revolution.

Agriculture in India can be justly proud of its achievements since the mid-sixties. The total food production has touched more than 259 million tonnes (2013-14) compared to just 50 million tonnes during 1950-51. The *per capita* food production has increased by more than 20% and agriculture has contributed substantially to overall economic development. The high-yielding, input-responsive varieties of rice and wheat and supportive government policies led to cereal-based green revolution. But, these successes were accompanied by two shortfalls. First, there was considerable unevenness in the food production progress in different commodities and ecologies. Rice and wheat yields increased in ecologies and management systems that provide good level of water and nutrients. But, the production of most other crops grown in regions less endowed with crop production potential was not as successful. A second shortfall generally identified with cereal-based green revolution was as inadequate focus on environmental issues. Green revolution technology, based on the high-external-input agriculture, started revealing its negative ecological mark during the 1980s. The concept of sustainable agriculture became more relevant to Indian agriculture today than even before.

Experience of the past four-and-a-half decades, plus an intelligent assessment of the future needs to achieve sustainable development suggests three major challenges in Indian agriculture. Firstly, due to continued increases in human population, future increases in food production must even exceed those of the remarkably successful past four-and-a-half decades. The expanded food needs must be met without major expansion in the area of land under cultivation. The added production must come primarily from increases in productivity. The second challenge is to move the green revolution into ecologies, systems and populations segments that up to now have not benefited significantly from technological advances. The third challenge is to couple food production efforts with those that enhance environmental quality. Every option for production improvement must take into consideration what it will do to environmental quality.

The National Agriculture Policy announced in July, 2000 provides the framework for planning and programme formulation in the agriculture sector. The policy sets out the following broad agenda (Hazra 2003):

- A growth rate in excess of 4 per cent per annum in the agriculture sector;

- Growth that is based on efficient use of resources and conserves our soil, water and bio-diversity;
- Growth with equity, that is growth which is wide spread across regions and farmers;
- Growth that is demand driven and caters to domestic markets and maximizes benefits from export of agricultural products in the face of challenges arising from economic liberalization and globalization;
- Growth that is sustainable technologically environmentally and ecologically.

The aspects of efficient use of resources with conservation, growth with equity, demand driven and sustainability are the hard tasks to accomplish given the background of agricultural diversity and stubborn traditions attached to agriculture in India.

Contextual Nature of Agricultural Sustainability

Sustainable agriculture has evolved as a complex and diffuse concept because of its multidimensional nature. Due to large number of definitions of sustainable agriculture, there has been a decline in clarity and rendered it a biased and value-laden concept. Raman (2006) emphasized the need for clearly understanding the contextual nature of agricultural systems before proceeding to analyze the conditions and means to make these systems sustainable.

Agriculture today is transformed into a variety of production systems at different places and at different times, such as hydroponics, greenhouse cultivation, high-external-input industrial agriculture, green revolution agriculture, traditional low-external-input agriculture, low/nil-input-resource-extractive agriculture, shifting cultivation, and natural ecosystems. The most important and fundamental difference among all these is the degree of human control/intervention that goes into them. Both supply and demand factors shape the type of agricultural systems and the practices that are followed. Together these factors determine the kind of production systems that can be used and the types of crops that can be grown in an area at a given point of time.

Raman (2006) delineated four groups of determinants-physical, biological, socio-economic, and cultural as important in the structuring and management of agricultural systems. Physical determinants include climate (temperature, rainfall, and radiation), land availability, and soil quality parameters such as physical, chemical, and biological properties, erosion, and water holding capacity, depth, and slope. Biological determinants include energy and biotic factors such as insect-pests and predators, weeds, plant diseases, functional diversity of soil biotic community, photosynthetic efficiency of the crops to be grown, crop rotations, and cropping patterns. Socio-economic and cultural determinants are the factors such as population density, economic and market opportunities (capital, credit, prices of inputs and outputs), policy issues, political relationships, availability, accessibility and affordability of technology, inputs, and labour, diets, work culture, traditional knowledge systems, socio-cultural beliefs and ethics.

Agro-ecosystems have co-evolved with the changing technological, biophysical, socio-economic and cultural determinants, all of which, independently and interactively, influence their evolution. Conditions outside the area of production, including industrial development, economic conditions, opportunities for employment in non-agricultural sectors, and capital availability, also affect the way production systems are designed and operated.

The determinants of agriculture are not spatially or temporally static. Changes can occur over comparatively short or long periods. Changes in these determinants change the type of agricultural system. The technological, socio-economic and political group of determinants is generally the primary engine of change, although biophysical changes such as resource degradation and environmental pollution can also trigger changes in production systems.

Sustainable agriculture seeks permanence to agricultural production systems to enable food security for all in an ecologically sound, economically viable, and socially responsible manner. In the current globalized and liberalized trade environment, changes that are favourable or adverse can occur over short periods to affect local and international prices and demand for agricultural commodities. Agricultural systems have to adjust to these changes to be sustainable. Sustainable agriculture requires the simultaneous maintenance of several complex dimensions, productivity, ecological integrity, economic viability, and social relevance. Each of these dimensions, by itself is complex and highly contextual, both spatially and temporally. In addition, inter-connections and interdependencies of various types and degrees exist among them that are also dynamic. More important, both synergistic and antagonistic relationships may be expressed simultaneously among the core tenets. Due to this, sustainability has become a highly complex and contested concept (Campbell, 1994). The concept of sustainable agriculture has been distorted and is often made more confusing and less exact by practitioners of various forms of agriculture vying with one another to stake their claims for sustainability analogous of the description of an elephant by five blind men from their own perspective. Thus, organic agriculture, regenerative agriculture, alternate agriculture, low-input traditional agriculture, biodynamic agriculture, and ecological agriculture have all been promoted under the banner of sustainable agriculture. It must be remembered that sustainability is contingent upon many factors: productivity, ecological, economic and social viability and acceptability; and the enabling factors of technology, policy, and service appropriate to local needs. Sustainability is not inherent in any particular set of practices or farming system, except that some forms of agriculture have more enabling factors for ecological sustainability than others (Raman, 2006).

Sustainable agriculture is not about finding a, or the right technology or protocol for the production process but about successfully adapting it to changing conditions. The crucial test of agricultural sustainability is that when any of the determinants change positively or negatively, agricultural practices, farmers, and communities should be able to adapt to the new circumstances and conditions. Sustainable agriculture is a process of learning about changes and adapting to those changes, and hence, the definition of sustainable agriculture should include the multidimensional elements of the space-time context. Harwood (1990) suggested a framework definition for sustainable agriculture that could be filled in with appropriate details according to the prevailing conditions in any country and the desired time frame. According to Harwood, "Sustainable agriculture is agriculture that can evolve indefinitely toward greater human utility with greater efficiency of resource use and in balance with the environment that is favourable to both human and most other species". The definition adopted by the FAO (1991) captures the multi-dimensional elements of sustainable development, especially with respect to the maintenance and the management of the resource base:

'Sustainable development is the management and conservation of the natural resource-base and the orientation of technological and institutional changes, in such a manner so as to ensure attainment and continued satisfaction of human needs for present and future generation. Such sustainable development (in agriculture, forestry and fishery sectors) conserves land, water, plant and genetic resources, is environmentally non-degrading, technically appropriate, economically viable and socially acceptable'.

