Recent Advances in Integrated Farming Systems

SS Rana

Department of Agronomy, COA, CSK HPKV, Palampur-176062
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Sr Scientist

Department of Agronomy, COA, CSK HPKV, Palampur-176062
Citation
Preface

Weakening of the traditional joint family concept combined with unchecked linear growth in human population lead indiscriminate fragmentation of land holdings. More than 85 percent farm families have been converted in to marginal and small categories of farmers having land less than one hectare. Small and fragmented land holdings do not allow a farmer to keep independent farm resources like draught animals, tractors, bore wells/ tube wells and other sophisticated machineries for various cultural operations. Further, most of the inputs have become costly and out of reach of these resource poor farmers which has resulted farming as an uneconomic and unsustainable enterprise. Large scale urbanization, industrial and infrastructural growth - a need of the day has necessitated looking for vertical growth rather than horizontal expansion as far as Indian agriculture is concerned.

In past, the focus had been on maximization of crop yields and that too for well endowed resource rich farm families. Marginal and small farmers in general are literally illiterate, financially handicapped, their holdings are small and scattered not suited for high-tech agricultural machinery, work in resource poor and risk prone diverse conditions. Lot of efforts have been made aiming at increasing the productivity of different components of farming system but lacking in their integration by following farming system approach. To fulfil the basic needs of household including food (cereal, pulses, oilseeds, milk, fruit, honey, fish meat, etc.) for human, feed and fodder for animals and fuel & fibre for general use warrant an attention about Integrated Farming System.

The emergence of Integrated Farming Systems (IFS) has enabled us to develop a framework for an alternative development model to improve the feasibility of small sized farming operations in relation to larger ones. Integrated farming system is a commonly and broadly used word to explain a more integrated approach to farming as compared to monoculture approaches. The prosperity of any country depends upon the prosperity of farmers. This in turn depends upon the adoption of improved technology and judicious allocation of resources. Human race depends more on farm products for their existence than anything else since food and clothing – the prime necessaries are products of farming. Even for industrial prosperity, farming forms the basic raw material. To sustain and satisfy as many as his needs, the farmers include crop production, livestock, poultry, fisheries, beekeeping etc. in their farms.

Presently, the farming objective is the sustainable economic yields for the present generations without dislocating the natural resource base for the future generations. This book is intended as a professional basic book for post-graduate level students of Recent Advances in Integrated Farming Systems. It will be very useful for students of agronomy and economics in particular and forestry, animal sciences, fisheries, horticulture and social sciences in general. In addition the text book will be a valuable reference on farming system for the candidates appearing in competitive examinations including agricultural research services. Professional training institutes like KVKs, polytechnics, rural institutes etc dealing in farmers would also find this book of immense value.

The book covers Farming system – definition, importance and classification; concept of sustainability in farming systems; efficient farming systems; natural resources; production potential of different components of farming system; mechanism of different production factors; stability in different systems; ecophysiological approaches in multiple cropping; simulation models in intercropping; soil nutrients in intercropping; preparation and evaluation of different farming system models; new concepts and approaches in farming, cropping and organic farming systems and case studies on different farming systems.
The book is written in a simple form with up to date statistics. It is a comprehensive basic text book on integrated farming system and will specifically meet out the requirement of the students of Agron 607 being taught at the university. The author would welcome suggestions from the readers to improve the book.

