

MODERN CONCEPTS OF AGRICULTURE

Sustainable Agriculture

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Agriculture is a key primary industry in India that makes a significant contribution to the wealth and quality of life for rural and urban communities in India.

Definition

Enshrined in the title of this chapter are two key words- ‘sustainable’ and ‘agriculture’. The word ‘sustain’, from the Latin *sustinere* (*sus-*, from below and *tenere*, to hold), to keep in existence or maintain, implies long-term support or permanence. The word ‘sustainability’ was used for the second time in 1712 by the German forester and mining scientist Hans Carl von Carlowitz in his book ‘*Sylvicultura Oeconomica*’. French and English scientists adopted the concept of planting trees and used the term ‘sustained yield forestry’ by Kara Taylor (ref., <http://www.answers.com/topic/sustainability>). Sustainability is an attempt to provide the best outcomes for the human and natural environments both for the present and future. It relates to the continuity of institutional, environmental, social and economic aspects of human society, as well as the non-human environment.

In agricultural parlance, sustainability means keep the crop productivity going without enhancing input levels. There are many definitions of sustainable agriculture. Simply stated, sustainable agriculture is a form of agriculture aimed at meeting the needs of the present generation without endangering the resource base of the future generations. Thus, a holistic and systems approach is essential for achieving sustainability. Sustainable agricultural systems are capable of maintaining their productivity and usefulness to society indefinitely. Such systems must be resource-conserving, socially supportive, commercially competitive, and environmentally sound.

Concepts

A group of Canadian scientists (MacRae et al., 1990) defined sustainable agriculture as: sustainable agriculture is a philosophy and system of farming. It has its roots in a set of values that reflect an awareness of both ecological and social realities. It involves design and management procedures that work with natural processes to conserve all resources, promote agroecosystem resilience and self regulation, minimize waste and environmental damage, while maintaining or improving farm productivity and profitability.

The concept set out by the Technical Advisory Committee (TAC) of the Consultative Group on International Agricultural Research (CGIAR) states “*Sustainable agriculture is the successful management of resources for agriculture to satisfy the changing human needs, while maintaining or enhancing the quality of environment, and conserving natural resources*”.

The United States Department of Agriculture defined ‘Sustainable agriculture’ as *a management system for renewable natural resources that provides food, income and livelihood for present and future economic productivity and ecosystem services of these resources*.

Sustainable agriculture systems are those that are economically viable and meet society’s need for safe and nutritious food while maintaining or enhancing natural resources and the quality of the environment for future generations (Baier, 1990).

Hallmark of these definitions is the harmony in maintaining buoyancy and dynamism in agricultural growth for meeting basic human needs and protection and conservation of natural resources.

Needs

Sustainable agriculture systems are designed to use existing soil nutrient and water cycles, naturally occurring energy flows for food production. As well, such systems aim to produce food that is both nutritious and without products that might harm human health. In practice, such systems have tended to avoid the use of synthetically compounded fertilizers, pesticides, growth regulators, and livestock feed additives, instead relying upon crop rotations, crop residues, animal manures, legumes, green manures, off-farm organic wastes, appropriate mechanical cultivation, and mineral bearing rocks to maintain soil fertility and productivity.

The need of sustainable agriculture owes its origin to the philosophy of 'holism', which enunciates that all things are connected and their interactions in nature are complex. Stimulus to one component creates response to that as well as the system as a whole also responds. Appreciation of the theory of holism is very much embedded in our sayings and scriptures. An ancient Tamil proverb goes as follows, "*No fodder, no cattle; no cattle, no manure; no manure, no crop*". Translation of a Sanskrit text from about 1500 BC reads as "*Upon this handful of soil our survival depends. Husband it and it will grow our food, our fuel, and our shelter and surround us with bounty. Abuse it and the soil will collapse and die, taking man with it*". Deep in the heart of these primeval quotes lies the concern on the health of the very basic elements that contribute to the sustenance of complete chain involving production to consumption. For instance, if the vitality of natural resources is impaired because of neglect or misuse, agricultural sustainability and environmental quality and the linkage among these in the quest for human survival becomes at stake (Katyal).

Indicators of Sustainability

Indicators are a composite set of attributes or measures that embody a particular aspect of agriculture. Indicators are quantified information, which help to explain how things are changing over time. Sustainability indicators look at economic, social and environmental information in an integrated manner.

Many professionals agree that at least three criteria should guide the development of sustainability indicators (Jeff Tschirley):

- (i) **Policy relevance** - indicators should address the issues of primary concern to a country or district and receive the highest priority. In some cases policy makers may already share concern about an aspect of sustainability (e.g. land degradation) and be ready to use indicator information for addressing the issue.
- (ii) **Predictability** - to allow a forward-looking perspective that can promote planning and decisions on issues before they become too severe. Anticipatory decision-making is at least as important to sustainable agriculture as is recognition of existing problems.
- (iii) **Measurability** - to allow planners and analysts the means to assess how the indicator was derived, either qualitatively or quantitatively, and decide how it can best be applied in the planning and decision-making process.

Some of the indicators of key natural resources in rainfed cropping systems are listed below.

Table 1: Indicators of Key Natural Resources in Rainfed Cropping Systems

S. No.	Indicators	Key Management Aspects
1	Nutrient Balance	Organic matter - rate of change Nitrogen cycling - especially when using grain legumes in rotation with cereals Monitoring status of phosphorus, sulphur and potassium Micro-nutrients
2	Erosion	Vegetation cover - includes trees as well as stubble Soil surface cover - stubble retained (30% sufficient to prevent wind and water erosion) Stream bank Sheet and gully erosion
3	Productivity, Yield and Quality	Water use efficiency - i.e. actual versus potential (in some areas the potential is much less than the actual) (biomass/grain yield/net return), recharge (dryland salinity and nutrient leaching) Pasture composition - legume and perennial Matched animal versus pasture production - appropriate enterprise selection/capability Maintenance of genetic base/improvement
4	Soil Structure	Infiltration Permeability/water storage Stability Waterlogging Compaction
5	pH	Change Toxicity - deficiency Indicator plants
6	Energy Efficiency	Energy input vis-à-vis energy output of the whole agricultural system
7	Biological Factors	Soil macro/micro flora and fauna Animal health Plant health (root growth and other) Pests (animals and plants)
8	Farm Management Skills	Understanding - a good indicator would be the understanding of the farmers of their own technical system
9	Rainfall/Precipitation	Performance of rainfall in a year as % of normal & its coefficient of variation; Distribution of area based on rainfall amount (dry: 0-750 mm, medium: 750-1150 & 1150-2000 mm, assured: > 2000 mm); Categorization of the amount of rainfall (excess: +20% or more, normal: +19% to -19%, deficient: 20% to -59%, scanty: -60% or less); Number of districts having mean annual rainfall of 750-1250 mm and moisture availability period for at least 150 days; Area affected due to drought (slight, moderate or calamitous)

The most widely accepted framework for sustainability is referred to as Pressure/State/Response (PSR framework), as described in the Table 2, and in the following flow diagram.

Table 2: Example of PSR Framework

Issue	Pressure (driving force)	State (resulting condition)	Response (mitigating action)
Soil erosion	Hillside farming	Declining yield	Terracing, perennial cropping
Water quality	Agro-industrial processing	Fish die-off	Water treatment, technology adjustment
Condition of grassland	Livestock grazing	Soil erosion	Stock rotation, de-stocking revegetation

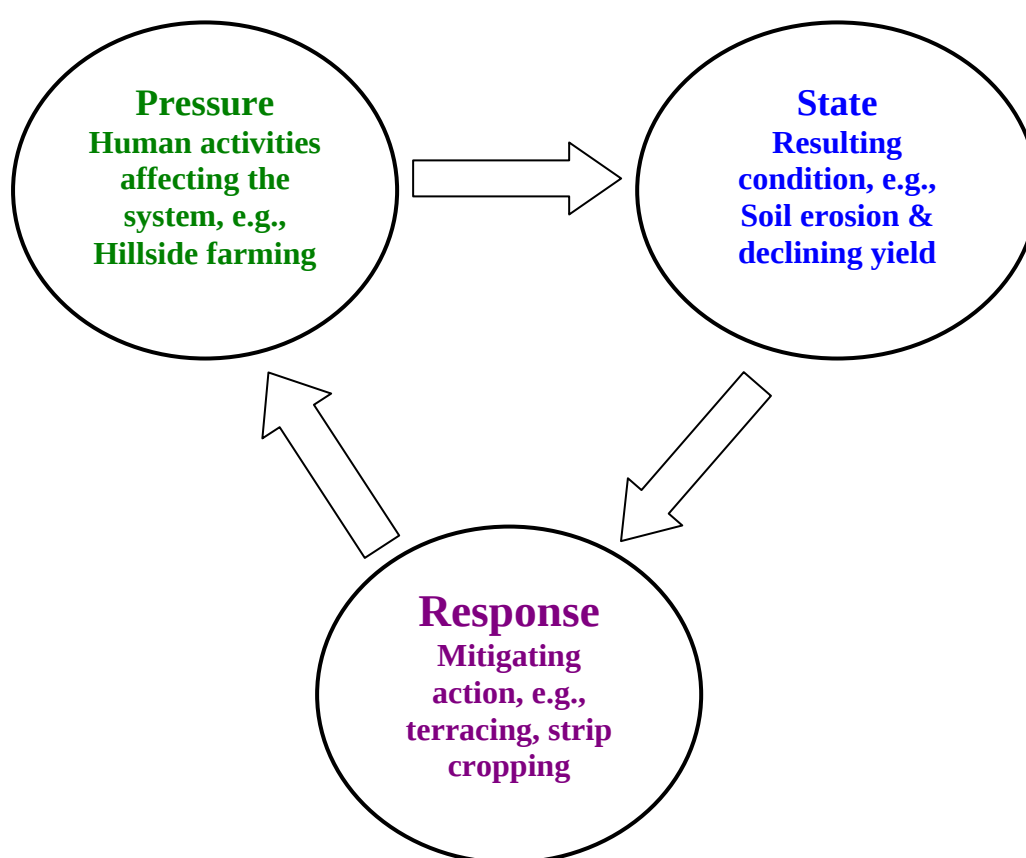


Fig. 1: The PSR framework for Sustainability Indicators
(Source: FAO Research Extension and Training)

Pressure refers to the driving forces that create environmental impacts. They could include hillside farming, agro-industrial processing, livestock grazing, deforestation, etc.

State refers to the condition(s) that prevail when a pressure exists. This could be for example declining yields, fish die-off or soil erosion, etc.

Response refers to the mitigation action(s) and levers that could be applied to reduce or eliminate the impacts.

Ecological basis of Sustainability/ Resource Management

The ecosystem provides services such as clean water, climate regulation and nutrient recycling, which make it possible for us to thrive. These ecosystem services are also the basis for agricultural production, which needs to continually increase, in order to feed the expanding global population. However, agriculture as practiced today also has negative impacts on the ecosystems. In the longer term, these negative impacts will reduce the efficiency of the ecosystem services that are needed to sustain agricultural production. This creates a fundamental conflict, and many farmers are already experiencing reduced yields as a result of declining soil fertility, increasing temperatures and less rainfall. Resolving the conflict between increasing agricultural production and maintaining biodiversity and ecosystem services is an enormous challenge (Meyer and Heffman, 1993).

A farm can also be a complex, interwoven mesh of soils, plants, animals, implements, people and other inputs, operating within a specific environmental and social context. On such farms, the farmer, with the intimate knowledge of local conditions, plants and animals, tries to enhance the natural ecological processes and to manage the whole farm to provide a wide range of produce. Agroecology sees a farm as a complex system in which natural ecological processes are always at work. These processes involve the breakdown of organic matter, nutrient cycling, interactions between pests and beneficial insects, competition between different plant and/ or animal communities, symbiosis between fungi or bacteria and plants and successional changes (Gold, 1999).

By combining farmers' traditional knowledge with recent experiences of ecologically-sound agriculture and new approaches in agricultural sciences, it is possible to develop ecologically-sound agricultural systems which combine high and sustained production with maintenance of the environment and its ecosystem services.

Ecological basis: The design of ecologically-sound, sustainable agricultural system is based on the application of ecological principles such as (LEISA, 2006):

- (i) Securing favourable soil conditions for plant growth by enhancing biological soil life through the management of soil, vegetation and organic matter;
- (ii) Optimizing the recycling of nutrients within the farm system and balancing nutrient availability and flows through the management of vegetation, animals and organic matter;
- (iii) Making optimal use of the biological and genetic potential of plant and animal species;
- (iv) Enhancing beneficial biological interactions and synergisms through the use of biodiversity and genetic resources by combining integrated systems with a high degree of functional diversity;
- (v) Minimizing losses from pests and diseases by enhancing the health and the self-regulating capacity of the farm system; and
- (vi) Maximizing the uptake of solar energy and minimizing the loss of water through management of microclimate, vegetation and water retention.

These principles reflect the functions of natural ecosystems and can be used to provide general guidance for developing ecological farming systems. Each principle can be applied through a range of different techniques and strategies. Each of these techniques will have different effects on productivity, stability and resilience within the farm system and will have to be adapted to the specific circumstances of each farm as local opportunities and resource

constraints differ from place to place. In this way biological efficiency can be optimized, the agro ecosystem remains productive and its self-sustaining capacity can be enhanced.