This clearly rules out a rigid protocol for approaching sustainable agriculture. There is need for continuously evolving adaptive technologies and institutional support for conservation and sustainable use of natural resources within the framework required for adequate productivity, ecological security and environmental safety, economic viability and social responsibility. The basic tenets of agricultural sustainability remain constant irrespective of the kind of production system or practices employed, but the processes that guide agricultural systems toward sustainability depend on the context that shaped them, the kind and rate of changes that they are undergoing, and the trade-offs required among the components of sustainability. Different systems require different types and degrees of trade-offs among the elements to be compatible with the context and remain sustainable (Raman, 2006).

No permanently sustainable system can exist because no system can remain robust in the face of adverse conditions or remain relevant in a changing technological, socio-economic, and demographic environment. Often, it is more difficult to define what is sustainable than to perceive what is likely to become unsustainable and tailor practices to mitigate adverse factors. Our ability to detect unsustainability exceeds our ability to confirm or predict sustainability with confidence (Carpenter, 1998; Jodha, 1994).

The differences in approach to sustainability of different systems can be seen in the way ecological sustainability is enforced in different forms of cultivation. Conservation of the natural resources of land, water, air and biodiversity is the mantra for ecological stability in all systems. These generalized principles for maintaining the ecological soundness of agricultural systems have at various points of time been expanded to include specific interventions. The extent and mode of compliance differ under different situations, although the intent is the same. The successful attainment of agricultural sustainability depends on determining what is to be sustained, how, for how long, for whom, and at what cost (Altieri, 1995). Notwithstanding the fact that problems of agricultural sustainability are contextual and deserve differential consideration, agro-ecology has defined a set of basic criteria that are essential in all kinds of situations in the pursuit of ecological soundness (Altieri, 2002):

1. Strengthening the immune system of agricultural operations: stabilizing pests and nurturing natural pest control;
2. Decreasing toxicity in the system and environment through optimum use of external synthetic chemicals;
3. Optimizing metabolic functioning such as nutrient cycling and organic matter recycling;
4. Balancing regulatory systems – nutrient cycles, water balance, energy-flows, population regulation;
5. Enhancing conservation and regeneration of soil and water resources and biodiversity; and
6. Increasing and sustaining long-term productivity.

Indicators of Sustainability

Measuring sustainability is most challenging and complex and there can be no universal measure possible as per the wide expectations seen from varied definitions and varied dimensions.

RIEDC (1997) indicated a general broad measurable components under each hierarchical level of components of sustainability.

Hoang (2013) had analysed productive performance of crop production systems in an integrated analytical framework considering economic, institutional, physical, social and technological factors and indicated that in a dynamic analysis to make efficiency framework to be forward looking, climate change innovations in crop science to be incorporated.

Table 2. Sustainability indicators (Adopted from RIEDC, 1997)

Hierarchical level	**Sustainability indicators (Economic, social and environmental)**
Cropping system/ Farming system	Non-negative trends in: 1. Farm productivity 2. Net farm income 3. Total factor productivity 4. Nutrient balance 5. Soil quality 6. Residues in soil, plant, products 7. Farm water use efficiency 8. Farmer skills and education 9. Debt service ratio 10. Health 11. Time spent on other social cultural activities
Agro-ecosystem (Watershed, Agroecozone, etc.	Non-negative trends in: 1. Regional production 2. Regional income 3. Regional total factor productivity 4. Regional nutrient balance 5. Income distribution 6. Species diversity 7. Soil loss 8. Surface water quality 9. Ground water quality 10. Regional social and economic development indicators
Global, National, Regional Systems	Indefinitely meet the demands at acceptable social, economic and environmental costs.

Simon Bell and Stephen Morse (2008) has put together various facts of measuring sustainability from many angles and discussed the relevance and applicability of different propositions. From the simple measure of yield increase from a given enterprise to complex regional issues affecting individual farm’s growth and sustainability viewed from many dimensions are discussed. Interestingly, the AMOEBA diagram approach of plotting sustainable indices of each enterprise and monitoring over time provide a clear picture of how the changes are occurring and where interventions are required to control the situation – individually – or together.

Rai and Yadav (2002) assessed relative agricultural sustainability status in Haryana by using different efficiency indices that provided different alternate levels of targeted sustainability to be kept for achieving the accepted goals (Table 3).

Table 3. Relative Agricultural Sustainability Status in Haryana

Particulars	**Existing Plan**	**Suggested Optimal Plan**		
		I	**II**	**III**
Ecological Security Index (ESI)	0.73	0.73	0.73	0.72
Rank	1	1	1	1
Economic Efficiency Index (EEI)	0.33	0.35	0.36	0.38
Rank	2	2	2	2
Social Equity Index (SEI)	0.38	0.40	0.40	0.41
Rank	2	2	2	2
Sustainable Livelihood Security Index (SLSI)	0.480	0.493	0.496	0.503
Rank	1	1	1	1
Weighted SLSI	0.500	0.501	0.501	0.507
Rank	1	1	1	1

AMOEBA diagram developed and proposed by Brink Ten et al., (1991) effectively integrate and monitor the different indicators of sustainability. Joshi *et al*., (2002) has compared the changes in sustainability of wheat and rice in different regions of the country using AMOEBA diagram over two time periods. The spokes of the wheel indicate each region and the solid and dotted lines indicate the sustainable yield index at period 1 and period 2 respectively (Fig 3). This provides good assessment for monitoring and correcting the situation as per the need. In general, the sustainability has decreased over the period from 1966 to 1996 in different rice growing regions in the country. The sustainability of rice has shrunk from a high of 3.0 during 1966 to a low of 1.5 in three decades in Arid regions followed by Central alluvial plain. Whereas in Baring plain region, it has improved from <1 to 1.3, in Vindyan region it has increased from 1.0 to 1.5. Similar to rice, the sustainability of wheat had also decreased over the period from 1966 to 1996 in different wheat growing regions in the country with similar trends followed as that of rice. Such decline in sustainability of the two major food crops in the country poses serious implications on the food security of the country with growing population and demand despite lesser proportionate consumption of the two cereals in direct form.