Palampur

SS Rana
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Introduction

All over the world, farmers especially small and marginal work hard but do not make money, because there is very little left after they pay for all inputs. The prosperity of any country depends upon the prosperity of farmers. This in turn depends upon the adoption of improved technology and judicious allocation of resources. Human race depends more on farm products for their existence than anything else since food and clothing – the prime necessaries are products of farming. Even for industrial prosperity, farming forms the basic raw material. The majority of the farmers are cultivating their lands just for the sake of cultivation without the backup of full scientific and technological backup. They are satisfied whatever they are getting finally. The general opinion of the masses is revealing that only 10-12% of the scientific knowhow has been reached to the farmers that too in piecemeal. To make the farming economically viable, and environmentally sound and sustainable a holistic all around approach is required to be inculcated. To meet the multiple objectives of poverty reduction, food and nutrition security, competitiveness and sustainability, several researchers have recommended the farming systems approach to research and development. A farming system is the result of complex interactions among a number of inter-dependent enterprises/components, where an individual farmer allocates certain quantities and qualities of four factors of production, namely land, labour, capital and management to which he has access (Mahapatra, 1994). Farming system approach is a powerful tool for natural and human resource management in developing countries such as India. It is a multidisciplinary whole-farm approach and can be effectively employed in solving the problems of small and marginal farmers. The approach aims at increasing employment and income from small-holdings by integrating various farm enterprises and recycling crop residues and by-products within the farm itself (Behera and Mahapatra, 1999; Singh et al., 2006).

The Indian economy is predominantly rural and agricultural and the declining trend in size of land holding poses a serious challenge to the sustainability and profitability of farming. In view of the decline in per capita availability of land from 0.5 ha in 1950-51 to 0.15 ha by the turn of the century and a projected further decline to less than 0.1 ha by 2020, it is imperative to develop strategies and agricultural technologies that enable adequate employment and income generation, especially for small and marginal farmers who constitute more than 80% of the farming community. The crop and cropping system based perspective of research needs to make way for
farming systems based research conducted in a holistic manner for the sound management of available resources by small farmers (Jha, 2003). Under the gradual shrinking of land holding, it is necessary to integrate land based enterprises like fishery, poultry, duckery, apiary, field and horticultural crops, etc. within the bio-physical and socio-economic environment of the farmers to make farming more profitable and dependable (Behera et al., 2004). No single farm enterprise is likely to be able to sustain the small and marginal farmers without resorting to integrated farming systems (IFS) for the generation of adequate income and gainful employment year round (Mahapatra, 1992; 1994). Farming systems approach, therefore, is a valuable approach to addressing the problems of sustainable economic growth for farming communities in India.

The basic aim of IFS is to derive a set of resource development and utilization practices, which lead to substantial and sustained increase in agricultural production (Kumar and Jain, 2005). There exists a chain of interactions among the components within the farming systems and it becomes difficult to deal with such inter-linking complex systems. This is one of the reasons for slow and inadequate progress in the field of farming systems research in the country. This problem can be overcome by construction and application of suitable whole farm models (Dent, 1990). However, it should be mentioned that inadequacy of available data from the whole farm perspective currently constrains the development of whole farm models.

Integrated farming systems are often less risky, if managed efficiently, they benefit from synergisms among enterprises, diversity in produce, and environmental soundness (Lightfoot, 1990). On this basis, IFS models have been suggested by several workers for the development of small and marginal farms across the country (Rangaswamy et al., 1996; Behera and Mahapatra, 1999; Singh et al., 2006).
Farming system definition and importance

Different scientists have defined a farming system differently. However, many definitions, in general, convey the same meaning that it is strategy to achieve profitable and sustained agricultural production to meet the diversified needs of farming community through efficient use of farm resources without degrading the natural resource base and environmental quality. Relatively recent definitions include:

- Farming system is a resource management strategy to achieve economic and sustained agricultural production to meet diverse requirements of farm livelihood while preserving resource base and maintaining a high level of environment quality (Lal and Miller 1990).

- Farming system is a set of agro economic activities that are interrelated and interact with themselves in a particular agrarian setting. It is a mix of farm enterprises to which farm families allocate its resources in order to efficiently utilize the existing enterprises for increasing the productivity and profitability of the farm. These farm enterprises are crop, livestock, aquaculture, agro forestry and agri-horticulture (Sharma et al 1991).

- Farming system is a mix of farm enterprises such as crop, livestock, aquaculture, agro forestry and fruit crops to which farm family allocates its resources in order to efficiently manage the existing environment for the attainment of the family goal. (Pandey et al 1992).