Profile of Indian Agriculture in relation to Sustainability

India occupies a strategic position in Asia, looking across the seas to Arabia and Africa on the west and to Burma, Malaysia and the Indonesian Archipelago on the east. Geographically, the Himalayan ranges keep India apart from the rest of Asia. A profile is listed in the following table.

Table 3: A Profile of India

S. No.	Profile Parameter	Description of Profile characteristics
1	Location	Latitude 8° 4' - 37° 6' N, longitude 68° 7' - 97° 25' E. Southwest-Arabian Sea, southeast- the Bay of Bengal, north, northeast & northwest- the Himalayan ranges, southern tip of the Indian peninsula- Kanyakumari, south- the Indian Ocean. Andaman and Nicobar islands in the Bay of Bengal and Lakshadweep in the Arabian Sea are parts of India.
2	Area	Total land area 3,287,263 sq km.
3	Extent	North to south-3214 km, east to west- 2933 km, land frontier-15,200 km, coastline- 7516.5 km
4	Population	1081.23 million
4	Climate	Mainly tropical or subtropical
5	Physiographic regions	The mainland comprises 7 regions. Northern Mountains including the Himalayas and the North Eastern mountain ranges, The Indo Gangetic plain, The Desert, Central highlands and Peninsular plateau, East Coast, West Coast, Bordering seas and islands
6	Mountain ranges	The Himalayas, the Patkai and other ranges bordering India in the north and north east, the Vindhyas, which separate the Indo Gangetic plain from the Deccan Plateau, the Satpura, the Aravalli, the Sahyadri, which covers the eastern fringe of the West Coast plains and the Eastern Ghats, irregularly scattered on the East Coast and forming the boundary of the East Coast plains.
7	Desert	The Desert region- the great desert and the little desert. The great desert extends from the edge of the Rann of Kachchh beyond the Rajasthan-Sind Frontier runs through this. The little desert extends from the Luni between Jaisalmer and Jodhpur up to northern west.
8	Watersheds	There are mainly three water-sheds. Himalayan range with its Karakoram branch in the north, Vindhyan and Satpura ranges in Central India, and Sahyadri or Western ghats on the West Coast.
9	Flora and fauna	45,000 plant sp. 33% of which are native; 15,000 flowering plant sp, accounting to 6% of the world's total flora. Out of these, about 3,000 to 4,000 are believed to be in danger of extinction. The fauna of India 5,000 species of larger animals.
10	Rivers	Three groups: the great Himalayan rivers of the north (the Indus, the Ganga and the Brahmaputra), the westward-flowing rivers (the Narmada and Tapi), and the eastward-flowing rivers of the Deccan Plateau and the rest of peninsular India (Godavari, Krishna, Cauvery, Pennar, Mahanadi, Damodar, Sharavati, Netravati, Bharatapuzha, Periyar, Pamba).

(Source: <http://www.southasianmedia.net/profile/india>)

India's Natural Resources and Sustainability of Agriculture: Land, climate, and bio-inhabitants (human, animal and plant) constitute the natural wealth of any country. Land, the primary natural resource, includes soil, water bodies, vegetation, landscape and microclimate. India's geographical area is 328.73 million ha with a reporting area (for land utilization statistics) of 305.84 million ha (Table 4).

Table 4: Land Utilization Pattern in India (2003-04)

S. No.	Land Use Pattern	Area (million ha)
1	Geographical area	328.73
2	Reporting area for land utilization statistics	305.84
3	Classification of reporting area excluding fallow land- not available for cultivation	
	a) Forests	69.70
	b) Area put to non-agricultural uses	24.48
	c) Barren & unculturable land	17.73
	d) Total (= b+c)	42.22
4	Classification of reporting area excluding fallow land- other uncultivated land	
	a) Permanent pastures and other grazing lands	10.45
	b) Land under misc. tree crops & groves not included in net area sown	3.37
	c) Culturable waste land	13.17
	d) Total (= a+b+c)	26.99
5	Fallow land	
	a) Fallow lands other than current fallows	11.24
	b) Current fallows	14.80
	c) Total (= a+b)	26.04
6	Net area sown	140.88
7	Area sown more than once	49.76
8	Total (gross) cropped area	190.64
9	Gross area irrigated	76.82
10	Net area irrigated	55.10
11	Area irrigated more than once (= 9-10)	21.71
12	Gross area under HYVs**	78.35
13	Share of gross irrigated to gross sown area (%) (= 9/8 x 100)	40.30
14	Cropping intensity (%) (= gross/net sown area x 100)	135.32

** Data pertain to total area covered under HYVs of wheat, maize, bajra, jowar and paddy in the year 1998-99
(Source: Fertiliser Statistics (2005-06))

On the basis of sustainability issues, the reporting area may be classified into 3 broad sectors as follows (Table 5):

Table 5: Reporting Area

S. No.	Broad sectors	Land use characteristics	Area (million ha)
1	Agricultural sector	Net area (cultivated) sown, current fallows, other fallows and culturable waste lands	180.09
2	Ecological sector	Forests, miscellaneous tree crops and groves, pasture and grazing, barren and unculturable lands	101.25
3	Non-agricultural sector	Area put to non-agricultural uses	24.48

Among these uses, the net sown area of about 141 million ha has remained almost constant over the last 35 years. Similarly, area under forests (not necessarily the forested area) is inflexible since 1972. On an overall basis, during the last three decades area under ecological sector has decreased significantly. Thus, agricultural area is non-expanding and at the same time there is shrinkage of area under ecological sector. There is unabated rise in area under non-agricultural sector also. The availability of land per capita is also decreased sharply from 0.48 ha in 1951 to 0.20 ha in 1981 and further decreased to 0.15 ha in 2000. Ideally, the policy aim of any Government should be to guide the land use pattern in such a way that it underpins the principle 'Future life rests on meeting basic human needs without destroying these resources on which all life rests'.

India shares only 2.4% of the world's geographical area, but supports around 16.7% of the world's population and over 17.2% of the world's livestock. Thus, there is immense pressure on India's land resources. The resultant overstraining of land resources by unproportional human and animal population is the cause of widespread land degradation and threat to sustainability of agro-ecosystem.

Carrying Capacity: Carrying capacity is the number of individuals that can be supported in a given area, or the maximum population that can be sustained in a habitat without the degradation of the life support system

Carrying capacity is the theoretical equilibrium population size at which a particular population in a particular environment will stabilize when its supply of resources remains constant. It can also be considered to be the maximum sustainable population size; the maximum size that can be supported indefinitely into the future without degrading the environment for future generations (Gold, 1999).

The Earth's capacity to support people is determined both by natural constraints and by human choices concerning economics, environment, culture (including values and politics) and demography. Simple mathematical models of the relations between human population growth and human carrying capacity can account for faster-than-exponential population growth followed by a slowing population growth rate, as observed in recent human history. The distribution of operational holdings indicates that the number of holdings occupied by the marginal and small farmers is about 80% of the total holdings (Table 6), the number of holdings decreased towards greater size farms.

Table 6: Distribution of Operational Holdings in India (1995-96)

Category of holdings	Number of operational holdings (million)	Area operated by each category (million ha)	Average size of operational holdings (ha)
Marginal (< 1 ha)	71.18 (61.6)	28.12 (17.2)	0.40
Small (1-2 ha)	21.64 (18.7)	30.72 (18.8)	1.42
Semi-medium (2-4 ha)	14.26 (12.3)	38.95 (23.8)	2.73
Medium (4-10 ha)	7.09 (6.1)	41.39 (25.3)	5.84
Large (>10 ha)	1.40 (1.2)	24.16 (14.8)	17.21
All holdings	115.58 (100.0)	163.36 (100.0)	1.41

Figures in parentheses indicate the percentage of respective column totals

(Source: Agricultural Statistics at a Glance (2004))

Land degradation: Degradation refers to reduced productivity of soils (and vegetation) compared to that what is attainable at a fixed level of non-land inputs. Land degradation is a principal factor inhibiting productivity and endangering sustainability of an agricultural system. Soil erosion is its principal puporter and soil cover viz., vegetation provides the shield.

Current estimates on land degradation show that about 173.64 million ha (53% of the total geographical area) suffers from soil erosion, water logging, and other special problems for cultivation (Table 7). There is hardly any doubt on the massiveness of land degradation due to collective passivity of various public institutions on the one hand and splinter group activity by individual farmers on the other.

Table 7: Distribution of estimated area under different soil erosion, land degradation and land utilization problems (estimated)*

S. No.	Categories of different problems	Area (million ha)
1	Geographical area	328.73
2	Area subject to water and wind erosion	144.12
3	Area degraded through special problems	29.52
	3.1 Water logged area	8.53
	3.2 Alkali soils	3.88
	3.3 Acid soils	4.50
	3.4 Saline soils including coastal sandy areas	5.50
	3.5 Ravines and gullies	3.97
	3.6 Area subject to shifting cultivation	4.91
	3.7 Riverine and torrents	2.73
	Total (3.1 to 3.7)	34.02
4	Total problem area (2+3)	173.64
5	Total flood prone area	40.00
	Annual average area affected by floods	8.00
	Annual average cropped area affected by floods	3.70
	Maximum area affected in the worst year	18.60
6	Total drought prone area	260.00

*Data pertain to land utilization statistics of 1981-82 and report till 1996-97
(Source: Fertilizer Statistics (2005-06))

Some of the impacts of land degradation are listed below:

- i. Declining yields
- ii. Need to use higher levels of inputs
- iii. Changes in land use pattern
- iv. Off-site effects (pollution of ground water, siltation of reservoirs)
- v. Loss of biodiversity
- vi. Environmental effects (loss of habitat due to devegetation)
- vii. Property damage

Declining yield of crops is basically due to the decline in land quality on-site where degradation occurs, for example erosion and off-site where sediments are deposited. However, the on-site impacts of land degradation on productivity are easily masked due to use of additional inputs and adoption of improved technology.

Nutrient depletion as a form of land degradation has a severe economic impact. There is invariably need to use higher inputs like fertilizers, because of land degradation, there is a

decline in soil structure leading to crusting, compaction, erosion, desertification, creation of anaerobic condition due to water logging, environmental pollution, and unsustainable use of natural resources. In addition, the chemical degradation processes in soil leads to acidification, leaching, salinization, decrease in cation exchange capacity, and declining soil fertility. Even crop productivity of irrigated lands is severely threatened by build up of salt in the root zone.

Impact of land degradation is remarkable because, in many severely degraded areas, biological processes are deteriorated. There is reduction in total and soil microbial biomass carbon, and eventual loss of biodiversity. This has important concerns related to eutrophication of surface water, contamination of groundwater, and emissions of CO₂, CH₄, N₂O, from terrestrial as well as aquatic ecosystems. Severe land degradation affects a significant portion of the earth's arable lands, decreasing the wealth and economic development of nations. The economic impact of land degradation is severe in densely populated South Asia, and sub-Saharan Africa.

The effects of land degradation have more significant impacts on receiving water courses (rivers, wetlands and lakes) since soil, along with nutrients and contaminants associated with soil, are delivered in large quantities to environments that respond detrimentally to their input. Land degradation therefore has potentially disastrous impacts on lakes and reservoirs that are designed to alleviate flooding, provide irrigation, and generate hydro-power.

Degradation is also considered responsible for a change in the ground cover to less palatable species, or a change from predominantly perennial grasses to predominantly annual grasses. Environmental dilapidation is brought about by pollution especially in urban areas, which not only experience a rapid growth of population due to high fertility rates, low mortality and increasing rural to urban migration, but also due to the industrialization.

Water resources: The sustainability in agriculture i.e., for crops/ cropping systems is primarily depends upon the availability of water in its optimum quantity and acceptable quality. Rainwater is the primary source to meet the demand of water. From rainfall, India annually receives a rainfall of 1085 mm (long-term average from 1950-1994). This rainfall is equivalent to roughly about 400 M hectare meter water (4000 billion cubic meters; one hectare meter of water weighs approximately 100 tonnes). Nearly three fourths (i.e., 799.6 mm) of the total rainfall received in India is through South-West monsoon activity (Table 8). Not even 3% of the total precipitation is contributed by North-Eastern monsoon. The remaining amount of rainfall comes via pre or post-monsoon activity.

Table 8: Distribution of Annual Rainfall according to Seasons in India

Rainfall	Duration	Amount (mm)	% of annual Rainfall
Pre-monsoon	March-May	112.8	10.4
South-West monsoon	June-September	799.6	73.7
Post-monsoon	October-December	144.3	13.3
Winter or north-east monsoon	January-February	28.2	2.6
Total		1085*	100.0

*Total annual rainfall = 1085 mm (long-term average, 1950 to 1994)

Prevailing conditions and locational placement on or out of path of progressing monsoon play a significant part in deciding the regional disparities observed in rainfall distribution and availability. Employing average annual rainfall as the criteria, 30% of the area in the country receives less than 750 mm, 42% of the area gets between 750 and 1150 mm, and 20% of the India's earth has access to rainfall between 1150 and 2000 mm. It is only 8% of the land area, which secures more than 2000 mm rainwater annually. Thus 70% of the land area receives rainfall greater than 750 mm (Table 9).