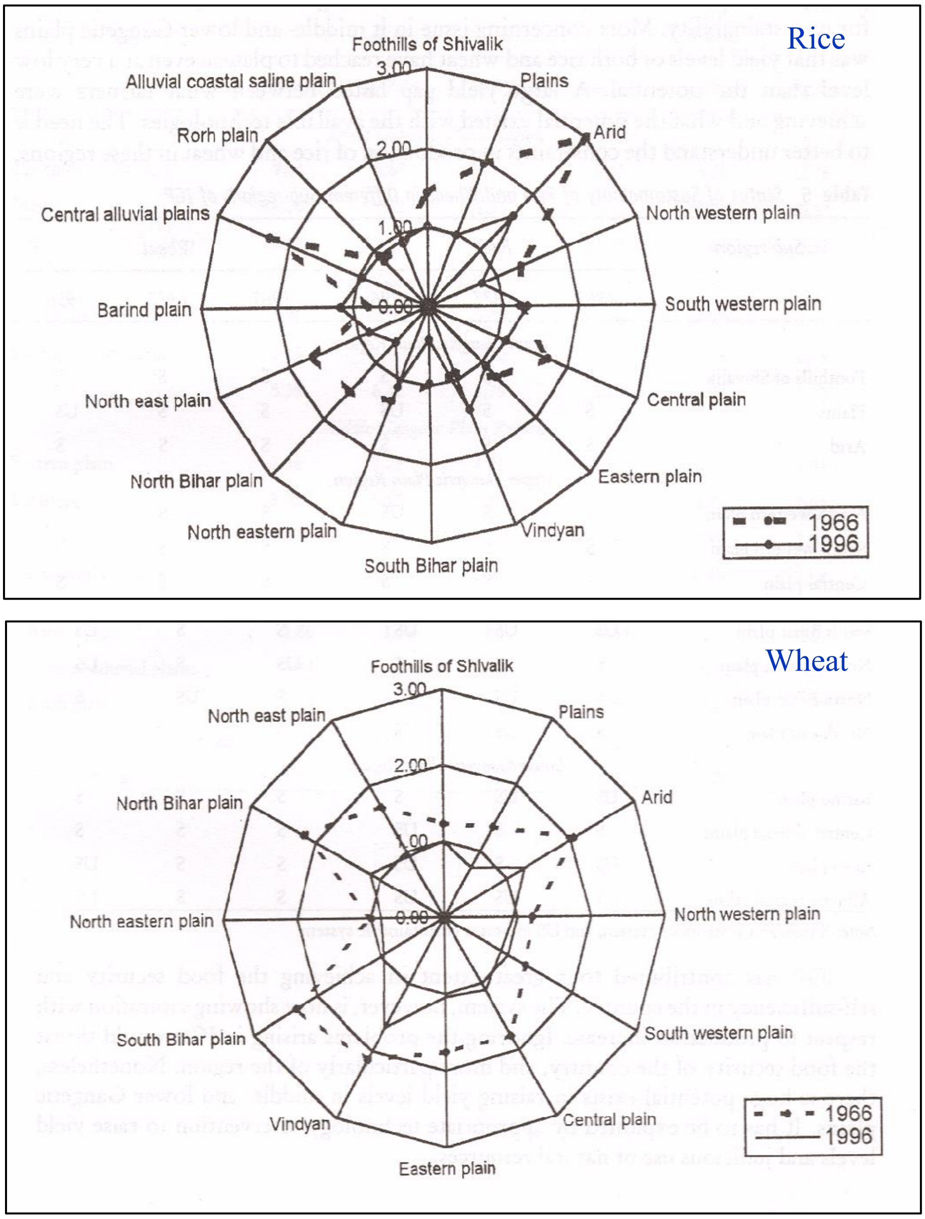

Fig 3. Sustainability of rice and wheat in Indo-Gangetic plain during 1966 to 1996 (Joshi *et al*., 2002)

Lopez-Ridaura *et al*., (2002) examined key methodological issues in the selection, transformation and aggregation of economic, environmental and social indicators for sustainability analysis through the MESMIS approach, a systemic, participatory, interdisciplinary and flexible framework for sustainability evaluation. The Framework for the Evaluation of Natural Resources Management Systems Incorporating Sustainability Indicators (Spanish acronym- MESMIS) allows the derivation, measurement, and monitoring of sustainability indicators as part of a systemic, participatory, interdisciplinary, and flexible evaluation process adaptable to different levels of data availability and local technical and financial resources (Fig 4).

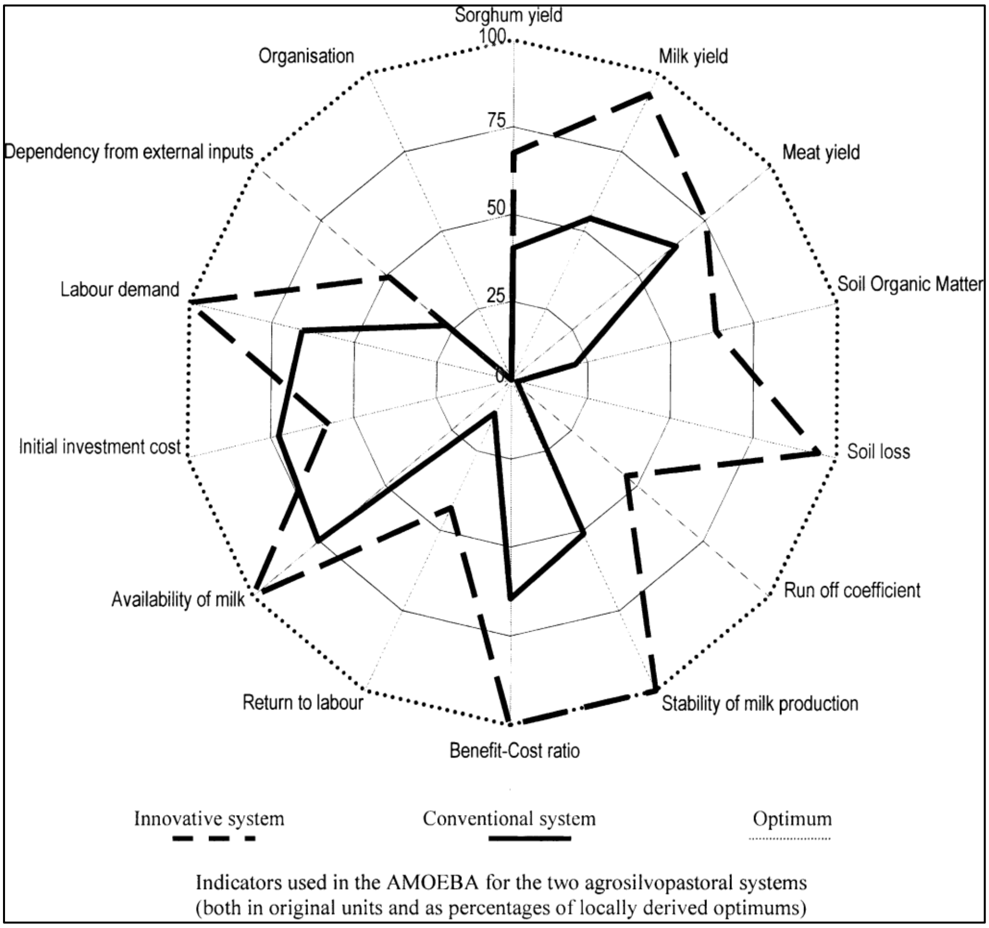

Fig 4. Integration of sustainability indicators for two agro-silvopastoral systems from Northern Mexico using AMOEBA diagram (Lopez-Ridaura et al., 2002)

Strategies for Realizing Agricultural Sustainability

Operationalization of sustainable agriculture can be split broadly into two essential components: (1) Ensuring ecological soundness and (2) Maintaining socio-economic equity and responsibility. These are mutually interdependent, but ecological sustainability commands a premium because the current abuse and neglect of natural resources poses a threat to agricultural sustainability under all circumstances.

The specific strategies for realizing broad goals of sustainable agriculture can be grouped into four separate though related areas of concern as issues related to farming and natural resources, crop and animal production practices and economic, social and political context that differ at different scale of operation as individual farm to region or country as per the applicability and in short term and long term.

Farming and Natural Resources Management

The basic natural resources of soil and water are the prime resources under the purview of management in a given ecological region with applicable potentials and limitations to achieve productivity of crops and animals. When the production of food and fibre degrades the natural resource base, the ability of future generations to produce and flourish decreases. The decline of ancient civilization in Mesopotamia, the Mediterranean region, Pre-Columbian south west U.S. and Central

America is believed to have been strongly influenced by natural resource degradation from non-sustainable farming and forestry practices.

Daly (1990) provided the general guidelines for conserving natural resources and ecological sustainability as:

1. The rate of harvest, consumption, and use of renewable resources should not exceed their rate of regeneration.
2. The rate of waste generation should not exceed the assimilative capacity of the environment.
3. The depletion of non-renewable resources should be compensated for by the development of an equivalent amount of a renewable substitute.