- Farming system represents an appropriate combination of farm enterprises (cropping systems, horticulture, livestock, fishery, forestry, poultry) and the means available to the farmer to raise them for profitability. It interacts adequately with environment without dislocating the ecological and socioeconomic balance on one hand and attempts to meet the national goals on the other (Jayanthi et al 2002).

In general there are three important components of a farming system (whole farm business) viz.,

(i) crop component (cereals, pulses, oilseeds, sugar, fibre, vegetable, fruits, agroforestry etc.) usually taken up in the main crop fields

(ii) animal component (cattle, goat, sheep etc) usually taken up within the homestead and

(iii) homestead farming (biogas, post harvest, value added products, grinding, splitting of pulses) which include other allied activities taken up within the homestead. Each of the above components may have one or more of several activities or processes. Thus selection, production/cultivation and /or rearing of the activities within a farm
will determine the nature of farming system being practiced in any situation. Nevertheless, the kind of activities (crop or animals) included under each component depend on their suitability, adaptability, marketability and ability to satisfy the needs of a farm family. The experience of the farmer and his predecessors (father and forefather) over years enable them to select the activities under each system. In fact the farmer has been experimenting with the crops and the crop varieties or species and animal types or breeds knowingly or unknowingly over years before finally incorporating these in the farm plan. Therefore, basically it is a case of simulation and experimenting with crops and animals before incorporating them in any system. Once a system is identified its adoption will primarily depend on availability of different types of limited resources at the disposal of the farmer.

**Importance of farming system**

1. **Recycling and utilization of other available resources in the farm**: There is effective recycling of waste material in farming system. The word system itself signifies the assemblage of objects united by some form of regular interaction or interdependence. It is an organized unitary whole composed of two or more interdependent and interacting parts or components or sub-systems delineated by identifiable boundary or its environmental super system. Farming is a stochastic dynamic biological and open system with human and social involvement. It specifically refers to crop-combination or enterprise -mix in which the products and/or the by-products of one enterprise serve as the input for the production of other enterprise. Farming system includes agricultural crops, fruit trees, forest trees, forages, grasses and animals, which have potential to contribute to improve resource use and management.

2. **Maximum possible return and Profitability**: Use of waste material of one component in the other at the least cost reduces cost of production and net profit is increased. Due to interaction of enterprises like crops, eggs, milk, mushroom, honey, cocoons silkworm farming there is flow of money to the farmer **round the year**.

3. **Create adequate employment opportunities**: Combing crop with livestock enterprises would increase the labour requirement and help in reducing the problems of under employment. IFS provide enough scope to employ family labour round the year.
4. **Productivity**: IFS provides an opportunity to increase economic yield per unit area per unit time by virtue of intensification of crop and allied enterprises.

5. **Potentiality or Sustainability**: Organic supplementation through effective utilization of byproducts of linked component provides an opportunity to sustain the potentiality of production base for much longer periods.

6. **Balanced Food**: The linked components of varied nature enable to produce different sources of nutrition.

7. **Environmental Safety**: In IFS waste materials are effectively recycled by linking appropriate components, thus minimize environment pollution.

8. **Adoption of New Technology**: Resourceful farmers (big farmer) fully utilize the technology due to linkage of different components (crop with dairy / mushroom / sericulture / vegetable). Money flow round the year gives an inducement to the small/marginal farmers to go for the adoption of latest technologies.

9. **Saving Energy**: Organic wastes available in the system can be utilized to generate biogas. This alternative source thus reduces our dependence on fossil energy sources within short time.

10. **Meeting Fodder crisis**: Every piece of farm area is effectively utilized. Plantation of perennial legume fodder trees on field borders fixes the atmospheric nitrogen. These practices will greatly relieve the problem of non – availability of quality fodder to the animal component linked.

11. **Solving Fuel and Timber Crisis**: By linking agro- forestry appropriately, the production level of fuel and industrial wood can be enhanced without any effect on crop. This will also greatly reduce deforestation, thus preserving our natural ecosystem.

12. **Agro – industries**: When one of produces in farming system is increased to commercial level, the surplus lead to the development of allied agro – industries.

13. **Increasing Input Efficiency**: Farming system provides good scope to use inputs in different component with greater efficiency and benefit cost ratio.