Table 9: Distribution of Area according to Annual Rainfall in India

Rainfall amount		Percentage of area receiving rainfall (approx.)
Dry	0-750 mm	30
Medium	750-1150 mm	42
	1150-2000 mm	20
Assured	above 2000 mm	8
Total (1085 mm)		100

(Source: Fertiliser Statistics (2005-06))

The water resources potential of the country which occurs as natural run off from rainfall and snow melt into rivers and streams is about 186.9 M ha m as per the estimates of Central Water Commission (CWC), considering both surface and ground water as one system (Water Related Statistics 2006, CWC). The Ganga-Brahmaputra-Meghna system is the major contributor (59%) to total water resources potential of the country. Due to various constraints of topography, uneven distribution of resource over space and time, it has been estimated that only about 112.3 M ha m of total potential of 186.9 M ha m can be put to beneficial use, 69 M ha m being due to surface water resources and 43.3 M ha m due to ground water resources. Again about 40% of utilizable surface water resources are presently in Ganga-Brahmaputra-Meghna system. This 112.3 M ha m would be used for irrigation, domestic and industrial purposes. Thus, practically the water available for irrigation to agricultural crops will be inadequate. So enhancing the efficiency of water use is an important option; and if India has to remain self-reliant in her food needs, there is no choice except to save every drop of water and use it most prudently for sustainability in agriculture.

Rainfed Areas: At present, nearly 60% of the agriculture is rainfed, which contributes a major portion of our food and supports a majority of the human population. About 30% of the country spread over 99 districts is drought-prone (ref., J.C. Katyal). In these districts, not only the agricultural sustainability is under threat because of critical water shortages, but also the region as a whole suffers chronically from serious drinking water crisis. In fact, there is uncertainty in rainwater availability, most of the years the onset, continuity, and withdrawal of monsoon is erratic.

Any breakthrough in these drought-prone areas will primarily happen via rainwater conservation, as it is the most important aspect of overall agricultural management. The main objective should be to minimize runoff by encouraging its entry into the soil (*in-situ* water conservation) and capturing the water, which cannot penetrate into the soil. Run-off, amounting up to 40% of the total precipitation, is a typical feature of tropical monsoon,

which tends to unleash in big storms. Runoff, when not harvested promotes unsustainable agriculture on two counts: (i) loss of precious rain water which otherwise could benefit withering crops, and (ii) busting of nutrient rich topsoil caused by erosion. Estimates on rainwater budgeting show that 24 m ha m equivalent runoff is available for harvesting in the donor areas of field level catchments (nested or micro watersheds). Capturing the runoff water and recycling it ensures stabilizing and sustaining the productivity of rainfed crops.

Demographic compulsions, increasing food, fuel and fodder needs and achievement in agricultural productivity: Based upon the anticipated growth in population India's population is likely to stand at around 1329 million by 2020. This will happen despite the fall in annual compound growth rate from 2.14 in 1991 to 1.97 in 2001 (Fig. 1). Since the growth in population is exponential in nature, India's population will continue to dilate by an additional ~16 million people each year (ref., J.C. Katyal, data updated). Just to meet the requirements on food for this population alone (leave aside seed and feed needs), India will be required to produce additional 3.2 million t foods each year (1 t food is assumed to feed 5 persons for one year). In order to keep below the Malthusian cross (i.e. when population growth rates exceed the rate of food supply increases) it will be necessary to achieve at least 2 t food grain productivity/ha from rainfed areas and 4 t/ha from irrigated areas. Current food grain productivity of rainfed crops stands at less than about 1 t/ha and that of irrigated crops at about 2 t/ha. Thus, the traditional agricultural systems though sustainable at low levels of productivity, will not be able to measure up to the rates of growth that can neutralize the needs of burgeoning population. A proper mix of technological interventions, inputs, extension and infrastructure support will become increasingly important to ward off any food deficiencies to arise.

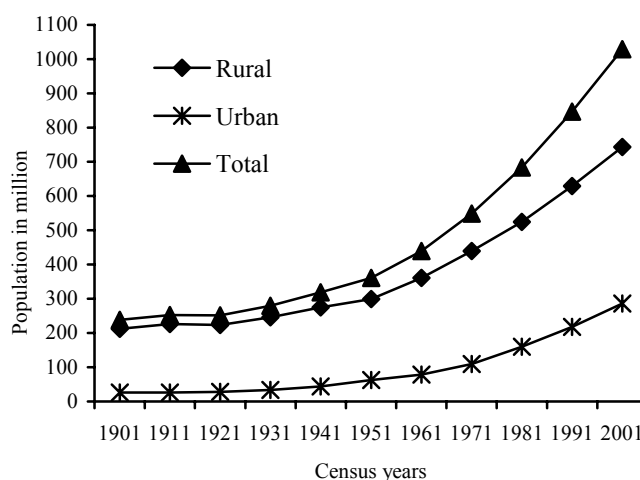


Fig. 2. Population in India
(Source: Fertiliser Statistics (2005-06),
Agricultural Statistics at a Glance (2004))

GDP in Agriculture & Allied Sectors: Though the absolute values in GDP in agricultural and allied sectors are increasing (except in 2003-03, because of severe drought in 2002), the rate of growth is not attractive. It is highly volatile. Low and volatile growth rates in Indian agriculture and allied sectors are reflected in the average annual growth rate (Table 10). The overall GDP was low during the period 2000-2003, again it has gained its momentum. With a favourable monsoon, growth was an impressive 9.9 per cent in 2003-04. The contribution of agricultural & allied sectors to total GDP is decreasing every year. Of course, this is because

of the fact that the rate of growth in service and other sectors are significantly higher than the rate of growth in agricultural sector.

Table 10: Gross Domestic Product (GDP) and contribution of agricultural and allied sectors to total GDP in India

Year	Total GDP (Rs crores)	Overall GDP Growth Rate	GDP in Agric. & allied sectors (Rs crores)	<i>GDP at current prices</i>	
				GDP in Agric. & allied sectors growth rate	Contribution of Agric & allied sectors to total GDP (%)
1993-94	781345	-	241967	-	31.0
1994-95	917058	17.4	278773	15.2	30.4
1995-96	1073271	17.0	303102	8.7	28.2
1996-97	1243547	15.9	362606	19.6	29.2
1997-98	1390148	11.8	387008	6.7	27.8
1998-99	1598127	15.0	442494	14.3	27.7
1999-2000	1761838	10.2	461964	4.4	26.2
2000-2001	1902998	8.0	468479	1.4	24.6
2001-2002	2090957	9.9	521907	11.4	25.0
2002-2003	2249493	7.6	509907	-2.3	22.7
2003-2004	2523872	12.2	560482	9.9	22.2
2004-2005 ^P	2713162	7.5	616530	10.0	22.7
2005-2006 ^Q	2957347	9.0	653522	6.0	22.1
2006-2007 ^A	3229423	9.2	671167	2.7	20.8

^P Provisional, ^QQuick estimate, ^AAdvance estimate

(Source: Economic Survey (2006-07))

Agricultural Production: Indian agriculture has witnessed a phenomenal increase in the agricultural production front. Compared to 50.83 million tonnes in 1950-51, India attained a food grain production of 208.31 million tonnes during 2005-06 (Fig. 3). Measured by the food grain availability criteria, per capita food availability has increased from 395 g/day in 1951 to 463 g/day in 2004. It is a vivid demonstration of the great big achievement because it has occurred against the backdrop of about three times rise in population during the same period (363.2 million in 1951 to 1085.6 in 2004) (ref., J.C. Katyal, data updated). The production of oilseeds has increased from a mere 5.16 million tones in 1950-51 to 27.73 million tones in 2005-06 (Fig. 4). During the year 2001, India ranks first in the world in production of milk, cattle, buffaloes, tea leaves, total pulses, jute and allied fibres; she ranks second in the world in production of rice, wheat, fruits and vegetables, groundnut, sugarcane, tobacco leaves and goat. However, declining land-man ratio happening in the wake of rising population is highly disquieting because it puts progressively more strain on the non-expandable assets, specifically land resources.

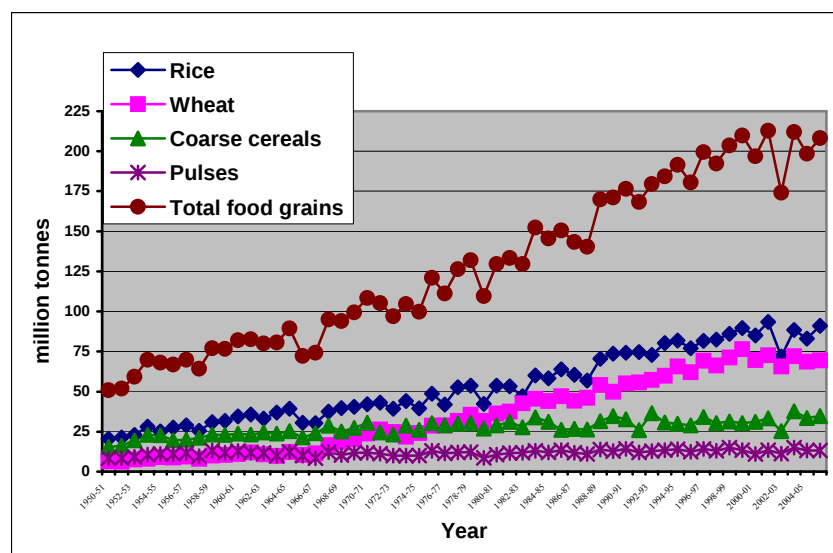


Fig. 3: Food Grains Production in India (1950-51 to 2005-06)
(Source: Fertilizer Statistics, 2005-06)

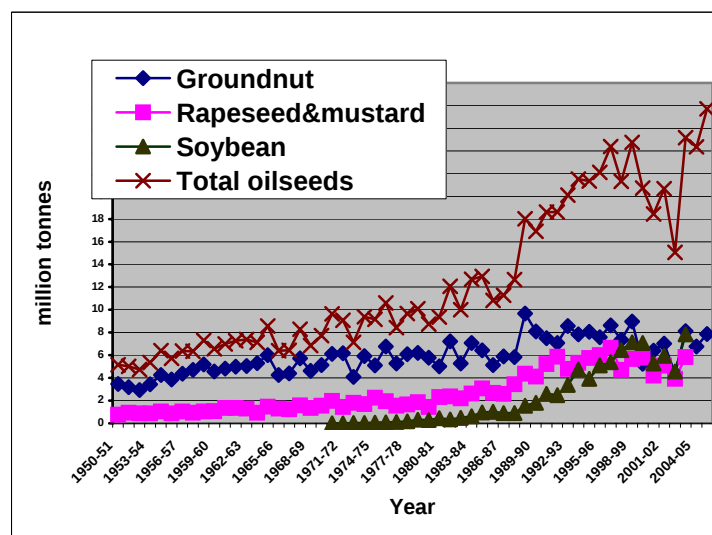


Fig. 4: Oilseeds Production in India (1950-51 to 2005-06)
(Years prior to 1969-70 relate to 5 oilseeds)
(Source: Fertilizer Statistics, 2005-06)

India's agricultural growth was triggered by massive public investments in agricultural research, education and extension, expansion in irrigated area, increase in agro-inputs (fertilizer, seeds, pesticides, etc), government policies and above all willing support of farmers in adopting improved technologies. Rise in the irrigation water availability has been the key factor promoting use of and response to all other agro-inputs. The irrigated area increased from 20 million ha in 1950 to 57 million ha in 2000-01. Fertilizer use has risen from 69.8 thousand tonnes (of NPK) to 18.4 million tonnes (a whopping rise of 266 times) in about 50 years. Fertilizer in the presence of irrigation and seeds of high yielding varieties has been the key input in ushering in the green revolution in India. However, at present, there is a falling response of cereal crops to fertilizers (NPK) (Table 11). This fall in response has largely been felt with rice and wheat. These together consume nearly 70% of the total

fertilizers used in the country and are cultivated in well-endowed irrigated or assured rainfall areas.

Table 11: Response to Fertilizer Application in Food Grains Production

Period	Food grains production (mt)	Increase in food grains production (mt)	Fertilizer use			Response** (kg/kg nutrient)
			Total (mt)	Food grains* (mt)	Increase (million tones (mt))	
1970-75	103.02	-	2.62	1.83	-	-
1975-80	120.04	17.02	4.19	2.93	1.10	15.49
1980-85	138.07	18.03	6.78	4.75	1.81	9.94
1985-90	155.03	16.96	9.70	6.79	2.04	8.30
1990-95	180.00	24.97	12.67	8.87	2.08	12.01
1995-2000	197.11	17.11	15.85	11.10	2.23	7.69
2000-2005	198.85	1.74	17.07	11.95	0.85	2.04

*Assuming 70% of the fertilizers were used for food grains

**Ignoring the effect of area expansion, irrigated area and the high yielding varieties
(Up to 1990, calculations were made by Dr. D.R. Bhumbra)

Along with unsustainable yields, nutrient imbalances encourage continuous build up of those nutrients that remain unutilized by growing crop plants. The left over nutrients are the principal cause of fertilizer use related environmental pollution. For instance: unutilized P can cause eutrophication of lakes and rivers, whereas unused N can lead to ground water pollution (as nitrate) or promote breakdown of protective ozone layer (as nitrous oxide) which shields earth against the harmful effects of ultraviolet radiation. It thus appears that the same factors (irrigation and fertilizer nutrients), which ushered in green revolution are being blamed to pull it down also. What is required is to emphasize integrated nutrient management (man made and native nutrient sources combined). This time tested strategy will assure balanced nutrition, sustainable yields and good soil health (Katyal).