These are the three commandments underpinning the sustainable management of all types of natural resources.

Soil: Soil is the foremost natural resource for agriculture. It is a critically important component of the biosphere from which all living organisms, including human beings, derive shelter, food, growth and all other activities. Soil acts as an integrator of the environment, namely, the lithosphere (land), hydrosphere (water), atmosphere (air), and biosphere (living organisms) and plays the most important role in sustaining biosphere.

Karlen *et al.* (1997) classified the essential functions of soil more explicitly and completely as follows:

1. Sustaining biological activity, diversity, and productivity
2. Regulating and partitioning water and solute flow
3. Filtering, buffering, degrading, immobilizing and detoxifying organic and inorganic materials, including industrial and municipal by-products and atmospheric deposition.
4. Storing and cycling nutrients and other elements within the earth's biosphere.
5. Providing support for socio-economic structures and protection for archaeological treasures associated with human habitation.

Soil is also a major source and sink for global gases and plays an important role in the regulation of radioactively active gases (greenhouse gases) in the atmosphere. Soils constitute the largest terrestrial pool of carbon, estimated at approximately 1550 Pg, which is central to the global carbon cycle. The world's soils also contain approximately 95 Tg nitrogen (Lal *et al*., 1995). Both of these pools contribute actively to atmospheric greenhouse gases through decomposition and oxidation as a consequence of deforestation and faulty land management practices. In the past decade, 1.6 billion tonnes of carbon is estimated to have been emitted annually as a result of land clearance, compared to 6.4 billion tonnes released into the atmosphere by the combustion of fossil fuels.

Soil erosion caused by water and wind is one of the important reasons for soil degradation. Water erosion is the most widespread form of erosion, affecting 56% of global land area. Deforestation, removal of vegetative cover through overgrazing, and mismanagement of agricultural land are the main causes of water erosion. Wind erosion occurs widely in arid and semi-arid regions and in coarse-textured soils without vegetative cover and affects 26% of the global area. The Global Agro-ecological

Zones (GAEZ) programme of the FAO (1978-1991) has estimated that some 16% of global land area at risk of soil erosion. Soil erosion continues to be a serious threat to our continued ability to produce adequate food. Numerous practices have been developed to keep soil in place, which include reducing or eliminating tillage, managing irrigation to reduce runoff, and keeping the soil covered with plants or mulch. Adoption of no tillage could benefit soil conservation in soils especially under initial high fertility conditions (Fabrizzi *et al*., 2005) without any adverse impact on productivity.

Water: Freshwater is the most critical and limiting natural resource for sustainable agriculture. Water is the principal resource that has helped agriculture and society to prosper, and it has been a major limiting factor when mismanaged. Agriculture uses as much as 60 to 80% of freshwater supplies globally. The number of people living in water-stressed countries will increase six fold in the next 20 years, and this will prove a big challenge to global and regional food security (IFPRI, 1997a; 1997b).

Huge investments in water storage and transfer systems have been established in many parts of the world which allowed crop production to expand to very arid regions. In drought years, limited surface water supplies have prompted overdraft of groundwater and consequent intrusion of salt water or permanent collapse of aquifers in many regions leading to degradation of potential lands and a serious threat to food security and the environment. Erratic patterns of precipitation, drought, and floods as a result of global warming exacerbate the existing constraints. Curtailing the share of water that goes to agriculture and ensuring its conservation and sustainable use are essential for future food security, economic and human development and social harmony. Projection indicate that the productivity of water in agriculture needs to be doubled within the next decade and a half to spare enough water for civic, and industrial use and to make agricultural water use sustainable. Areas of improving water management include improving water conservation and storage measures (*in situ*) and safe run off collections, growing drought-tolerant crop species and adopting efficient irrigation methods/systems (Raman, 2006).

The challenge programme for water and food launched by the CGIAR envisages integrated action combining science and technology, management, and environmental factors, and provides hope for ushering in a “Blue water Revolution”.

Energy: Energy has been identified as the second most critical factor next only to water, for sustainable development. The economic progress is coterminous with energy consumption (Brown, 2001). Global agricultural systems are flawed as a result of energy profligacy or energy poverty. Energy over-use leaves dirty ecological foot prints, whereas, energy poverty creates serious impediments to food security, livelihoods, and human development. Energy-poor systems, require energy infusion, preferably of the renewable kind, such as solar, wind and biomass energy.

Modern agriculture is heavily dependent on non-renewable energy sources, especially petroleum that cannot be sustained indefinitely as clear projections of the finiteness of the resource is established. Sustainable agricultural systems should reduce reliance on non-renewable energy sources and explore and exploit many opportunities of on-farm renewable sources of energy generation and use that can also mitigate climate change, as biomass is a carbon-neutral resource. Renewable energy sources like solar, wind and bioenergy are particularly useful in rural areas because of their local availability, adaptability to dispersed small-and medium scale energy requirements, reliability, and environmental safety. It has been estimated that these could provide up to 57% of commercial energy needs in Africa, 33% in Latin America and 22% in the Asia Pacific region (Hicks, 1997).

Crop Production Practices

Sustainable production practices involve a variety of approaches. Specific strategies must take into account the site-specific and individual nature of sustainable agriculture, several principles can be applied to select appropriate management practices based on the principles of site specific management of soil, nutrient, crop, pest, etc for responsible farming as per the capability of the resource base that results in increasing the value and capacity of resources due to conservation and thereby increases productivity gradually.

Minimizing dependence on monocultures can provide greater resilience and risk minimization against total system failure that is central for achieving sustainable agricultural development. It is a dynamic, continuous process to adjust to changing circumstances. Diversification is also the process to take advantage of emerging opportunities created by technology, new markets, changes in policy, etc., to meet certain goals, challenges and threats and to reduce risk (Chand and Chauhan, 2002). It also acts as a powerful tool in minimization of risk in farming (Hegde *et al*., 2006). Under the situation of weather and market-induced risks and capital constraints, diversification helps in stabilizing farm income at a higher plane. These considerations make a strong cause for farm/crop diversification in India (Gupta and Tewari, 1985).

Diversified agriculture has its place in cushioning the variability across the enterprises. Crop diversification is a useful means to increase crop output under different conditions. It should be approached in two ways. The commonly understood mechanisms is the addition of more crops to the existing cropping systems, which is the broadening of the base of the system. This method of horizontal diversification has special significance under small-holder production systems and has been responsible for production increases due to high cropping intensities. The other type is vertical crop diversification, which reflects the extent and stage of industrialization of the crops with enterprises like agro-forestry, dryland horticulture, medicinal and aromatic plants, other economic shrubs and livestock. Both types of diversification will be essential to improve crop yields and income generation at local, regional and national levels.

Diversification is a feature of cropping systems because it assists the achievement of cropping objectives (sustainable productivity) by allowing farmers to employ biological cycles to minimize inputs, maximize yields, conserve the resource base and also to reduce risk due to both environmental and economic factors (Raman, 2006). Growing a range of crops suited to different sowing and harvesting times also enables farmers to manage greater areas while attending to each crop at optimal times. The benefits of biodiversity arise from differences in productivity of species, their product prices, nutritional requirements, responses to stresses, and from the biological contributions they can offer to the control of weeds, pests and disease. Biodiversity will only reduce risk when the yields of the alternate crop choices are not positively correlated. Benefit arises when cropping systems are designed and managed to utilize these differences and establish complementarity. The advantages can be considerable, and there are many examples in the literature. At the same time, Raman (2006) emphasized that observed benefits do not necessarily persist under all conditions, and further that alternate non-biological interventions can achieve the same objectives, and may do so more easily at a lesser cost and farmers cannot ignore these possibilities.