**Farming System Concept and Scope**

Utilization of inputs without impairing the quality of environment is the main objective in the farming system approach. Therefore, it is clear that farming system is a process in which
sustainability of production is the objective. The overall objective is to evolve technically feasible and economically viable farming system models by integrating cropping with allied enterprises for irrigated, rained, hilly and coastal areas with a view to generate employment and income from the farm.

The Specific Objectives are:

1. To identify existing farming systems in specific areas and access their relative viability.
2. To formulate farming system models involving main and allied enterprises for different farming situations.
3. To ensure optional utilization and conservation of available resources and effective recycling of farm residues within system and to maintain sustainable production system without damaging resources/environment.
4. To raise overall profitability of farm household by complementing main/allied enterprises with other.

**Scope of Farming System**

Farming enterprises include crop, livestock, poultry, fish, tree, sericulture etc. A combination of one or more enterprises with cropping when carefully chosen, planned and executed gives greater dividends than a single enterprise, especially for small and marginal farmers. Farm as a unit is to be considered and planned for effective integration of the enterprises to be combined with crop production activity.

**Integration of Farm Enterprises Depends on Many Factors Such as:**

1. Soil and climatic features of the selected area.
2. Availability of the resources, land, labour and Capital.
3. Present level of utilization of resources.
4. Economics of proposed integrated farming system.
5. Managerial skill of farmer.
Classification of Farming Systems

Many farms have a general similarity in size, products sold and methods followed. When farms are quite similar in kind and production of the crops and livestock that are produced and methods and practices used in production, they may be grouped together.

On the basis of the share of gross income received from different sources and comparative advantage, the farming systems may be classified as follows:

**Classification of Farming Systems- According to size of farm**

- **Collective Farming**: It includes the direct collection of plant products from non-arable lands. It may include either regular or irregular harvesting of uncultivated plants; honeying and fishing usually go hand in hand with collection. Actual cultivation is not needed. The natural products like honey, gum, flower etc are collected. Such plant products may be collected from forestry area.

- **Cultivation Farming**: In this system, farming community cultivates the land for growing crops and rearing livestock.
  - **Small Scale Farming**: In this type, the farming is done on small size of holding and other factors of production are small in quantity and scale of production is also small.

**Advantages:**

- Intensive cultivation is possible.
- Labour problem do not affect the production.
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c) It is easy to manage the farm.
d) There is less loss due to natural calamities like frost, heavy rainfall and diseases.
e) Per unit output increases.

Disadvantages:

a) Small-scale farming cannot take advantages of various economic measures.
b) Cost of production per unit is more.
c) Mechanization of agriculture is not possible.
d) Farmer does not get employment round the year.

ii) Large scale farming: When farming is done on large size holding with large amount of capital, large labour force, large organization and large risk is called large-scale farming. In other words when the factors of production are large in quantity, the kind of farming is said to be large. In India 40 to 50 hectares land holding may be said large scale farming but in countries like America, Canada and Australia even 100 ha farms are also called as small farms.

Advantages:

a. Production is more economical as cost of production per unit is less.
b. Higher production per unit area.
c. Better marketing of agricultural products is possible. Processing, transportation, storage, packaging of produce is economical.
d. Costly machine like tractor, combined harvester can be maintained on the farm.
e. Subsidiary occupation such as dairy, poultry, beekeeping based on maintained on the farm.
f. Proper utilization of factors of production is possible.
g. Research work is possible.

Disadvantages:

a. If demand of produce decreases and production exceeds the market demand there will be more loss to the large farm.
b. Due to natural calamities like frost, drought, flood, insect-pests and diseases or other influences the large farm will suffer a lot.

c. It will be difficult to manage large scale farm.

**Classification of Farming Systems- According to Production of Land, Labour and Capital Investment**

The farmer on a given plot of land obtains more or less definite quantity of production/yield of a commodity/commodities during any particular time. If he wants to increase his output he can either i) bring more land under cultivation or ii) apply more labour and capital to the same piece of land.