The sustainability of agriculture is ostensibly imperiled by the lack of adequate land management systems and inputs in the fragile and marginal environments like dryland regions. For example, rice, wheat and sugarcane - the three predominantly irrigated crops, usurp about 80% of the fertilizer - N used in the country. Share of fertilizer-N for sorghum, which is chiefly rainfed and ranks third after rice and wheat in area, does not exceed even 2% of the total consumption. Without intensification in fertilizer use along with organic manure, sustainable productivity from rainfed areas will remain a mirage (ref., J.C. Katyal).

Animal Production, its carrying capacity and fodder needs: From the agricultural standpoint, India is endowed with very significant diversity among domesticated animals. These represent. some 26 breeds of cattle, 8 of buffaloes, 40 of sheep, 20 of goats, 8 of camels, 14 of horses and 18 of poultry. Another vital issue on sustenance of cattle wealth is related to their overflowing number. Thus, the rate of growth of animal production (including the total fish production) is remarkable (Fig. 5). The estimated population (year 2001) of cattle (220 million), buffaloes (94 million), camels, sheep, goats etc. is remarkable in the country compared to the world population. This animal population exceeds the carrying capacity of India's natural resources. According to one estimate, the ideal number of

livestock, keeping in view the carrying capacity of land to support grazing, is only about 50 million heads, i.e., one-ninth of the current population. As a result of mismatch between the number of livestock and inability of natural resources to sustain them, sub-optimal nutrition is rampant. National Commission on Agriculture estimated that only 56% of the dry fodder and 27% of the green fodder requirement were being met (Katyal). The demand supply gap is likely to widen further in future. It is the poor availability of fodder which forces uncontrolled grazing, leading to diminished vegetative cover and accelerated degradation of land. In rain fed areas with possibility of double cropping farmers are constrained to take a post rainy season crop because of uncontrolled grazing. Clearly, improvement in forage production is an important strategy to increase animal productivity and saving natural resources from degradation.

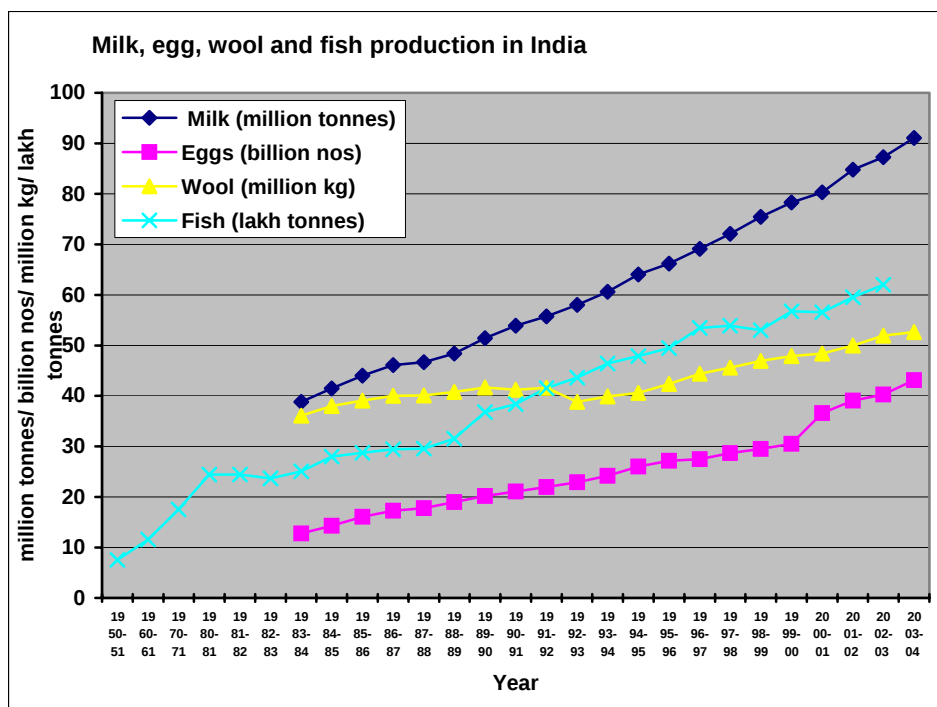


Fig.5: Production of Animal Products in India
(Source: Fertilizer Statistics, 2005-06)

Advances in agricultural production technology has considerably raised farm output but has created problems of land degradation, declining of soil organic carbon, pesticide residues in farm produce, degradation of genetic resource base, environmental pollution, climate change, shrinkage in water reservoir capacity, problems of water scarcity, water pollution etc. Emission of smoke and gases from industry and automobiles etc. increase CO₂ content of the atmosphere. Effluents of the industry and mining are contaminating water bodies and are degrading the land. High dose of N- fertilizers in some areas are polluting water bodies with high level of nitrates. Pesticide residue in soil contaminates water bodies. The pace of agricultural activities hastens the process of degradation, denudation of forests, and loss of arable land, desertification and reduction of genetic diversity. The natural resource base is degraded and the quality of the environment sustaining human life is adversely affected.

The remedial measures to combat these problems rely on the adoption of conservation farming techniques. The suitable measures include conservation of genetic resources, integrated nutrient management, efficient on-farm water management, participatory watershed management, integrated pest management, etc. The soil and water conservation measures should be adopted for successful conservation farming. The management of crop

residues through conservation tillage (zero or minimum tillage), mulch farming rather than residue burning is encouraged. The recycling of farm waste (crop residues and animal dung, urine etc.) to the crop field should be practiced considering the farm as a self-sustaining system. The selection of efficient crop rotation is important for successful sustainable agriculture. Thus, the conservation farming approach and practices only will ensure long-term sustainability in the agricultural systems.

Maintenance of Production Base in Irrigated Agriculture

Compared to 1950, the net area under irrigation is increased by about three times. The net irrigated area of 52.96 million ha is distributed among canals (30.4%), tanks (5.1%), wells (20.7%), tube wells (37.3%) and others (6.5%) (Fertiliser Statistics 2005-06). While there is no doubt on the valuable contribution of irrigated area to ushering in of green revolution, it is the vast gap (~10 million ha) between the irrigation potential created (94.73 million ha) and utilized (84.7 million ha) by the end of 1999-2000, which is quite disturbing. The Table 12 indicates the area covered under irrigation by the major crops in India.

The actual potential of an irrigation project is diminished due to difficulties in reaching by gravity flow to high ground patches, changes in cropping pattern favouring high water requiring crops and the greedy use of water by the farmers at the top end of the distributaries. Unscrupulous use of canal water is the root cause of widespread poor water use efficiency, which produces side effects like water logging, soil salinity and alkalinity. As per the available data, the total area suffering from water logging is 8.53 million ha, while that affected by salinity and alkalinity is around 9 million ha. Compared to canal water, ground water is used more efficiently. With groundwater the problems are more of social nature. For instance, wealthy groundwater farmers continue to extract more water despite falling depth of water table. Unabated deepening of wells and withdrawals cause drying of open shallow wells which usually poorer farmers depends for irrigation.

Table 12: Percentage Area covered under Irrigation for Principal Crops (2000-2001)

S. No.	Crops	Area (million ha)	Percentage covered under irrigation
1	Rice	44.71	53.6
2	Wheat	25.73	88.1
3	Maize	6.61	22.4
5	Jowar	9.86	7.9
6	Bajra	9.83	8.0
7	Total cereals	100.77	49.8
8	Gram	5.19	30.9
9	Arhar	3.63	4.2
10	Total pulses	20.35	12.5
11	Total foodgrains	121.05	43.4
12	Groundnut	6.56	17.6
13	Rapeseed&Mustard	4.48	66.1
14	Soybean	6.42	1.4
15	Total oilseeds	22.77	23.0
16	Cotton	8.53	34.3
17	Tobacco	0.26	52.8
18	Sugarcane	4.32	92.1
19	Total area under all crops	140.88	40.2

(Source: Agricultural Statistics at a Glance (2004), Fertilizer Statistics (2005-06))

In the tracts where ground water recharge is limited, it is the sustainability of agriculture, which becomes at stake. Deepening of water tables in the areas where less rainwater is captured than necessary to offset the withdrawals is likely to lead ultimately to permanent water deficit situation. Further, overdraft of ground water aggravates surfacing of harmful fluorides and salts. To reverse the situation, apparently the priority area of activity is to rationalize ground water withdrawals. More important than that from the sustainable agriculture point of view is the maximization of the ground water recharge through appropriate but farmer supported interventions favouring minimization of runoff water. This is reiterating the point made earlier on reining the rainwater if agriculture in India has to remain sustainable.

Thus, in the green revolution areas/ irrigated areas it is the prosperity and overuse of inputs, which threaten sustainability; while in marginal and fragile environments it is the poverty and over-exploitation, which endanger sustainability.

Modernization of Agriculture and its relation with Sustainability

The Low External Input Sustainable Agriculture (LEISA) relies mostly on the inputs from the local farm, village or region and deliberate action is taken to ensure sustainability.

The principles are:

- i) Securing favourable soil conditions for plant growth particularly managing organic matter and enhancing soil life,
- ii) Optimizing the nutrient availability and balancing the nutrient flow, particularly by means of nitrogen fixation, nutrient acquisition and complementary use of external fertilizers,
- iii) Minimizing the losses due to plant and animal pests by means of prevention and safety treatment,
- iv) Minimizing losses due to flows of solar radiation, air, water by way of microclimate management, water management and erosion control.

In the High External Input Agriculture (HEIA), production for the far off markets necessitated use of external inputs like chemical fertilizers, hybrid seeds, pesticides, irrigation etc. Increased dependency on high cost external inputs in agriculture also made farmers to depend on external credit on a regular basis. Cultivation of cash crops like cotton and tobacco, also led to scarcity of fodder. This resulted in farmers giving up animal husbandry, thereby resulting in acute scarcity of farmyard manure and making the use of chemical fertilizers inevitable.

Adoptions of modern technologies in agriculture like tractors and pump sets have resulted in the neglect of draught animals. Even the livestock production has been totally changed into industrial type of production from backyard system. Animals provide manure, food and income and are used for cultivation and transport economically. Different animals can be fed on farm wastes efficiently, which provide financial security at the time of distress. In Indian culture, cattle are treated as an integral part of the family. After undergoing the huge losses from adapting crossbred cows like Holstein, Friesian and Jersey, farmers are fast changing towards indigenous cattle, since their maintenance is cheaper and the male calves can be used for cultivation and transport.

Agriculture in India, was an integrated cultivation of crops, animals and trees to meet most of the family and community needs rather than market. Trees played an important role in

providing green manure, fodder, fruits, fuel and timber besides conserving soil water and hosting beneficial insects and birds. Now, it is necessary to revive the traditional knowledge on seed selection and preservation to bring back the self-reliance and seed availability at the time of sowing.

Similarly, rural population is fast changing their medical treatments since synthetic drugs have become more expensive and found to create side effects. They now started growing medicinal plants like Neem, Aswagandha, Asparagus, Aloe vera, Adathoda etc., for medication of both humans and their livestock.

The Government's concern of impending scarcity of fossil fuel resources is an encouraging factor for promotion of ecological agriculture. However, the fear of lower food production and availability of biomass is coming in the way of progressing towards organic farming. The goal of LEISA, therefore, should be based on economic interests by popularizing production of seeds, vermicompost, botanical pesticides etc.

LEIA vis-à-vis HEIA: A brief account of LEIA vis-à-vis HEIA is presented in Table 13.

Table 13: LEIA vis-à-vis HEIA

S. No.	Characteristics of HEIA	Characteristics of LEIA
1	The farming pattern depends heavily on external and chemical inputs.	LEIA relies on the optimal use of natural processes. Although yields have increased substantially, contributing to raising total production, farmers and the environment have had to pay the price for keeping up with this development.
2	The focus of agricultural development and research has mainly been on maximizing yields coupled with increasing specialization of production	The focus is on the sustainability of farming system
3	There is a great damage to the environment	Environmentally sound and that have the potential to contribute to the long-term sustainability of agriculture.
4	The continuing drop in prices of farm produce and the rising costs of agricultural inputs have made farming increasingly unprofitable	Greater emphasis is on the long-term sustenance and balance between the profit and livelihood.
5	HEIA depends on the higher production and profit, without consideration of the local needs and local market	Sustainable ecological practices depend largely on local agro-ecological conditions and on local socio-economic circumstances, as well as on farmers' individual needs and aspirations.
6	Primarily one or two commodity driven development, lack of diversity in the farming practices, as a result, there is greater risk of failure and price fluctuation. The number of products and commodities are very minimum.	One way of LEIA is to diversification of farms; with a range of crops and/or animals, farmers will suffer less from price fluctuations or drops in yield of single crops. Maintaining diversity will also provide a farm family with a range of products to eat or sell throughout a large part of the year.

7	Under HEIA system, soil quality deteriorates, and there is resurgence of pests, lack of resilience in the soil-plant system	LEIA maintains a healthy soil, recycling nutrients on the farm, and utilizing approaches such as integrated pest management (IPM).
8	In HEIA, there is lack of use of indigenous technologies.	Best bet technologies, for example, soil and water conservation (terraces, ditches, and vegetation strips on sloping land), better timing of operations, improved crop spacing and densities, manure or compost and water application based on local conditions.