A range of functions through which biodiversity can improve the performance of cropping systems covers a range from yield stabilization through crop nutrition, weed, disease and pest control, to soil and water conservation. That range is bounded, on the one hand, by strategies and tactics to increase economic yield that dominate agriculture on robust agricultural land, and on the other, the conservation of the basic soil and water resources on more fragile land. In essence, we should ensure to grow crops which are most suitable for each soil and climate.

Diversified farms are usually more economically and ecologically resilient. While monoculture farming has advantages in terms of efficiency and ease of management, the loss of the crop in any one year could put a farm out of business and/or seriously disrupt the stability of a community dependent on that crop. By growing a variety of crops, farmers spread economic risk and are less susceptible to the radical price fluctuations associated with changes in supply and demand. Properly managed, diversity can also buffer a farm in a biological sense. For example, in annual cropping systems, crop rotation can be used to suppress weeds, pathogens and insect-pests. Also, cover crops can have stabilizing effects on the agro-ecosystem by holding soil and nutrients in place, conserving soil moisture with mowed or standing dead mulches, and by increasing the water infiltration rate and soil water holding capacity. Cover crops in orchards and vineyards can buffer the system against pest infestations by increasing beneficial arthropod populations and can therefore reduce the need for chemical inputs. Using a variety of cover crops is also important in order to protect against the failure of a particular species to grow and to attract and sustain a wide range of beneficial arthropods (Raman, 2006).

Optimum diversity may be obtained by integrating both crops and livestock in the same farming operation. This was the practice for centuries until mid-1900s in the West, when technology, government policy and economics compelled farms to become more specialized. Mixed crop and livestock operations have several advantages. First, growing row crops only on more level land and pasture or forages on steeper slopes will reduce soil erosion. Second, pasture and forage crops in rotation enhance soil quality and reduce erosion; livestock manure, in turn, contributes to soil fertility. Third, livestock can buffer the negative impacts of low rainfall periods by consuming crop residue that in "plant only" systems would have been considered crop failures. Finally, feeding and marketing are flexible in animal production systems. This can help caution farmers against trade and price fluctuations and, in conjunction with cropping operations, make more efficient use of farm labour.

Raman (2006) brings out a logical narration that biodiversity plays a critical role in agriculture and is inseparable part of agricultural sustainability. Sustainable agriculture and the conservation of biodiversity are not mutually exclusive; they are synergistic and partnership seeking. Agricultural intensification using high-yielding varieties and pesticides has led to a shrinking of the number of species and genetic diversity of food crops and destabilization of insect pests, both of which favour productivity at the cost of sustainability. Traditional agro-systems balance productivity and sustainability by maintaining high species, and genetic diversity and natural pest control. Maintaining biodiversity and achieving agricultural sustainability and food security for a huge population requires multi-pronged strategies such as conservation of existing plant genetic resources, broadening their genetic base, diversification of food crops, and nurturing a combination of large-scale modern systems, traditional systems, and natural ecosystems. The modern systems have unparalleled labour and land productivity and contribute enormously to food security, whereas, traditional systems are relevant under stressed ecological and socio-economic conditions. They contribute 20% or more of human nutrition and livelihood to million and are important in safeguarding traditional knowledge. The immense potential of soil biodiversity for agricultural productivity and sustainability is still undervalued and needs to be understood and harnessed.

There are three levels of biodiversity which contribute individually and interactively to produce ecological goods and services. Diversity of species and genes increases the ability of ecological communities to withstand and recover from adverse environmental stresses. Diversity within species is the basis for their evolution and their adaptation to the changing environment. Diversity of natural ecosystems leads stability and sustainability to the planet as a whole. The loss of any one of these components of biodiversity or their diminished performance below threshold levels can lead to a deficiency in the benefits they confer both qualitatively and quantitatively. Redundancy of functionally similar species is common in nature and acts as a buffer or insurance against stresses and shocks. When ecosystems are diverse, a range of pathways are available for primary production and ecological processes such as nutrient cycling and waste decomposition, so that if one is damaged or destroyed, an alternate pathway can be used and the ecosystem can continue to function at its normal level. If biological diversity is greatly reduced, the functioning of an ecosystem is put at risk (Naeem *et al*., 1994). This is a serious concern for modern croplands, where large-scale erosion of species and genetic diversity has been allowed.

Soil management: Sustainable soil management is maintaining or upgrading the potential performance of a soil over several crop cycles. Failure to do so often results in some form and degree of degradation of the soil. Degradation is used here in a broad sense to imply any kind of temporary or permanent impairment to performance potential. Degradation is a manifestation of a disturbance, stress or shock as an impairment of one or more soil properties or attributes necessary for optimum crop growth and productivity, for example:

1. Depletion of nutrients or organic matter;
2. Impairment of soil structure, rooting depth, and tilth;
3. Water infiltration as a consequence of erosion;
4. Depreciation of soil ecological functions such as nutrient cycling and waste decomposition; and
5. Nutrient imbalance resulting in salinity, acidity, alkalinity and accumulation of toxic metals such as aluminum and iron, particularly in Ultisols.

Such negative factors operating singly or in combination, prevent the soil from performing to its maximum potential.

The management of soil for sustainable production should focus on preventing degradation or implementing timely remedial measures to ameliorate any deficiency as and when it occurs. Although, prevention of degradation is the best course, it may be an ideal concept rather than a practical possibility, because some degree of soil and land degradation is unavoidable over one or more crop cycles, depending upon the management and intrinsic qualities of the soil. Any form of agriculture disturbs the natural equilibrium among the biophysical components of the soil system. This disturbance is greater with intensive and conventional agriculture than with traditional systems. This can lead to a temporary decline in soil productivity and ecological functions after one or more crop cycles. Only 6% of the overall 38% of human-induced crop land degradation is irreversible. The remainder is amenable to full or partial restoration with appropriate inputs (Raman, 2006).

Soil resilience can be looked upon as the buffering capacity of the soil against physical, mechanical, chemical or biological impacts. Soil resilience in the context of agriculture includes all the processes that enable it to counteract stresses and alterations imposed by cultivation processes. Soils and soil processes are generally conditionally renewable, provided degradation has not exceeded threshold limits, beyond which it may not be possible to renew their productivity or other ecological functions.

Soil physical, chemical, and biological properties and soil processes are at the heart of land management for sustainable agriculture, because, along with climate, they determine the intrinsic productivity potential of any soil. High quality soils, such as alluvial soils and mollisols with high organic matter content and fertility and inceptisols with high base content and rooting depth, support high and sustained productivity over long periods. On the other hand, alfisols, aridisols, vertisols and the like are more problematic and suffer from poor attributes such as low texture, low nutrient content, and low permeability and require more careful management to keep them productive (Raman, 2006).

Anderson (1998) used the phrase "growing the soil to grow crops" in relation to (1) maintaining good soil depth and other favourable physical properties such as soil structure by preventing erosion, (2) feeding the soil by providing chemical nutrition to plants, and (3) encouraging deep and prolific root systems to promote nutrient uptake from sub soil horizons. The core strategies for sustainable soil management can be catalogued broadly as follows:

- Preventing soil erosion to maintain good soil depth and tilth
- Maintaining favourable fertility and nutrient status
- Enhancing soil organic matter status
- Facilitating good soil structure
- Preventing performance debilitating problems such as salinity, alkalinity, sodicity and iron and aluminum toxicity in specific soils;
- Enhancing soil biodiversity through crop rotations, intercropping and mixed cropping
- Practicing sustainable water management

These strategies are often interlinked and contribute synergistically to sustainability.