**a) Intensive Cultivation:** In intensive cultivation more labour and capital are used in the same piece of land. In other words land remains fixed in quantity while other factors are increased. If the same land is rare due to population pressure, while labour and capital are comparatively cheap, intensive cultivation is preferred than extensive cultivation. The application of intensive cultivation method depends mainly upon- i) Increasing population and ii) Technical improvement. In the earlier stages of development population was small and technical knowledge of agriculture was also limited hence extensive method was adopted but, as population increases intensive cultivation become necessary and improvement in technology make its adoption possible.

**b) Extensive Cultivation:** When more area is brought under cultivation to increases the output it is termed as extensive cultivation. In extensive cultivation land is chiefly available but availability of other factors increases less proportionately. A cultivator wishing to increases his output may follow either intensive method or extensive method but the selection of these two methods is based on cost. Extensive cultivation if raise
the additional output more cheaply than intensive cultivation, extensive method of cultivation will be useful. If on the other hand intensive cultivation seems to be the cheaper method farmer will naturally adopt it. If land is cheaper and it can be had at a normal cost while labour and capital are comparatively costlier, extensive cultivation will be cheaper method of obtaining increased output. In early times when land was plentiful extensive cultivation was followed. The extensive and intensive cultivation go side by side in a country for a certain period of time and afterwards intensive cultivation may become more important method. In most of the countries extensive and intensive methods of cultivation generally go hand in hand.

According to the Value of Products or Income or Comparative Advantages:

Specialized Farming: The farm in which 50% or more income of total crop production is derived from a single crop is called specialized farming. The farm in which only single crop is cultivated for selling in the market and the income of the farm depends mainly on that crop is called specialized farming by Hopkins.

Advantages:

1. Better use of land: More profitable to grow crops on land best suited to it e.g. jute growing or cultivation on swampy land in west Bengal.
2. Better marketing: it allows grading, processing, storing, transporting and financing the produce.
3. Less equipment and labour.
4. Costly and efficient machinery can be kept: A wheat harvester/thresher can be maintained in a highly specialized wheat farm.
5. The efficiency and skill of the labour increased: Specialization allows a man to be more efficient and expert at doing a few things.
6. Farm records can be maintained easily.
7. Intensity of production leads to relatively large amount of output.
8. Better management: fewer enterprises on the farm are liable to be less neglected and sources of wastage can easily be detected.

**Disadvantage:**
These disadvantages of specialization are evident when the farmer realizes that “all his eggs are in one basket”.

1. There is greater risk: When failure of crop and decreasing market price of the product, demand in market of product.
2. It is not possible to maintain soil fertility-lack of crop rotation.
3. The productive resources i.e. land; labor and capital are not fully utilized.
4. Irregular income of the farm as they get income only once or twice in a year.
5. Proper Utilization of resources is not possible.
6. By product of crop are not property utilized, as numbers of livestock’s are less in number.
7. Due to specialization of a single enterprise, the knowledge about other enterprises vanishes.
8. Does not help in supplying all the food needs of the family members of the farmer.

**Mixed farming:** Mixed farming is one where crop production is combined with the rearing of livestock. The live stock enterprises (cows, buffaloes, sheep goat, and fisheries) are complementary to crop production; so as to provide a balance and productive system of farming. In mixed farming at least 10% of its gross income must be contributed by livestock activity. The upper limit is 49% under Indian conditions. So the farm on which at least 10 to 49% income is found from livestock is called mixed farm. In mixed farming cow and buffaloes are included with crop production.

**Advantages:**
1. It offers highest return on farm business, as the byproducts of farm are properly utilized.
2. It provides work throughout year.
3. Efficient utilization of land, labour, equipment and other resources.
4. The crop by products such as straw, bus, fodder etc. is used for feeding of livestock and in return they provide milk.
5. Manures available from livestock maintain soil fertility.
6. It helps in supplying all the food needs of the family members.
7. Intensive cultivation is possible.
8. If one source of income is lost he can maintain his family from other source of income.
9. Milk cattle’s provide draft animals for crop production and rural transport.
10. Mixed farming increases social status of the farmer.