Conventional vis-à-vis Organic Farming for Sustainability: Escalating production costs, heavy reliance on non-renewable resources, reduced biodiversity, water contamination, chemical residues in food, soil degradation and health risks to farm workers handling pesticides all bring into question the sustainability of conventional farming systems.

It has been reported, however, that organic farming systems are less efficient, pose greater health risks and produce half the yields of conventional farming systems. Nevertheless, the importance is fastest growing in favour of organic farming in selected crops and agro ecological conditions. Organic management practices should be made popular which are combined with traditional conservation-minded farming methods with modern farming technologies but conventional inputs such as synthetic pesticides and fertilizers are excluded, instead greater emphasis on building up the soil fertility with compost additions and animal and green manures, controlling pests naturally, rotating crops and diversifying crops and livestock.

Just because a system is organic or integrated does not ensure its sustainability; nor does sustainability readily lend itself to quantification. To be sustainable, a farm must produce adequate yields of high quality, be profitable, protect the environment, conserve resources and be socially responsible in the long run. But under conventional economic systems, market and social forces can change the viability of a production system independent of its environmental sustainability. However, ecological and economic systems should be linked so that sustainable land management is a prerequisite for economic sustainability.

Basic Ecological Principles of LEISA

(i) A living soil: Soil can be regarded as a non-renewable resource, as soil formation is such a slow process. The soil provides a medium to anchor plant roots, but is also a very complex ecosystem. A productive agricultural soil is full of life, with millions of microorganisms which all interact chemically and physically with their soil environment. These processes regulate the release of nutrients from minerals and organic matter to feed the plants. A living soil has a better structure and can absorb and retain more water and air than a sterile soil. Sound ecological production therefore begins with improving the soil. Good practices, which can help improve the condition of the soil, are (LEISA, 2006):

- (i) Growing legumes to fix nitrogen from the air and provide it to the following crop,
- (ii) Feeding the soil with as much organic matter as possible through green manure, compost, cover crops, returning of non-toxic organic wastes and agroforestry;
- (iii) Keeping the soil covered at all times with mulch or cover crops

- (iv) No or reduced tillage which enhances water availability and soil conservation,
- (v) Cultivating a range of crops and animals to reduce risks of disease and pest outbreaks, maintain a balanced nutrient supply and provide resilience;
- (vi) Planting trees on contours or making terraces to prevent soil erosion by wind or water.

(ii) Biological diversity: The diversity of different species of plants and animals, and the genetic variation within each species, provides the vital resource of biological diversity, which enables life on earth. Healthy ecosystems are relatively stable and the diversity they contain enables them to adapt to changing circumstances.

For many small-scale farmers the available agrobiodiversity is the basis of survival. A mix of different locally adapted crops and animals and different varieties of the same increases on-farm diversity, increasing the chances of producing something even under adverse conditions. These principles of traditional farming can be further developed and used systematically in ecological farming.

Some examples of such practices are (LEISA, 2006):

- (i) Intercropping in time and space: planting different crops together in different combinations or formations, or in sequence, can optimize the use of available resources and reduce the pressure of pests.
- (ii) Different plant species can also be used to support the ecological functioning of the whole farm system: examples are trees or bushes for windbreaks, flowering plants which provide food and habitat for beneficial insects that help control pests, shade trees for light-sensitive plants, trees to provide green manure and fuel wood.
- (iii) Integration of different crops or weeds with animals to better utilizes resources, for example fish in rice fields, integrated crop-chicken-fish systems and other combinations of crops and animals.

(iii) Water: Growing populations, rapid urbanization and increasing industrial and agricultural production are all increasing competition for and pressure on water. As agriculture is one of the major users of water, and one of the major polluters of water resources, it is imperative that water use in agriculture is as efficient as possible and that leaching of surplus nutrients and in small scale farming it is important to make the best possible use of the limited amounts of available water. Infiltration can be improved by keeping the soil covered, through minimum disturbance of the soil, adding organic matter from cover crops and mulching.

When introduced, water-harvesting systems are generally multi-purpose. Farm ponds, earth dams and sub-surface tanks will often serve as a source of drinking water and water for livestock during periods of water scarcity. Water harvesting can open up new livelihood options. Subsistence farmers, who invest in water harvesting systems with a storage component, often diversify their farming system to include cash crop production, for the local market during off-season when prices are high. This diversification increases the resilience of farm households, as they are better equipped to cope with periods of climatic hazards such as droughts and floods.

(iv) Energy: Solar energy is captured by plants that are able to transform it into biomass. This is the basis for all higher life forms, animals as well as humans, and is a process that is unique for green plants. Biomass contains stored energy as well as nutrients, and agriculture

should focus on maximizing the amount of solar energy, which is captured and transformed into plant growth and thereby food and fodder resources. But additional energy is required for cooking and heating and is useful for irrigation, threshing and processing. Fortunately there are many opportunities to make use of renewable energy, most frequently fuel wood, straw, crop residues and even manure are used. There are also other possibilities to make use of renewable energy: small scale bio-digesters which use manure, solar energy devices, small scale hydropower generators, wind-power and wood lots for fuel wood.

(v) Exploiting Animal-Plant Interaction: In nature, nothing functions in isolation; everything depends on the other factors present. In animal production, to optimize the performance of cattle, it is very important that management practices should enhance the ecological functioning of the web of living organisms within the production system - climate, soil and soil life, vegetation and cattle - by influencing their interactions.

For cattle production, it is important that the breed is selected first, then the pasture suited to that breed and finally the soil is corrected with proper fertilizer or amendment (if needed) to make the pasture grow. This order has to be reversed. The pasture has to be adapted to the soil and the cattle to the pasture, and all of it has to fit the climate. In addition, the forage crops are to be grown. Of course, in dry areas, forage yields depend strongly on the availability of water. In a well-structured soil, roots are able to explore a larger soil volume for more water and nutrients. Integrating deep-rooting crops and trees into the pasture system will further increase the production of biomass and the overall performance of the system (LEISA, 2006).

In native grassland, cattle always first eat the plants it likes most. The plants that are not eaten get old, hard and are not tasty. The eaten plants sprout again and are grazed on another time. This goes on until these palatable plants disappear. But the less appreciated plants continue to grow and multiply and with time the entire pasture gets hard, rough and has little nutritive value. Then the ranchers set fire to the pasture. Many plants die, and only those that can protect their growing points against fire survive. Thus the pasture becomes worse and the forage volume smaller. Thus all organic matter that nourishes soil microorganisms is burned out, resulting in their death. The soil compacts, water runs off and the vegetation gets scantier. Thus, the division of pastures into smaller sub-units for grazing rotation is fundamental for sustainability of pasturelands.

However, to prevent 'global climate change' by 'greenhouse gases', it is important to reduce methane emission by cattle. This obliges farmers to speed up animal production per unit area and to reduce the slaughter age to get a lower ratio of kg methane/kg animal protein (meat). The use of grains for animal feed has to be reduced as well, giving priority to human consumption. This then increases the dependence on forage. But, as grass cellulose is the main source of methane emission, management practices that contribute to an increase of forage yield per unit area and maintain stocking rate without weight losses, all year long, are needed.

(vi) Towards Local Resources-based Integrated Crop- Livestock Systems: The present livestock production systems in most industrialized countries are in direct competition with human needs. Livestock presently consume almost 50% of world cereal grain supplies. In the intensive large-scale production systems, increasingly promoted by corporate agriculture, livestock wastes contaminate soil and water resources, create less than favourable working conditions for the personnel involved in feeding and cleaning, and decrease employment

opportunities. To meet food needs in 2050, it is necessary to develop livestock production systems, which do not depend on cereal grain.

In developing countries like India, instead of grain-based livestock systems, alternative production systems must be developed which make optimal use of locally available resources. Close integration of livestock in the farming system, with recycling of all excreta, will be the basis of agriculture, which can be highly productive and also sustainable.

In tropical countries, especially in the humid zone, there are many crops and farming systems that considerably exceed the productive capacity of grain cereals. Key plants in this scenario are sugar cane, cassava, and the palm family, especially the oil and sugar palms. The yield potential of the sugar palm (*Borassus flabellifer*) is extremely impressive. An annual average yield equivalent to 18 tonnes of soluble sugars per hectare has been documented in a study with 12 family farm households in Cambodia.

Some Promising LEISA Techniques and Practices

(i) Nutrient management: Nutrient management is managing the amount, source, placement, form, and timing of the application of nutrients and soil amendments to ensure adequate soil fertility for plant production and to minimize the potential for environmental degradation, particularly water quality impairment. Nutrient management has taken on new connotations in recent times. Soil fertility traditionally dealt with supplying and managing nutrients to meet crop production requirements, focusing on optimization of agronomic production and economic returns to crop production (LEISA, 2006). Contemporary nutrient management deals with these same production concerns, but recognizes that ways of farming must now balance the limits of soil and crop nutrient use with the demands of intensive animal production.

Farmers in the hill agriculture follow a system of close integration of crop, livestock and forestry/grassland management. Farmers maintain traditional practices such as terracing, manure management, legumes inter cropping, and mulching where appropriate. Farm yard manure quality can be increased by better decomposition and the N-content can be increased by at least 2 to 3 times from about 0.5% N to 1.5% N through proper management of urine and manure.

Liquid manure can be prepared from urine and various plants extracts rich in minerals or secondary plant compounds. These “manure teas” were shown to be effective liquid fertilizers on crops such as vegetables and also for organic pest and disease management. Local marketing systems for such “manure teas” are emerging in some areas. The use of urea fertilizer declined in several areas due to liquid manure use. In Nepal, some of the LEISA practices are: Bio-pesticide (cow urine, neem products, tobacco, ash etc), composting (pit), tree plantation, green manuring, vermicomposting, liquid compost, NADEP compost, seed treatment, seed production.

(ii) Integrated pest management (IPM): IPM is an ecologically based approach to pest (animal and weed) control that utilizes a multi-disciplinary knowledge of crop/pest relationships, establishment of acceptable economic thresholds for pest populations and constant field monitoring for potential problems. Management may include such practices as (LEISA, 2006):

- use of resistant varieties;

- crop rotation;
- cultural practices;
- optimal use of biological control organisms;
- certified seed;
- protective seed treatments;
- disease-free transplants or rootstock;
- timeliness of crop cultivation;
- improved timing of pesticide applications;
- removal or 'plow down' of infested plant material."

The term biointensive IPM emphasizes a range of preventive tactics and biological controls to keep pest population within acceptable limits. Reduced risk pesticides are used if other tactics have not been adequately effective, as a last resort and with care to minimize risks.

Biological control is, generally, man's use of a specially chosen living organism to control a particular pest. This chosen organism might be a predator, parasite, or disease, which will attack the harmful insect. A complete biological control program may range from choosing a pesticide which will be least harmful to beneficial insects, to raising and releasing one insect to have it attack another, almost like a 'living insecticide.'"

(iii) Crop Residue Management and Conservation Tillage: Conservation tillage is a term that covers a broad range of soil management systems that leave residue cover on the soil surface, substantially reducing the effects of soil erosion from wind and water. These practices minimize nutrient loss, decreased water storage capacity, crop damage, and improve soil quality. The soil is left undisturbed from harvest to planting except for nutrient amendment. Weed control is accomplished primarily with herbicides, limited cultivation, and, in more sustainable systems, with cover crops.

The National Crop Residue Management Survey (Conservation Technology Information Center (CTIC)) specifies that 30 percent or more of crop residue must be left after planting to qualify as a conservation tillage system. Some specific types of conservation tillage are Minimum Tillage, Zone Tillage, No-till, Ridge-till, Mulch-till, Reduced-till, Strip-till, Rotational Tillage and Crop Residue Management.

(iv) Converting Farm Wastes into useful Organic Manure under LEISA System: The ingredients required are green leaves, dry leaves, weeds from adjacent farms, cow dung and urine, fodder wastes from cattle sheds, gobar gas slurry, coir pith, tank silt, quarry dust and rock phosphate. These items are put in alternate layers (cow dung in between layers) in a heap and left for 45 days. The heap is turned once or twice. In 45 days, the items get semi-decomposed. The partially decomposed material can be used in two ways- for vermi compost preparation, which gets converted to vermi compost in 45 days, and the other way is to add coir pith, tank silt and quarry dust to semi decomposed material, which turns into good quality manure in 45 days.

(v) Green Manuring and Cover Crops: Green manure and cover crop species should fit the agroecological condition. In general, these crops should have the characteristics as: easy establishment, vigorous growth under local conditions, ability to cover weeds quickly, ability to either fix atmospheric nitrogen or concentrate plenty of phosphorus, should also have multiple uses.

The green manure and cover crops can be grown intercropped with another food for example beans with maize or cassava, or perennial peanut with coffee. These crops can be grown on wasteland or on fields under fallow. The species should survive on very poor soils, such as beans, tephrosia, or particularly hardy trees. Farmers in Vietnam, for example, seed *Tephrosia candida* into their first year fallow, thereby reducing the normal five-year fallow to just one or two years.