Conservation Agriculture

Conservation agriculture is an approach to managing agro-ecosystems, for improved and sustained productivity, increased profits and food security while preserving and enhancing the resource base and the environment. It is characterized by three inter-linked principles, namely:

1. Continuous minimum mechanical disturbance
2. Permanent organic soil cover
3. Diversification of crop species grown in sequence and/or associations

Conservation agriculture principles are universally applicable to all agricultural landscapes and land uses with locally adapted practices. Conservation agriculture enhances biodiversity and natural biological processes above and below the ground surface. Soil interventions such as mechanical soil disturbance are reduced to an absolute minimum or avoided, and external inputs such as agrochemical and plant nutrients of mineral or organic origin are applied optimally and in ways and quantities that do not interfere with or disrupt, the biological processes.

Conservation agriculture facilitates good agronomy, such as timely operations, and improves overall land husbandry for rainfed and irrigated production. Complemented by other known good practices, including the use of quality seeds, and integrated pest, nutrient, weed and water management, etc., conservation agriculture is a base for sustainable agricultural production intensification. It opens increased options for integration of production sectors, such as crop-livestock integration and the integration of tress and pastures into agricultural landscapes. Conservation agriculture along with best crop management practices will lead to improvement in input use efficiency and greater sustainability (Gathalo *et al*., 2013; Wright *et al*., 2007; Vanden Bygaart *et al*., 2003).

A common philosophy among sustainable agriculture practitioners is that a 'healthy' soil is a key component of sustainability, that is, a healthy soil will produce healthy crop plants that have optimum vigour and are less susceptible to pests. While many crops have key pests that attack even the healthiest of plants, proper soil, water and nutrient management can help prevent some pest problems brought on by crop stress or nutrient imbalance. Furthermore, crop management systems that impair soil quality often result in greater inputs of water, nutrients, pesticides, and/or energy for tillage to maintain yields.

In sustainable systems, the soil is viewed as a fragile and living medium that must be protected and nurtured to ensure its long-term productivity and stability. Methods to protect and enhance the productivity of the soil include using cover crops, compost and/or manures, reducing tillage, avoiding traffic on wet soils, and maintaining soil cover with plants and/or mulches. Condition in most soils in arid and semi-arid regions, do not favour the build-up of soil organic matter. Regular additions of organic matter or the use of cover crops can increase soil aggregate stability, soil tilth and diversity of soil microbial life. Reducing tillage and increasing crop diversity to include perennial grasses and legumes could be very effective in carbon and N sequestration leading to sustainable production (Gathala *et al*., 2013; Alkaisi *et al*., 2005; Riedell *et al*., 2009).

Efficient use of inputs

For sustainable crop production, it is extremely important to maintain adequate levels of such inputs as mineral fertilizers, organic matter and water. Perpetuating the potential productivity of land in an environmentally safe and economically viable manner requires that the magnitude, flux, and efficiency of use of inputs-particularly fertilizers, water and energy are optimized. Improper management of these inputs has been the case of land degradation and environmental pollution in both low and high-external-input intensive agriculture.

The amount of external inputs needed is guided by the efficiency of their use. High input agriculture has seen indiscriminate over use of nitrogen and phosphate fertilizers, which has caused damage to the production resources as well as the environment. The excessive use of fertilizers often leads to wastage and runoff, causing pollution of surface and ground water and leading to nitrate accumulation. Likewise, overuse of water in irrigated agriculture also leads to many problems causing unsustainable production.

The best prescription to prevent inefficient use of external inputs is to follow the golden rule of need-based supply of such inputs as tillage, water and fertilizers and to check their wastage. Revision of fertilizer recommendations for site-specific nutrient management is preferable to blanket recommendations. There are proven methods for increasing the use efficiency of different inputs like nutrients and water which must be made use of to attain sustainable crop production. The integrated soil-crop system management paradigm features (1) improving soil quality, (2) enhancing the use of various nutrient resources, (3) closing the yield gap, and (4) effectively reducing N losses (Zhenling *et al*., 2014). This is a novel agricultural paradigm that can improve food security and environmental quality worldwide, especially in regions of high input with low efficiency systems.

Many inputs and practices used by conventional farmers are also used in sustainable agriculture. Sustainable farmers, however, maximize reliance on natural, renewable and on-farm inputs. Equally important are the environmental, social, and economic impacts of a particular strategy. Converting to sustainable practices does not mean simple input substitution. Frequently, it substitutes enhanced management and scientific knowledge for conventional inputs, especially chemical inputs that harm the environment on farms and in rural communities. The goal is to develop efficient, biological systems which do not need high levels of material inputs.

Farmers frequently ask if synthetic chemicals are appropriate in a sustainable system. Sustainable approaches are those that are the least toxic and least energy intensive, and yet maintain productivity and profitability. Preventive strategies and other alternatives should be employed before using chemical inputs from any source. However, there may be situations where the use of synthetic chemicals would be more "sustainable" than a strictly non-chemical approach using toxic organic chemicals. For example, one grape grower switched from tillage to a few application of a broad spectrum contact herbicide in the vine row. This approach may use less energy and may compact the soil less than numerous passes with a cultivator or mower.

Animal Production Practices

In the early part of this century, most farms integrated both crop and livestock operations. Indeed, the two were highly complementary both biologically and economically. The current picture has changed quite drastically since then. Crop and animal producers now are still dependent on one another to some degree, but the integration now most commonly takes place at a higher level – between farmers, through intermediaries, rather than within the farm itself in US and European agriculture. This is the result of a trend toward separation and specialization of crop and animal production systems. Despite this trend, there are still many farmers, particularly in the Midwest and Northeastern US and in most of India, that integrate crop and animal systems – either on dairy farms, or with range cattle, sheep or hog operations.

Even with the growing specialization of livestock and crop producers, many of the principles outlined in the crop production section apply to both groups. The actual management practices will, of course, be quite different. Some of the specific points that livestock producers need to address are listed below:

Management planning

Including livestock in the farming system increases the complexity of biological and economic relationships. The mobility of the stock, daily feeding, health concerns, breeding operations, seasonal feed and forage sources, and complex marketing are sources of this complexity. Therefore, a successful ranch plan should include enterprise calendars of operations, stock flows, forage flows, labour needs, herd production records and land use plans to give the manager control and a means of monitoring progress toward goals.

Animal selection: The animal enterprise must be appropriate for the farm or ranch resources. Farm capabilities and constraints such as feed and forage sources, landscape, climate and skill of the manager must be considered in selecting which animals to produce. For example, ruminant animals can be raised on a variety of feed sources including range and pasture, cultivated forage, cover crops, shrubs, weeds and crop residues. There is a wide range of breeds available in each of the ruminant species, i.e., cattle, sheep and goats. Hardier breeds that, in general, have lower growth and milk production potential, are better adapted to less favourable environments with sparce or highly seasonal forage growth.

Animal nutrition: Feed costs are the largest single variable cost in any livestock operation. While most of the feed may come from other enterprises on the ranch, some purchased feed is usually imported from off the farm. Feed costs can be kept to a minimum by monitoring animal condition and performance and understanding seasonal variations in feed and forage quality on the farm. Determining the optimal use of farm-generated by-products is an important challenge of diversified farming.