In India the livestock is much closely connected with agriculture because animal power is the main source of power in agriculture. FYM is the main source for maintaining soil fertility and animals make good use of subsidiary and by-products on farms and in turn they provide milk under such circumstances mixed farming will most suit in Indian conditions.

Disadvantages:

1. Indigenous method of cultivation is used till now.
2. Draft and milch animals should be sold when they fail in production.
3. Healthy calf should be reared to replace age old animals.

**Required of Mixed Farming:**

i) Complicated management practices.
ii) Sound cropping scheme.
iii) Good cattle in suitable number.
iv) Transport facility.
v) Marketing facilities.

**Ranching:** A ranch differs from other type of crop and livestock farming in that the livestock graze the natural vegetation. Ranch land is not utilized for tilling or raising crops. The ranchers have no land of their own and make use of the public grazing land. A rancher occupies most of
the time of one or more operators. Ranching is followed in Australia, America, Tibet and certain parts of India.

**Dry Farming:** Farmers in dry land, which receives 750 mm rainfall or even less than that struggle for livelihood. The major farm management problem in these tracts, where crops, which are entirely dependent upon rainfall and the conservation of, soil moisture is needed. Dry Farming Involves the Adoption of the Following Practices:

- a) Timely preparation of the land to a condition in which it is best able to receive and conserve the available moisture.
- b) Time and proper inter culturing during growth of the crop.
- c) Improving the water holding capacity of the soil by the profitable application of organic manure.
- d) Use of such implements as is capable or rapidly breaking of the surface of the soil.
- e) Building of fields.
- f) Use of optimum seed rates.
- g) Thinning of excess plant populations.
- h) Mixed cropping.

Environmentally sustainable dry land farming systems emphasizes conservation and utilization of natural resources. Agronomic practices of conservation, tillage and mulch farming, rotational cropping, use of legumes and cover crops for improving soil fertility and suppressing weeds and efficient uses of cattle manure are some of the components of sustainable farming system.

**Classification of Farming System-According to Water Supply**

![Classification Diagram]

i) Rain Fed Farming: Agriculture mainly depends on the rainfall in most part of the country. 80% of the total cultivated arable land is rain fed. Rain fed farming is very risky system of farming.
where the success of the crop depends on the cycle of the monsoon. Timely rainfall is the pre-requisite of this farming. The uneven rainfall is quite detrimental to crop production.

Characteristics of Rain Fed Farming:

1. Crop and varieties, which can withstand moisture stress should be cultivated.
2. Kharif crops are sown after receiving monsoon.
3. Not possible to adopt improved methods of cultivation only one or two crops are grown.
4. Crops rotation is not followed.
5. Soils of these areas are deficits in nutrient.
6. Mixed cropping should be practiced and adopt deep-rooted crops.
7. Short duration varieties fit well in rain fed areas.
8. The crops that are tolerant to drought should be cultivated.
9. Soil moisture should be preserved by mulching, FYM application.
10. Soil erosion which may be called “Creeping death” of the soil is a worldwide problem, so necessary measures should adopt to keep the soil productive.

Principles of relevant components of environmentally sustainable farming systems should include.

1. Reduce soil erosion and improving soil conservations.
2. Inclusion of legumes and cover crops in crop rotations.
3. Agro-forestry as an alternate land use system and

**ii) Irrigated Farming:** The crop can be grown throughout the year; moisture is not a limited factor.

**Characteristics:**

1. The round the year cropping pattern becomes possible.
2. Intensive cropping is possible.
3. Production can be increased by proper utilization of productive resources.
4. Crop rotation can be executed properly due to adequate irrigation facility.
5. Manuring is safely done in irrigated crop.
6. The field experiment is possible, because of timely irrigation facility.

