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Sustainable Agriculture

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Abstract
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. According to the Food and Agricultural Organization (FAO), people in the developing world where the population increase is very rapid, may face hunger if the global food production does not rise by 50–60 per cent. The contribution of developing countries to world agricultural production in 1975 was about 38 per cent, while that of developed countries, which account for 33 per cent of world's population, was 62 per cent. Only those countries, which can match the demands of the increasing population with increased production, can escape mass hunger. In the pre-independence period, Indian agriculture was usually described as a gamble with monsoons. There used to be a great deal of uncertainty about crop prospects, as monsoons played a decisive role in determining agricultural output and their failures resulted in widespread famine and misery.

Keywords: agricultural sustainability; sustainability assessments

Introduction

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. 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.

The concept of sustainable development became an appropriate basis for defining future development goals for 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 [2] 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 [2]. 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) [7] 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.

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. 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.

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) [14]. 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.

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 agro ecological conditions.

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. 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.

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.

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.

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.

Prioritization

All the components of sustainable agriculture together form the foundation of agricultural sustainability and need to be considered. 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.

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) [15] 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.

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.

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]:

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) [16] indicated general broad measurable components under each hierarchical level of components of sustainability.

Table 1: Indicators of Sustainability

Indicators of Sustainability	
Sustainability indicators (Economic, social and environmental)Sustainability indicators (Adopted from RIEDC, 1997) [16] Hierarchical level 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

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.

General guidelines for conserving natural resources and ecological sustainability as (Daly, 1990) [6]:

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.

Soil is also a major source and sinks 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.

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.

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. 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) [3]. 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) [13].

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) [4]. It also acts as a powerful tool in minimization of risk in farming. 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) [10].

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 are 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, dry land 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) [15]. 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. 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.

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.

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.

The core strategies for sustainable soil management can be catalogued broadly as follows:

- Preventing soil erosion to maintain good soil depth and tilth
- Maintaining favorable 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.

Achieving 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. 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. Sustainable systems start with the adoption of Best Management Practices (BMPs).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 SudhakaraBabu 2009) [12]. 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.

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