These crops can be grown during the dry season, planted after the normal crops like the rice bean/ rice system in Vietnam, or intercropped with the normal crop and then allowed to grow through the dry season such as the sweet clover/maize system in Mexico. It can also be planted as a relay crop amongst rainy season crops at the end of the wet season to take advantage of the residual moisture, such as the cowpea/maize and lablab/maize systems in Thailand.

Green manuring adds organic matter to the soil; green manure crops return to the upper top soil the plant nutrients taken up by the crop from deeper layers; improves the soil structure and other soil physical properties; leguminous crops add nitrogen to soil; increases the availability of certain plant nutrients like P, K, Ca, K, Mg and Fe; facilitates infiltration of water thus decreasing runoff and soil erosion; green manure crops hold plant nutrients that would otherwise be lost by leaching.

The main problem in adoption of green manuring is that the land on which green manure crop is raised could have been profitably utilized for growing a crop of economic importance. Another problem is adequate soil moisture either through rainfall or irrigation is essential for in-situ decomposition of green manure crop. Under rainfed condition, if sufficient rainfall is not received proper decomposition may not take place, and the germination of the succeeding crop is hampered. There is a possibility of incidence of diseases and pests, even nematodes.

(vi) Practices for Land Degradation: A good plant cover is very important for preventing soil degradation and achieving soil rehabilitation. A vegetative cover has a number of beneficial effects on soil aeration, soil moisture and organic matter content, physical characteristics and biological activity in the soil. In addition, a plant cover protects against soil erosion. Cover crops can be quite aggressive creepers and may compete with the main crop. On the other hand if leguminous plants are used as cover crops they add nutrients because they fix atmospheric nitrogen and make it available for the crop.

Selection of crops is very important while dealing with degraded soils. Sodic soils in South Indian region were corrected for their soil pH by including cucumber in the cropping pattern. Similarly, raising Eucalyptus plantation along the canal bunds helped in solving the drainage problem in low-lying delta areas. Farmers follow their own traditional practices in maintaining soil physical structure and health. Practices like application of sand, groundnut shell, sal leaves, retention of sunflower stalks are a few among those followed by the farmers for mulching in South Indian condition.

(vii) Intercropping: Intercropping is defined as growing of two or more crops simultaneously on the same piece of land; crop diversification is in both temporal and spatial dimension; there is intercrop competition during all or part of the crop growth. There are many types of intercropping viz., mixed intercropping, row intercropping, strip intercropping and relay intercropping.

The usefulness of intercropping are: (a) greater stability of yield over different seasons, (b) intercropping provides biological insurance against failure of one crop due to biotic or biotic factor, (c) better use of growth resources, (d) better control of weeds, insect-pest and diseases (e) for some cases one crop provides physical support to the other crop (e.g. growing of betel vine or black pepper vines on the support of mango or coconut and arecanut), (f) one crop provides shelter to the other crop e.g. growing of tea under the shade of *Albizia*, (g) erosion control through providing continuous leaf cover over the ground surface, and (g) it is the small farmers of limited means who is most likely to benefit.

There are some problems as well related to adoption by the farmers, as for example (a) yields decreased because of adverse competition effect, (b) allelopathic effect i.e. any direct or indirect harmful effect that one plant has on another through production of chemical compounds that escape into the environment, (c) creates obstruction in free use of machines for intercultural operations, particularly where the component crops have different requirements for fertilizer, herbicides, pesticides etc., and (d) large farmers with adequate resources may likely to get less benefit out of intercropping.

(viii) Organic Manuring: Organic manures are organic materials derived from animal, human and plant residues which contain nutrients in complex organic forms. They are the sources of plant nutrients. They release nutrients after their decomposition. They provide organic acids that help to dissolve soil nutrients and make them available for the plants. Organic manures can be grouped into bulky organic manures and concentrated organic manures based on the concentration of the nutrients.

The usefulness of organic manures are several: (a) they supply plant nutrients including micronutrients needed for optimum plant growth, (b) Continued use of manures builds organic matter in soils and improves soil structure. This modification of soil structure helps improve water holding capacity, aeration, friability, and drainage, (c) they improve soil condition for better penetration of roots into deeper layers, (d) they increase the availability of nutrients through improvement in cation exchange capacity, (e) carbon dioxide released during decomposition acts as a CO₂ fertilizer, (f) improves soil health in terms of soil microbial biomass carbon, rhizosphere environment, (g) plant parasitic nematodes and fungi are controlled to some extent by altering the balance of microorganisms in the soil.

The problems of organic manures are: nutrient from organic manures are not immediately available to the plants; they are released slowly and over a longer period of time than from most commercial fertilizers; if there is an immediate need for nutrients, organic manures cannot readily supply nutrient to plants. Many organic manures have low nutrient content and therefore need to be applied in larger quantities. Some organic manures need composting before its application to the field. Improperly processed organic manures may contain pathogens from plant or animal that are harmful to human or plants. The composition of fertilizers is almost constant. For example, urea contains 46% N regardless of which factory makes it any where in the world. Another problem of using manures is the handling and transportation problems associated with large amounts of manure required to obtain sufficient quantities of nutrients for crops. The use of fresh manure may introduce new weeds into fields since certain weed seeds remain alive even after passage through animals. Organic manures can also contaminate produce or burn plants.

Mulching

Any material, such as straw, plant residues, leaves, loose soil or plastic film which is placed on the soil surface to reduce evaporation, erosion or to protect plant roots from extremely low or high temperature, is called as a mulch; and the practice of applying mulches is called mulching.

Mulching is practiced for various purposes:

- (i) Mulching favorably influences the soil moisture regime by controlling evaporation from soil surface, improving infiltration and soil moisture retention and facilitating condensation of water at night due to temperature reversals.
- (ii) Mulching suppresses weed growth
- (iii) Mulching invariably decreases soil erosion and often reduces runoff rate. Mulch cover protects the soil from raindrop impact and surface sealing, increases the infiltration rate and decreases run-off velocity through physical resistance to water flow.
- (iv) Mulch has a moderating influence on the soil thermal regime.
- (v) Crop residue mulch improves soil aeration by promoting free exchange of gases between the soil and the atmosphere.
- (vi) Mulching improves soil structural properties directly by preventing the raindrop impact and indirectly by promoting the biological activity.
- (vii) Organic mulches add organic matter and plant nutrients to soil upon decomposition. Thus, they improve carbon sequestration. Cation exchange capacity is substantially influenced by organic matter content in soils containing predominantly low activity clays.
- (viii) Soil biological activity is either directly influenced by supply of food substrates by organic mulches or indirectly influenced by both organic and inorganic mulches through alteration of soil hydrothermal regime.

The mulch materials include: organic residues (grass clippings, leaves, hay, straw, shredded bark, sawdust, wood chips, shredded newspaper, cardboard, wool, etc.), compost, rubber mulch, plastic mulch, organic sheet mulch (various products such as biodegradable alternative to plastic mulch), rock and gravel mulch, living mulch etc. Mulching is an important part of any no-dig gardening regime, such as practiced within permaculture systems. Of course, the way particular organic mulch decomposes, and reacts to wetting by rain and dew, determine in great degree of its effectiveness.

Mulch is usually applied towards the beginning of the growing season, and may be reapplied as necessary. It serves initially to warm the soil by helping it retain heat. This allows early seeding and transplanting of certain crops in cold regions, and encourages faster growth. As the season progresses, the mulch stabilizes temperature and moisture, and prevents sunlight from germinating weed seed.

There are some problems of mulching with respect to its adoption by the farmers.

Mulch hinders the operation of sowing (if it is applied before sowing), fertilizer applications, irrigation etc. For conservation tillage it clogs the seed drill proper sowing of seeds; planting under residue is not always successful. Sometimes thick mulching in areas of high rainfall

may lead to water logging conditions and provide an environment for disease infestation. Plastic mulches usually require pick up and disposal at the end of the season and their manufacture and disposal entail significant environmental cost, as these are not biodegradable. Plastic mulch can interfere with the recharge of soil profile by rain or overhead irrigation. The infestation of termite is aggravated due to mulching especially in the humid areas.

Most of the plant residues are used as cattle fodder, farmers may not adopt this practice under the conditions of scarce fodder. There are competing demands for crop residues for other uses in the semi arid tropics of the developing countries. In the tropics, crop residues are also used for fencing, roofing and as a source of household fuel. Mulching is thus practiced under the conditions where the marginal return from this practice is higher than its other competing demands. The surface residue mulch may generate a more favorable habitat for soil and residue borne insects and pathogens.

Windbreaks

Windbreaks are barriers used to reduce and redirect wind. They usually consist of trees and shrubs, but may also be perennial or annual crops and grasses, fences, or other materials. The reduction in wind speed behind a windbreak modifies the environmental conditions or microclimate in the sheltered zone. The direction from which wind is blowing is called *windward* side and direction to which wind blowing is called *leeward* side. As wind blows against a windbreak, air pressure builds up on the windward side, and large quantities of air move up and over the top or around the ends of the windbreak.

Windbreak structure- its height, density, number of rows, species composition, length, orientation, and continuity determines the effectiveness of a windbreak in reducing wind speed and altering the microclimate.

Windbreaks are most effective when its *orientation* is such that it is at right angles to prevailing winds. The purpose and design of each windbreak is unique, thus the orientation of individual windbreaks depends on the design objectives. To control soil erosion, windbreaks should be planted to block the prevailing winds during the times of greatest soil exposure.

Water Harvesting

Water harvesting, defined in its broadest sense as the collection of runoff for its productive use, is an ancient art practiced in the past in many countries. More specifically, it is the collection and storing of water on the surface of the soil for subsequent use. It is relevant to areas where the rainfall is reasonably distributed in time, but inadequate to balance potential evapotranspiration (ET) of crops.

Water harvesting supports a flourishing agriculture in many dry areas. The sustainability of the various water harvesting techniques is found to depend largely upon the timing and the amount of rainfall. As mentioned, some water harvesting techniques are of ancient origin. However, the techniques should be site-specific.

Although the term water harvesting is used in different ways, the following are among its characteristics:

- (i) It is practiced in arid and semiarid regions, where surface runoff often has an intermittent character.

- (ii) It is based on the utilization of runoff and requires a runoff producing area and a runoff receiving area.
- (iii) Because of the intermittent nature of runoff events, storage is an integral part of the water harvesting system.

Water may be stored directly in the soil profile or in small reservoirs, tanks, and aquifers. Each water harvesting system should therefore have the following four components: (a) runoff producing catchments, (b) runoff collection scheme, (c) runoff storage facility, and (d) cultivated or cropped area.

Spring water harvesting draws attention in the hilly areas. In the Lahaul and Spiti areas of Himachal Pradesh, water from hill streams are diverted through small excavated channels, called Kuls, for domestic use and irrigation. In Jammu region they pronounce it as Kuhals. This practice can also be seen in Arunachal Pradesh, Meghalaya, Nagaland, Manipur, Sikkim and Darjeeling area of West Bengal. However, such sources are available mostly in hilly terrain, foothill areas or intermontane valleys.

Water Ponds/ Tanks: This is by far the most commonly used method to collect and store rain water in dug ponds or tanks. Most ponds have their own catchments, which provide the requisite amount of water during the rainy season. Where the catchments are too small to provide enough water, water from nearby streams is diverted through open channels to fill the ponds. In some places water from irrigation canals is also used to fill ponds.

Ponds are excavated in different shapes and sizes depending upon the nature of the terrain, availability of land, water requirements of the village community etc. These are known by different names in different regions, as described below:

Nagaland –	Zabo
Gujarat –	Kunda (sacred ponds), Jheel
Orissa –	Katas, Mundas (As in Bihar)
Maharashtra –	Bandharas (Bunds across small streams)
Karnataka –	Volakere (Small pond fed by shallow channel) Katte or Kunte (Pond with bund mainly for bathing) Kola or Kunda (Natural Pond) Kalyani (Temple Pond)
Andhra Pradesh –	Tank (Mainly for irrigation)
Kerala –	Tank (Mainly for irrigation)

Khadin is a system basically innovated for runoff farming by the Paliwal Brahmin Community in Jaisalmer area in the 15th Century. In Jaisalmer the ruler used to encourage people to develop this system at suitable sites for agriculture and share the part of crop with ruler, who would remain the owner of those structures. There are as many as 500 big and small Khadins in Jaisalmer district, which are productive, even with 40 mm rainfall.

Rocky-hill-terrain around a valley including the valley slopes, constitute the catchments area of a Khadin. At the lower point of the valley, earthen bund is constructed to arrest the runoff. The stored water helps the crops as well as recharging of ground aquifer. Spillway of stone masonry is provided in the bund to let out the excess runoff. A sluice is provided at bed level to drain out standing water, if any at the time of bed cultivation.

A similar system called Haveli is used in some parts of Madhya Pradesh. In this system, the field is enclosed on all four sides by earthen bunds called Bandhan to retain rain water. This practice is also in vogue in the drought prone districts of Orissa especially Kalahandi, Bolangir and Koraput.

Water Harvesting Structures: During the last 100 years there has been considerable technological development, *inter alia*, in the design and construction of water harvesting structures for various purposes. The structures, which are commonly built for surface storage and / or ground water recharge, are:

(i) **Check dams:** These are concrete or masonry structures built across small streams for surface storage and incidental benefit of ground water recharge. The design of these structures is done considering the volume of water that can be stored in the upstream channel, the surplus flood discharges safely.