Classification According to Type of Rotation

I) Type of Rotation:

The world rotation has two meanings according to the time period involved. There is long term alteration between various types of land use such as arable farming, tree farming, grassland use etc. In this rotation means the sequence of this basic type of land use on a given field. Within arable farming there is also the term crop rotation which means the short-term sequences of different arable crops on one field.

a) Lay System:

In this system, several years of arable farming are followed by several years of grassed and legumes utilized for livestock production.

i) Unregulated Lay Farming:

In this system natural vegetation grasses, bushy growth on pasture is allowed to grow during the period of fallow. This is an improved managed pasture.

ii) Regulated Lay System: During the period of fallow, certain types of grasses are grown or planted. These are the well managed pasture with fencing and adopting rotational grazing system.

b) Perennial Crop System: The crop which covers the land for many years e.g. Tea, Coffee, sugarcane. In some cases tree crops (oil palm, rubber) are alternated with fallow in other with arable farming, grazing etc.
Farming system according to Intensity of the Rotation

II) Intensity of the Rotation: It is denoted by “R”, simple and appropriate criteria for classification, which gives the true relationship between crop cultivation and following within the total length of one cycle of utilization.

\[
R = \frac{\text{No. of years of cultivation}}{\text{Length of the cycle of land utilization}} \times 100
\]

The length of the cycle is the sum of the number of years of arable farming. The number of fallow years “R” indicates the production of the area under cultivation in relation to a total area available for arable farming.

a) Shifting cultivation: \( R < 33\% \). In the case there is more number of years of fallow than actual cultivation.

b) Lay or fallow farming: In this case \( R < 66\% \) and \( 33\% \)

c) Permanent cultivation: In this large area is cultivated and small area is left fallow. \( R > 66\% \).

d) Multiple cropping: where \( R = > 100\% \). If \( R = 150\% \) means 50% area is under two crops in a year. If \( R = 300\% \) means three crops in a year are being grown.

Classification According to Degree of Commercialization

Commercialized farming Partly commercialized farming Subsistence farming
Depending Upon the Produce Sold in the Market for Earning Money:

a) **Commercialized Farming:** More than 50% of the produce is for sale.

b) **Partly Commercialized Farming:** More than 50% of the value of produce is for home consumption.

c) **Subsistence Farming:** Virtually there is no sale of crop and animal products, but used for home consumption. Subsistence farming is a type of farming where the farmers of our country cultivate the crop in their land for the livings. Hence, the holding is small in size; so improved method of cultivation is not possible. They fail to meet the total requirement. They reared cattle, poultry, along with crop cultivation in limited land to meet their requirement.

Advantages:

1. Utilizing productive resources profitably.
2. Farmers with their family members engaged though the year as they rearing cattle, poultry etc.
3. Farmer meet their demand from the income from cattle, poultry etc.
4. By product used properly.

Disadvantages:

1. Fails to adopt improved crop cultivation technique do to small holding.
2. Cultivation mainly depends on monsoon rain.
3. Procurement of seed, fertilizer as and when required is difficult.
4. Income of this farm is very low.

**Classification According to Degree of Nomadic, Cropping pattern and Implements**

**Grassland Farming:** In this type of farming, it involves the rearing of animal for economic production and is classified on the basis of nomadic.
a) Total nomadic: In this system, the animal owners do not have permanent place of residence. They do not practice regular cultivation. Their families move with the herds.

b) Semi nomadic: Animal owners have a permanent place of residence, while supplementary cultivation is practiced. However, for long periods of time, they travel their herd to distant grazing areas.

c) Transhumant: Means seasonal migration of livestock to suitable grazing ground or it is the situation in which farmer with a permanent residence sends their herd with herdsman for long period of time to distant grazing areas.

d) Partial nomadic: Farmer has permanent residence and who have herds at their disposal, which remains in the vicinity.

e) Stationary animal husbandry: Occurs where the animals remain on the holding or in the village throughout the entire year.

Classification According to Cropping and Animal Activities:

In this system classification according to the leading crops and livestock activities of the holdings e.g. Paddy holding, coffee banana holding. Rice-Jute holds, Sugarcane farming.

Classification According to Implements Used for Cultivation:
Spade farming: manual labour is used.

Moe farming or hoe farming: Bullock power is used for cultivation.