Reproduction: Use of quality germplasm to improve herd performance is another key to sustainability. In combination with good genetic stock, adapting the reproduction season to fit the climate and sources of feed and forage reduce health problems and feed costs.

Herd health: Animal health greatly influences reproductive success and weight gains, two key aspects of successful and sustainable livestock production. Unhealthy stock waste feed and require additional labour. A herd health programme is critical to sustainable livestock production.

Grazing management: Most adverse environmental impacts associated with grazing can be prevented or mitigated with proper grazing management. First, the number of stock per unit area (stocking rate) must be correct for the landscape and the forage sources. There will need to be compromises between the convenience of tilling large, unfenced fields and the fencing needs of livestock operations. Use of modern, temporary fencing may provide one practical solution to this dilemma. Second, the long-term carrying capacity and the stocking rate must take into account short and long-term drought. Especially in Mediterranean climates such as in California, properly managed grazing significantly reduces fire hazards by reducing fuel build-up in grasslands and brushlands. Finally, the manager must achieve sufficient control to reduce over use in some areas while other areas go unused. Prolonged concentration of stock that results in permanent loss of vegetative cover on uplands or in riparian zones should be avoided. However, small scale loss of vegetative cover around water or feed troughs may be tolerated if surrounding vegetative cover is adequate.

Confined livestock production: Animal health and waste management are key issues in confined livestock production. The moral and ethical debate taking place today regarding animal welfare is particularly intense for confined livestock production systems. The issues raised in this debate need to be addressed.

Confined livestock production is increasingly a source of surface and ground water pollutants, particularly where there are a large number of animals per unit area. Expensive waste management facilities are now a necessary cost of confined production systems. Waste is a problem of almost all operations and must be managed with respect to both the environment and the quality of life in nearby communities. Livestock production systems that disperse stock in pastures so the wastes are not concentrated and do not overwhelm natural nutrient cycling processes have become a subject of renewed interest.

The Economic, Social and Political Context

The human-imposed socio-economic environment within which the farm operates also has a number of control factors, broadly categorized as 'PEST' factors:

1. Political (agricultural and non-agricultural policies and priorities of the government: imports, exports, free market, etc.)
2. Economic (price of inputs and outputs, subsidies on inputs, procurement pricing, credit, etc.)
3. Sociological (regional preferences, population, labour constraints, skill and awareness of the cultivator, value system, etc.)
4. Technological (level of available technology and support services such as timely availability of inputs, infrastructure and markets).

The farm interacts with this system through the purchase of inputs and sale of outputs and is facilitated or constrained according to the PEST environment. The socio-economic environment also sets limits to the sustainability of the farm's production.

In addition to strategies for preserving natural resources and changing production practices, sustainable agriculture requires a commitment to changing public policies, economic institutions, and social values. Strategies for change must take into account the complex, reciprocal and ever-changing relationship between agricultural production and the broader society.

The 'food system' extends far beyond the farm and involves the interaction of individuals and institutions with contrasting and often competing goals including farmers, researchers, input suppliers, farm workers, unions, farm advisors, processors, retailers, consumers, and policy makers. Relationships among these actors shift over time as new technologies spawn economic, social and political changes.

A wide diversity of strategies and approaches are necessary to create a more sustainable food system. These will range from specific and concentrated efforts to alter specific policies or practices, to the longer-term tasks of reforming key institutions, rethinking economic priorities, and challenging widely-held social values. Areas of concern where change is most needed include the following:

Food and agricultural policies

Existing national and state government politics often impede the goals of sustainable agriculture. New politics are needed to simultaneously promote environmental health, economic profitability, and social and economic equity. For example, commodity and price support programmes could be restructured to allow farmers to realize the full benefits of the productivity gains made possible through alternative practices. Tax and credit policies could be modified to encourage a diverse and decentralized system of family farms rather than corporate concentration and absentee ownership. Government and state agricultural universities research policies could be suitably modified to emphasize the development of sustainable alternatives. Marketing orders and cosmetic standards could be amended to encourage reduced pesticide use. Coalitions must be created to address these policy concerns at state and national level.

Land use: Conversion of agricultural land to urban uses is a particular concern in all the states around towns and cities, as rapid growth and escalating land values threaten farming on prime soils. Existing farm land conversion patterns often discourage farmers from adopting sustainable practices and a long-term perspective on the value of land. At the same time, close proximity of newly developed residential areas to farms is increasing the public demand for environmentally safe farming practices. Comprehensive new policies to protect prime soils and regulate development are needed, particularly around towns and cities. By helping farmers to adopt practices that reduce chemical use and conserve scarce resources, sustainable agriculture research and education can play a key role in building public support for agricultural land preservation. Educating land use planners and decision-makers about sustainable agriculture is an important activity.

Labour: In India, the conditions of agricultural labour are generally far below accepted social standards and legal protections in other forms of employment. Policies and programmes are needed to address this problem, working toward socially just and safe employment that provides adequate wages, working conditions, health benefits, and chances for economic stability. The needs of migrant labour for year-round employment and adequate housing are a particularly crucial problem needing immediate attention. To be more sustainable over the long-term, labour must be acknowledged and supported by government policies, recognized as important factor of production systems, and carefully considered when assessing the impacts of new technologies and practices.

Rural community development: Rural communities in many regions of different countries are currently characterized by economic and environmental deterioration. Many are among the poorest locations in different nations. The reasons for the decline are complex, but changes in farm structure have played a significant role. Sustainable agriculture presents an opportunity to rethink the importance of family farms and rural communities specially in US and European agriculture. Economic development policies are needed that encourage more diversified agricultural production on family farms as a foundation for healthy economics in rural communities. In combination with other strategies, sustainable agriculture practices and policies can help foster community institutions that meet employment, educational, health, cultural and spiritual needs.

Consumers and the food system: Consumers can play a critical role in creating a sustainable food system. Through their purchases, they send strong messages to producers, retailers and others in the system about what they think is important. Food cost and nutritional quality have always influenced consumer choices. The challenge now is to find strategies that burden consumer perspectives, so that environmental quality, resource use and social equity issues are also considered in shopping decisions. At the same time, new policies and institutions must be created to enable producers using sustainable practices to market their goods to a wider public coalitions organized around improving the food system are one specific method of creating a dialogue among consumers, retailers, producers and others. These coalitions or other public forms can be important vehicles for clarifying issues, suggesting new policies, increasing mutual trust, and encouraging a long-term view of food production, distribution and consumption.

Achieving Perpetual Agricultural Sustainability

The world needs to double the current food production over the next 50 years which is a daunting task given the current status of agriculture. Global agriculture in the present status points to a formidable challenge to agricultural sustainability. Dwindling *per capita* natural resources and the depletion and degradation of resources are the most serious threat to food security and the environment. Existing technologies for intensification are showing clear signs of growing fatigue. The overwhelming loss of biodiversity, ground water deficit, mining of fossil water, pollution of ground water and increase in atmospheric greenhouse gases are serious threats to sustainability. Climate change and its erratic manifestations will have their greatest impact in the most vulnerable areas. Ecological limits to plant productivity may be reached, if stagnation of marine fisheries is any indication. Agronomic and genetic potential seems to be saturated. Biophysical constraints apart, socio-economic maladies such as widespread poverty, hunger, inadequate energy, lack of livelihood opportunities, and increasing inequalities in resource access as a result of globalization may exacerbate the already severe socio-economic divide between the haves and have-nots. The problems require out-of-the-box thinking and human-centered solutions (Raman, 2006).