(ii) **Percolation tanks:** These are built mainly to impound monsoon runoff over a large area to augment ground water recharge. Moderate to high porosity of soil and/ or underlying rocky strata is the main criteria for the choice of percolation tanks. Ponding is achieved in much the same way as is done in case of check dams except that the height of the bund is low but the length is large.

(iii) **Sub-surface dykes:** These are impermeable walls or barriers in masonry, concrete and/ or clay built below the bed level across natural streams to arrest sub-surface flow of water to improve the yield of existing wells and hand pumps in the upstream.

Besides these direct methods of water harvesting some indirect methods have also been developed. These aim at augmenting soil moisture retention and preventing soil erosion and land degradation. These are:

(i) **Contour bunding:** These are small earthen bunds built horizontally in parallel rows across the hill slope. These help in augmenting soil moisture and prevent erosion of topsoil.

(ii) **Gully plugging:** These are soil and water retaining structures built across gullies in hilly areas. These are built with locally available materials like stone boulders, earth, brushwood etc.

In-situ Water Conservation through various Land Configurations:

(i) Broad Bed and Furrow System (BBF): The BBF system has been mainly developed at the International Crops Research Institute for the Semi-arid Tropics (ICRISAT) in India. It is a modern version of the very old concept of encouraging controlled surface drainage by forming the soil surface into beds. In medieval times in Britain this was used for improving pastures and called "rigg and furrow"; it has also been used in North America and in Central Africa. A variation known as the camber-bed system was used in Kenya.

The recommended ICRISAT system consists of broad beds about 100 cm wide separated by sunken furrows about 50 cm wide. The preferred slope along the furrow is between 0.4 and 0.8 percent on vertisols. Two, three, or four rows of crop can be grown on the broad bed, and the bed width and crop geometry can be varied to suit the cultivation and planting equipment. The main objectives are: a) to encourage moisture storage in the soil profile. b) to dispose safely of surplus surface run-off without causing erosion. c) to provide a better drained and

more easily cultivated soil in the beds, d) the possibility of the re-use of run-off stored in small tanks. The inter-cropping or sequential cropping is also possible on the broad-beds. Small amounts of life-saving irrigation applications can be very effective in dry spells during the rains, particularly on soils with lower storage capacity than the deep vertisols.

The BBF system is particularly suitable for the vertisols. The technique works best on deep black soils in areas with dependable rainfall averaging 750 mm or more. It has not been as productive in areas of less dependable rainfall, or on alfisols or shallower black soils - although in the latter cases more productivity is achieved than with traditional farming methods.

(ii) Ridging and Tied Ridging: This method is also known as furrow blocking, furrow damming, furrow diking, and basin listing. The principle is to increase surface storage by first making ridges and furrows, then damming the furrows with small mounds, or ties.

Tied-ridging is system of land configuration where semi-permanent ridges are prepared with cross-ties along the furrows to trap run-off of water. The ridges are generally laid across the main slope at a grade of 0.4-1%. Normally once constructed the ridges are not destroyed for a period of six seasons depending on the crop rotations practiced by the farmer. Planting is done on top of the ridges. In subsequent seasons land preparation simply involves planting on top of the ridges (i.e., no tillage or direct drilling of seeds). For emergence and good establishment of the crop, planting is recommended only when the ridges are optimally moist. In drier areas planting may also be carried out in the furrows where most of the run-off water collects.

(iii) Conservation Bench Terraces (CBT): This is also known as Zingg terrace, and flat channel terrace. This method was pioneered by Austin W. Zingg in 1955 in the south-west of the USA. This is another type of water harvesting technique, using part of the land surface as a catchment to provide additional run-off onto level terraces on which crops are grown. CBTs are comparable to the conventional practice of level terraces (i.e. level along the length, but the original slope is left between terraces), and also with all over bench terracing.

(iv) Contour Bunds: This is also known as contour furrows and desert strip farming. The principle is the same as conservation bench terraces that is to collect run-off from the catchment to improve soil moisture on the cropped area. On heavier soils, contour bunds may be less effective because of the lower infiltration. Studies conducted by ICRISAT on vertisols in India showed that yields were lower near the bunds, both upslope and down, as a result of water logging.

Strip Cropping

Strip cropping is a system of crop production in which long and narrow strips of erosion-resisting crops are alternated with strips of erosion permitting crops. Erosion-resisting crops, e.g., pulses, groundnut, moth beans, horse gram and grasses, are generally close growing, and having soil binding type of root growth, whereas erosion-permitting crops, e.g., sorghum, maize and millets, are generally erect growing.

The strips are laid across the slope of the land. Strips of close-growing crops reduce the transporting and eroding power of water. It forms an obstruction to runoff water and rolling soil particles, and filters out the soil from run off and retains it in the field. The width of the erosion-resisting and erosion-permitting crops depends on the slope of the land (Table 14):

Table 14: Width of Erosion resisting and Erosion-permitting Crops

Slope of the land (%)	Width of strips (m)	
	Erosion-resisting crops	Erosion-permitting crops
Up to 1	9.0	45.0
1-2	6.0	24.0
2-3	4.5	13.5

(Source: Principles of Agronomy(1994))

Intercropping Trap and Decoy Crops

Trap cropping is the planting of a trap crop to protect the main cash crop from a certain pest or several pests. The trap crop can be from the same or different family group, than that of the main crop, as long as it is more attractive to the pest. There are two types of planting the trap crops; *perimeter trap cropping* and *row intercropping*. Perimeter trap cropping (border trap cropping) is the planting of trap crop completely surrounding the main cash crop. It prevents a pest attack that comes from all sides of the field. It works best on pests that are found near the borderline of the farm. Row intercropping is the planting of the trap crop in alternating rows within the main crop.

The trap crop technique relies on the attraction of insect pests to plantings other than the main crop. Timing is important in utilizing a trap crop. The pests should not be allowed to reproduce on the trap crop and the crop itself should not sacrifice much of field area. However, it is important to plant a trap crop over an area large enough to attract the resident pests.

Trap crops of susceptible plants are grown on land known to contain pathogens. They become infected and are then destroyed before the pathogens' life cycles are complete, thus reducing the amount of inoculum in the area. Of course, trap crops are advocated for cyst nematodes. The technique involves sowing of crucifers and ploughing in before the nematodes of beets can develop fully. Similarly, in pineapple plantations, tomatoes are planted and ploughed in to reduce root-knot nematodes. Marigold reduces the population of *Pratylenchus* eelworms.

Advantages of Trap Cropping:

- (i) Lessens the use of pesticide
- (ii) Lowers the pesticide cost
- (iii) Preserves the indigenous natural enemies
- (iv) Improves the crop's performance
- (v) Helps conserve the soil and the environment quality

Tips for successful Trap Cropping:

- (i) Make a farm plan. This will guide you on where the trap crops are to be sown or planted.
- (ii) Learn to know and identify the pests.
- (iii) Select a trap crop that is more attractive to the pest than the main crop. Ask for assistance from local agriculturist.
- (iv) Monitor the plants regularly.

- (v) Immediately control the pests that are found in the trap crop. Prune or remove the trap crops once the pest population is high, otherwise they will serve as the breeding ground and the pests will attack the rest of your farm.
- (vi) Be ready to sacrifice your trap crop as an early crop and destroy them once pest infestation is high.
- (vii) Always keep farm records.

Decoy Crops: Decoy crops are non-host crops that are planted to make nematodes waste their infection potential, examples are given below (Table 15). This is affected by activating larvae of nematodes in the absence of hosts by the decoy crops. Decoy crops stimulate the hatching or germination of pathogen eggs or propagules, but the pathogens are unable to establish and infection of the decoy host and die, again reducing the amount of available inoculum. The ideal decoy crop is one that has economic value and can be used in a routine crop rotation.

Table 15: Decoy Crops for the Control of Nematodes

Crop	Nematode	Decoy crops
Brinjal	<i>Meloidogyne incognita</i> <i>M. javanica</i>	<i>Sesamum orientale</i>
Tomato	<i>M. javanica</i> , <i>Pratylenchus alleni</i>	Castor, Crysanthemum, Groundnut
Soybean	<i>Pratylenchus sp.</i>	<i>Crotalaria spectabilis</i>

(Source: Principles of Agronomy (1994))

Bio-intensive Gardening

The bio-intensive method is an organic agricultural system that focuses on maximum yields from the minimum area of land, while simultaneously improving the productivity of soil. The goal of the method is long term sustainability on a closed system basis. Because biointensive is practiced on a relatively small scale, it is well suited to anything from personal, family, or community gardens, market gardens, or minifarms. It has also been used successfully on small-scale commercial farms (John Jeavons).

The history of the techniques, that comprised the biointensive method, were present in ancient Chinese, Greek and Mayan agriculture, as well as in the agriculture of the Early Modern period in Europe. Alan Chadwick brought together the biodynamic and French intensive methods, as well as his own unique approach, to form what he called the Biodynamic-French Intensive method. The method was further developed by John Jeavons and Ecology Action into a sustainable method known as "grow biointensive" (John Jeavons).

In order to achieve greater productivity, the biointensive method uses double dug raised beds, intensive planting, and companion planting. In double digging, a 30-cm deep trench is dug across the width of the bed with a flat spade, and the soil from that first trench is set aside. The 12 inches below the trench are loosened with a spading fork. When the next trench is dug, that soil is dropped into the empty space of the first trench, and the lower layer is again loosened with a spading fork. This process is repeated along the full length of the bed. The final trench is filled with the soil that was removed from the first trench. The result is a bed that has been tilled to a depth of 24 inches (Cox and Jeavons).

In order to plant intensively, beds of suitable dimensions are preferred. Crops are not planted in traditional rows according to a square pattern, but are planted in a hexagonal or triangular pattern in the bed so that no space is left unnecessarily unused. These wide beds and close

spacings not only allow more plants per area, but also enable the plants to form a living mulch over the soil, keeping in moisture and shading out weeds.

Contour Farming

Contour farming is the farming practice of ploughing across a slope following its contours. The rows formed have the effect of slowing water run-off during rainstorms so that the soil is not washed away and allows the water to percolate into the earth. In contour ploughing, the ploughman ploughs perpendicular rather than parallel to slopes, generally resulting in furrows that curve around the land and are level. The Phoenicians first developed the practice of contour farming and spread it throughout the Mediterranean. However, the Romans preferred cultivation in straight furrows and this practice became standard in many countries.

Demonstrations showed that contour farming, under ideal conditions; increase yields of row crops by 50% with increases of between 5 and 10% being common. Importantly, the technique also reduced soil erosion significantly. The practice is effective only on slopes with between 2% and 10% gradient and when rainfall does not exceed a certain amount within a certain period. On steeper slopes and areas with greater rainfall, a procedure known as strip cropping is used with contour farming to provide additional protection.

How Contour Farming works: Crop row ridges built by tilling and planting on the contour create hundreds of small dams. These ridges or dams slow water flow and increase infiltration, which reduces erosion. It can also be used with stripcropping, whereby the crop is alternated with strips of meadow or small grain planted on the contour. The small grain/meadow strip slows runoff, increases infiltration, traps sediment and provides overall cover. Crop rotation with legumes may also be included to add nitrogen as part of the strip cropping measure. The following are the benefits of contour farming (<http://www.mascd.net>).

- (i) Contouring can reduce soil erosion by as much as 50%, compared with up and down hill farming.
- (ii) By reducing sediment and runoff, and increasing water infiltration, contouring promotes better water quality.
- (iii) Establish a key line around the hill using a hand level or contour gauge.
- (iv) Contour key line grade should not exceed 2% except within 100 feet of an outlet. In that case, the grade can be a 3% slope.
- (v) Perform all tillage and planting operations parallel to the key contour line.
- (vi) Replace end rows with field borders to reduce erosion.
- (vii) Row crop strips need to be nearly the same width as small grains or meadow. A 10% variance is allowed.
- (viii) Strip widths may be adjusted downward to accommodate equipment width for even rounds.
- (ix) Strip cropping is not as effective if crop strips become too wide, especially on steep slopes.

Integrated Crop-Livestock-Fish Farming

Definition of Integrated Farming: The word 'integrated' is derived from the Latin verb "integrare" which means to make whole, to complete by addition of parts, or to combine parts into a whole. The crop, livestock and fish subsystems may function independently in certain farming systems, and their products are only additive. However, an output from one subsystem in an integrated farming system which otherwise may have been wasted becomes

an input to another subsystem resulting in a greater efficiency of output of desired products from the land/water area under a farmer's control.

Rapidly increasing population trends in developing countries generally require a rapid increase in agricultural production and, as the majority of the population of developing countries are small-scale farmers; the major development challenge is to increase the production of food by this particular group. Experience indicates that farming systems based on the integration of crops, livestock and fish production can make a significant contribution to this required increase in food supplies.

Advantages:

- (i) There is synergism in integrated farming since the working together of the subsystems has a greater total effect than the sum of their individual effects. The total output of the farm is increased beyond that which would be possible if the different production systems were operated independently.
- (ii) The main biological feature of an integrated farming system is byproduct recycling; through the application of the waste products from one system as fertilizer or supplementary feed to boost the production in another system (as in the application of vegetable waste as compost or feed in a fish pond).
- (iii) There is improved space utilization, in which two subsystems occupy part or all of the space required for one subsystem, may be an important aspect of increased productivity.
- (iv) A major socioeconomic benefit of integrated farming is that inputs to the various subsystems that comprise the farming system tend to be intra-farm, with a diminished reliance on inter-farm or agro-industrial inputs. Moreover, fish efficiently convert low grade feeds into high quality animal protein and can be kept alive on maintenance diets without loss of condition
- (v) Integrated farming systems also spread the risks associated with farming because of the increased diversity of produce.
- (vi) They also lead to a more balanced, high-value and nutritious source food that could be obtained with a minimum of effort and external inputs.