The total reliance in the last six decades on productivity-oriented and external-input-intensive technologies for food security and belief in the trickle-down theory of economic development have seriously impaired the environment, particularly for the people of the less developed countries. An experiential and customized approach based on the differential capabilities of natural resources and the socio-economic capabilities of people in different regions should be the sole goal for sustainable food security and development in the future. Although technological intensification will continue to be relevant in the high-potential areas of the globe, the reductionist model needs to be replaced by holistic and resource-conserving technologies such as conservation tillage, integrated pest management, integrated plant nutrient management, and crop rotation ultimately leading to integrated crop management. Cutting-edge technologies such as biotechnology, and precision farming provide additional alternatives. The less endowed and fragile ecologies will need to strengthen traditional agriculture using agro-ecological principles supplemented with opportunities from common property resources. Similarly, broad-based economic development will have to follow the bottom-up model of rural development, with its roots in improving the productivity of small farms. This in turn will increase livelihood in the secondary and tertiary sectors. Preparedness to ameliorate the adverse impacts of climate change, globalization and free trade is essential for future agricultural sustainability, which will require adaptive, innovative approach rather than generic prescriptions (Raman, 2006).

Sustainable systems start with the adoption of Best Management Practices (BMPs). Once in place, BMPs lead to Maximum Economic Yields (MEY) and together they lead to sustainability both economically and environmentally (Hegde *et al*., 2012). High yields and increased profit potential go hand in hand. A systematic effort to integrate BMPs for all the controllable crop production factors helps to attain MEY which gives the highest profit-the second component of sustainability. The implementation of new crop production technologies, soil management practices and other BMPs satisfy the third component of sustainability which is safeguarding the environment (Hegde and

Sudhakara Babu 2009). The use of BMPs, promotes a more vigorous, healthy and productive crop. A crop which develops bigger root systems, more above-ground residues, reduced soil erosion, greater amounts of carbon assimilation, improved nutrient use efficiency, build up of organic matter, quicker ground cover, greater water use efficiency and more resistance to crop stresses such as drought, cold temperatures or late planting. All these factors make full utilization of inputs and resources leading to reduced environmental degradation and together moving towards sustainability.

Performance of a particular package of sustainable agriculture vary in terms of the basic farm size, available resources, growing conditions as rainfed or irrigated, urban or rural setting, different types of crops and enterprises being operated under a given macro-economic policies of the governments, demand and supply dynamics and societal traditions. Pretty *et al.* (2006) has made extensive studies on various facts of sustainability as being adopted in different countries as per the socio-economic requirements and the overall outcome of the study reveal a positive note that adoption of systematic better practices of crop and livestock production and care for natural resources can usher higher sustainability (Table 4).

Table 4. Summary of adoption and impact of agricultural sustainability technologies and practices on 286 projects in 57 countries. (Pretty *et al*. 2006).

FAO farm system category[a]	**No. of farmers adopting**	**No. of hectares under sustainable agriculture**	**Average % increase in crop yields[b]**
Smallholder irrigated	177287	357940	129.8 (G21.5)
Wetland rice	8711236	7007564	22.3 (G2.8)
Smallholder rainfed humid	1704958	1081071	102.2 (G9.0)
Smallholder rainfed highland	401699	725535	107.3 (G14.7)
Smallholder rainfed dry/cold	604 804	737896	99.2 (G12.5)
Dualistic mixed	537311	26846750	76.5 (G12.6)
Coastal artisanal	220000	160000	62.0 (G20.0)
Urban-based and kitchen garden	207479	36147	146.0 (G32.9)
All projects	12564774	36952 903	79.2 (G4.5)

[a] Farm categories from Dixon et al. (2001).
[b] Yield data from 360 crop-project combinations; reported as % increase (thus a 100% increase is a doubling of yields). Standard errors in brackets.

UNEP (2010) clearly formulated with consensus that of the many potential supportive policies toward agricultural sustainability, the following deserve particular attention: *1) Encouraging resource-use efficiency* is the key to lessening the environmental impact of crops and livestock. There is evidence that water and nutrient use efficiency can be raised by a factor of 2-4 in intensive systems; *2) Correcting for negative environmental externalities of agriculture* will reflect the true costs of agricultural products. Costs for environmental damage will have to be passed on to consumers. This is thought to impact on the avoidance of waste, and on dietary change towards food of lesser environmental impact; *3) Rewarding farmers for the provisioning of environmental services* will provide incentives for farmers to engage in environmentally beneficial practices. Payment schemes for environmental services are currently under study, also in the context of the conservation of AgBD; *4) The need for increasing investments in agriculture and agricultural research* cannot be overstated. The development of technological innovations and the knowledge underpinning policy decisions as well as infrastructure improvements will require unprecedented research and development efforts. *5) Empowering poor farmers* that contribute most agricultural produce in developing countries will require a host of policies: revamping extension services, ensuring smallholders' land tenure, providing market access, and strengthening the productive capacities of women.

Summary

Sustainability is a perpetual issue in time scale with associated dynamism in resource base and outputs in terms of variety and quantity. Sacrificing agriculture sustainability will pose grave threat to the basic food security in agriculturally dependent countries. The ecological aspect of the negative effects is immeasurable. Agriculture is no longer location specific in terms of production as well as product outreach due to the technological advancements in production, transport, communication, supply chain and networking to cater to the demands of global citizens. The value system attached to the primary products of agriculture with the associated limitations has transformed it altogether to an era of value added products and specialty services. The rate of changes expected and demanded from agriculture is acute and this precisely puts pressure on the long term perspective of sustainability, that is directly related to the maintenance of support systems i.e., natural resource base. Measurement of sustainability through key indicators and their integration from multitude of aspects can best be depicted using AMOEBA diagram as per the processes of MESMIS.

The reality of climate change, shrinking natural resources both in quantity and quality, the glaring catastrophic projections of the shortages of 5Fs (Food, Fodder, Fiber and Fuel and Forest-timber) to meet the burgeoning population and industrial raw material calls for urgent action for sustainability of agriculture. The realization of the shrinking carrying capacity of our planet to support humanity perpetually is essential to avoid over exploitation with the resultant protection of the natural resources and simpler and essential demographic changes. Yet, the resilience of natural systems with proper understanding, care and support from the humans can slow the clock of destruction. Assessment of sustainability should be done by including many indicators of physical, economical, demographic and ecological that have interrelationships in short term and modifier effects in long term of various magnitude. The dynamics of resource changes in their *per se* availability, quality and utilization changes with time and newer scenarios emerge that should be valued in its entirety of inter-relationships.

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Questions

1. What do you understand by sustainable agriculture?
2. What is the operational definition of sustainable agriculture?
3. What is ecological foot print?
4. Can agricultural sustainability be stabilized?
5. Bring out the historical perspective of agricultural sustainability.
6. What are the components and indicators of sustainable agriculture?
7. Describe the causes for declining agricultural sustainability.
8. How perpetual agricultural sustainability be achieved under the present circumstances of Indian Agriculture?
9. How climate change affects agricultural sustainability?
10. Can the development goals (of developing countries) and environmental conservation goals be converged for sustainability?
11. Describe land, crop and animal production practices oriented towards achieving agricultural sustainability.
12. What are the strategies for achieving higher agricultural sustainability?
13. Relate how increasing input use efficiency usher higher sustainability.
14. How the multitude of sustainability indicators can be integrated and understood graphically?