Integrated crop-livestock-fish systems are also highly flexible in that a wide range of fertilizing and supplementary feed substances can be utilized and a similarly wide range of levels of management, from extensive to highly intensive, can be successfully applied. Obviously, the higher the grades of fertilizer and feeds and the more intensive the level of management applied, the higher the yield of fish is likely to be. However, the important consideration for the small-scale farmer is that increases in yield can be achieved without recourse to costly inputs and by applying management strategies that are within the capacities of existing small-scale farming systems. These features of low external input and flexibility in the level of management make integrated crop-livestock-fish systems highly attractive solutions, especially for the small-scale farmers.

In integrated crop-livestock-fish production systems, since the key integrating elements are the wastes produced by crop and livestock production, it is especially important that the crop and livestock farming systems are fully understood. It clearly follows that the economic development of crop-livestock-fish farming requires a broad, multi-disciplinary and holistic approach.

Table 16: Component and System Productivity (Rice Grain equivalent yield) of different Integrated Farming Systems in Tamil Nadu

Farming systems	Component Productivity (kg/ha)					System productivity (t/ha)
	Crop	Poultry	Pigeon	Fish	Goat	
Cropping alone	12223	-	-	-	-	12.2
Crop+Poultry+ Fish	29166	630	-	2063	-	31.9
Crop+Pigeon+Fish	27973	-	2592	1790	-	32.4
Crop+Goat+Fish	28809	-	-	1983	8818	39.6

(Source: Extended summaries on National Seminar on Farming Systems Research in New Millenium, 2001)

For an example, two year results of a farming systems experiment reveals that under low land conditions of Tamil Nadu integration of crop with fish, poultry, pigeon and goat rearing resulted in higher productivity than cropping system alone (Table 16). An example of recycling of resources, generation of income and mandays is exemplified in the form of model (Fig. 6) developed in Tamil Nadu for the enterprises viz. crop, pigeon, buffalo, agroforestry and farm pond system (Esther Shekinath et al., 2005).

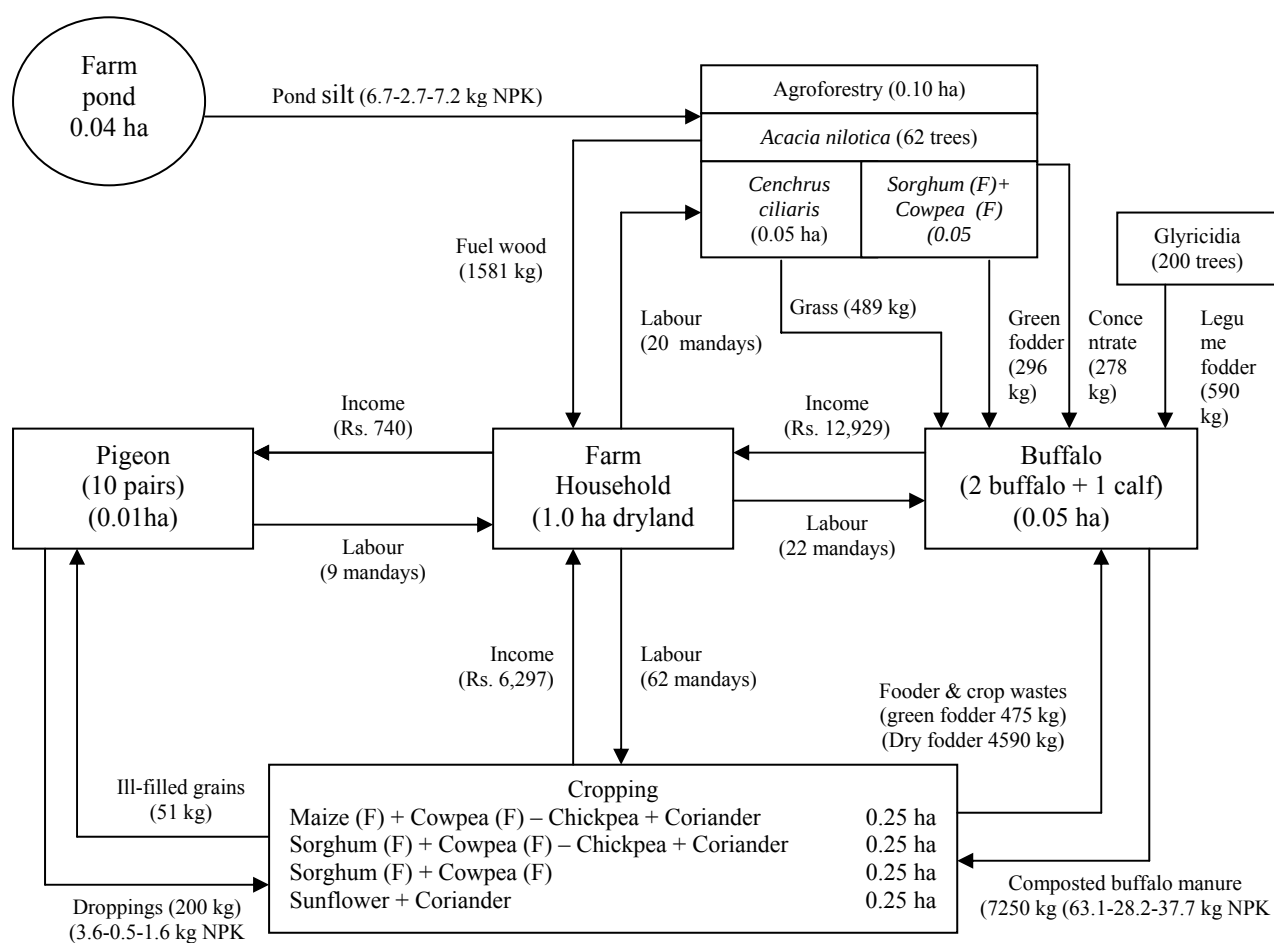


Fig. 6. An example for a model on Crop + Pigeon + Buffalo + Agroforestry + Farm Pond System in Tamil Nadu (Source: Journal of Sustainable Agriculture, 2005)

Evaluation of Constraints

The evaluation of a farming system consists essentially of measuring how adequate and how effective an existing system has been in achieving its objectives. In the process of assessment, constraints are identified and the components of the system are so optimized that higher productivity, greater stability as well as sustainability is achieved. To evaluate the constraints of farming systems, three types of analysis are important (Norman et al., 1995).

- (i) Technological analysis: is performed by the agronomist or animal scientist from the farming system team and determines if the new technology is practical in a technical sense.
- (ii) Economic analysis: is used to determine if the farmer will receive a greater economic and more stable return from adopting the technology, Part of the economic evaluation is an assessment as to whether the farmer has enough resources available to adopt the technology or can acquire them by borrowing or receiving a government subsidy to facilitate adoption.
- (iii) Social analysis: is used to determine if the technology is acceptable within the household (i.e., intra-household) and overall village (i.e., inter-household) situation. Sociocultural analysis looks at the technology in a whole farm, analyzes acceptability for the various members of the household who are involved with the technology, determines if there are cultural factors that influence acceptability, examines consumption/nutrition implications, etc.
- (iv) Environmental impact assessment: whether there are likely to be long-term beneficial or harmful effects to using a new technology. The whole area of long-term impacts of a technology on the environment is of interest to society and also possibly to the individual farmer.

It is extremely important to all these types of analysis to evaluate whether a technology should be disseminated or not. Farmers may be willing to use a new technology, even when biological research results are not statistically significant. This is particularly true when the farmer's investment is small and the potential results are relatively large. Even though the level of biological return (i.e., yield) may not be significantly greater for a new technology, there may be other benefits such as reduced labour demand at certain times, greater reliability in return, etc., that makes the technology attractive to farmers.

Some tools for assessment/ evaluation of farming systems are described below in a tabular format.

Table 17: Quantitative and Qualitative Tools for evaluation of Farming Systems

S. No.	Category of analysis	Quantitative tools	Qualitative tools
1	Technical	Productivity of individual resources, total system productivity, stability and sustainability; energy input-output relationship, use efficiency of inputs to the system, factor productivity	Farmer/ researcher evaluation and observation
2	Economic	Cost of production, benefit-cost analysis, net return, system	Farmer/ researcher evaluation and observation

		intensiveness, Returns to factors of production, marginal analysis, sensitivity analysis	
3	Social	Adoption indices, gender analysis, equitability analysis, consumption/nutrition effects, health status, household debt etc.	Farmer/ researcher evaluation and observation
4	Environmental	Pollution in the system, soil and water pollution, analysis of pollutant elements or ions, quality of the environment-soil, water and air.	Farmer/ researcher evaluation and observation

Optimization of Farming Systems

Agricultural input-output relationships are, in themselves, of a physical nature. Their manipulation and control by the farmer so as to achieve his or her goals, however, implies that these physical relationships have to be evaluated in value terms as determined by the market price or opportunity cost of outputs and inputs.

Since optimization is to be achieved in economic terms, it is necessary to convert the total physical product (TPP), average physical product (APP) and marginal physical product (MPP) into a value basis for the farming system. This is done simply by multiplying TPP, APP and MPP by the unit price of the output to obtain total value product (TVP), average value product (AVP), and marginal value product (MVP). On the input side, total cost (TC), fixed cost (FC), variable cost (VC) and marginal cost (MC) should be estimated. Then, the relationships with respect to value products are to be determined with the help of statistical/mathematical analysis or by graphical approach (McConnel and Dillon, 1997).

Optimization of multi-variable input processes can be achieved by partial budgeting using relationships of the value products and inputs, but this method would be limited by the work involved in preparing the large number of necessary partial-budget tables. In practice, optimization of resource use in multi-variable input processes is best approached by the response equation method, regardless of whether two- or three- or n-variable inputs are involved. Again the relevant relationships are the physical response function, the MVP of each variable input used and the unit price of each input in relation to the unit price of the output. The optimizing rule as outlined by McConnel and Dillon (1997) is described hereunder. Each input is used at the level at which the ratio of its marginal physical product to its unit price is equal to the inverse of the unit product price. Thus the response process $Y = f(X_1, X_2, \dots, X_n)$ is optimized when $MPP_1/p_1 = 1/p_y = MPP_2/p_2$, where MPP_i denotes the MPP of X_i , and P_i denotes the cost of variables and P_y denotes the price of output. To illustrate the procedure it is assumed that a response function relating grain output (denoted by G) to input of nitrogen (N) and water (W) could be obtained by fitting some appropriate equation to input-output data from a field trial to obtain the response function $G = f(N, W)$. The unit price of grain is given as p and the unit costs of the two inputs are given as p_n and p_w respectively. Now the optimization is done based on $MVP = MC$

Given the response relationship $G = f(N, W)$, the marginal value product of N, denoted by MVP_n , is defined as $p_g (MPP_n) = p_g (\delta G / \delta N)$ where $\delta G / \delta N$ denotes the partial derivative of G with respect to N. Likewise, $MVP_w = p_g (\delta G / \delta W)$.

Setting these respective marginal value products equal to their respective input prices (i.e., the marginal cost of each input factor), profit maximization implies that:

$$\begin{aligned} \text{(i)} \quad & p_g (\delta G / \delta N) = p_n \\ \text{(ii)} \quad & p_g (\delta G / \delta W) = p_w \end{aligned}$$

Dividing each of these equations by p_g gives

$$\begin{aligned} \text{(iii)} \quad & \delta G / \delta N = p_n / p_g \\ \text{(iv)} \quad & \delta G / \delta W = p_w / p_g \end{aligned}$$

Dividing (iii) and (iv) through, respectively, by the prices p_n and p_w ,

$$\begin{aligned} \text{(v)} \quad & (\delta G / \delta N) / p_n = 1 / p_g \\ \text{(vi)} \quad & (\delta G / \delta W) / p_w = 1 / p_g \end{aligned}$$

Since both equations (v) and (vi) are equal to $1/p_g$ they are equal to each other and, noting that the left-hand numerators are the respective marginal physical products of N and W, equations (v) and (vi) can be rewritten as the optimality condition:

$$\begin{aligned} \text{(vii)} \quad & MPP_n / p_n = MPP_w / p_w = 1 / p_g \\ \text{or, equivalently, after multiplying through by } p_g, \\ \text{(viii)} \quad & MPP_n / p_n = MPP_w / p_w = 1 \end{aligned}$$

Another approach is by using existing data. In most countries, especially Asia-Pacific, there exists a large volume of potentially useful data relating to the major crops and their inputs/outputs in specific farming environments. Useful data from this earlier period usually concern yield relationships relative to the variables like water application, spacing, pruning method, fertilizer and/ manure application, crop age at harvest, harvest frequency etc.. These relationships are seldom presented as formal response functions but as tables of input/output data from which such functions may be constructed. Thus, farming system analyses will ensure helps to diagnose the system weaknesses and gives prescriptions for overcoming the constraints and optimization of resources.

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