Mechanized or tractor farming: Power operated implements are used for cultivation e.g. plough, tractor.

The classification on the basis of agro-ecological factors (such as climate, soil, slope, altitude and, not unrelated to these factors, the crop and livestock systems used) overlaid, to a lesser extent, with socioeconomic criteria (Fresco and Westphal 1988) inevitably leads to a plethora of farm types. FAO has taken a different approach. Emphasis is on farm-system structure from a farm management and farm-household perspective with classification based on: (1) the main purpose of the farm, (2) its degree of independence and (3) its 'size'. From such a structural viewpoint there are basically six major types of farm system to be found in Asia and elsewhere around the developing world with dozens of subtypes constituting a continuum of farm types between the extremes of a totally subsistence to a totally commercial orientation.

The six basic farm types are:

Type 1. Small subsistence-oriented family farms.

Type 2. Small semi-subsistence or part-commercial family farms, usually of one half to two hectares, but area is not a good criterion: the same basic structure can be found on much larger 20- to 30-hectare farms as in the Punjab, Sind, and North West Frontier Provinces of Pakistan.

Type 3. Small independent specialized family farms.

Type 4. Small dependent specialized family farms, often with the family as tenants.

Type 5. Large commercial family farms, usually specialized and operated along modified estate lines.

Type 6. Commercial estates, usually mono-crop and with hired management and absentee ownership.
Concept of sustainability in farming systems

Definitions of sustainable 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. As it pertains to agriculture, sustainable describes farming systems that are "capable of maintaining their productivity and usefulness to society indefinitely. Such systems must be resource-conserving, socially supportive, commercially competitive, and environmentally sound."

Under Food, Agriculture, Conservation, and Trade Act of 1990 (FACTA, Washington, DC.), "the term sustainable agriculture means an integrated system of plant and animal production practices having a site-specific application that will, over the long term:

- satisfy human food and fiber needs;
- enhance environmental quality and the natural resource base upon which the agricultural economy depends;
- make the most efficient use of nonrenewable resources and on-farm resources and integrate, where appropriate, natural biological cycles and controls;
- sustain the economic viability of farm operations; and
- enhance the quality of life for farmers and society as a whole."

Wendell Berry has simply said, “A sustainable agriculture does not deplete soils or people.”

Over time, the International Alliance for Sustainable Agriculture and an increasing number of researchers, farmers, policy-makers and organizations worldwide have developed a definition that unifies many diverse elements into a widely adopted, comprehensive, working definition: A sustainable agriculture is ecologically sound, economically viable, socially just and humane.

These four goals for sustainability can be applied to all aspects of any agricultural system, from production and marketing to processing and consumption. Sustainable agriculture involves farming systems that are environmentally sound, profitable, productive, and compatible with socioeconomic conditions (J. Pesek, in Hatfield and Karlen, Sustainable Agriculture Systems).
"Sustainable agriculture is a philosophy based on human goals and on understanding the long-term impact of our activities on the environment and on other species. Use of this philosophy guides our application of prior experience and the latest scientific advances to create integrated, resource-conserving, equitable farming systems. These systems reduce environmental degradation, maintain agricultural productivity, promote economic viability in both the short and long term, and maintain stable rural communities and quality of life."

"Sustainable agriculture does not mean a return to either the low yields or poor farmers that characterized the 19th century. Rather, sustainability builds on current agricultural achievements, adopting a sophisticated approach that can maintain high yields and farm profits without undermining the resources on which agriculture depends."

"A systems approach is essential to understanding sustainability. The system is envisioned in its broadest sense, from the individual farm, to the local ecosystem, and to communities affected by this farming system both locally and globally… A systems approach gives us the tools to explore the interconnections between farming and other aspects of our environment."

The definitions of sustainable agriculture as described above and various others those in the literature, may be analyzed in terms of three components viz., unit; form and criteria. The units referred to by the authors to define sustainable agriculture are as follow:

- Development of future generations;
- Farming or agriculture;
- Agricultural programme policy or practice;
- Agro-ecosystem;
- Integrated systems of plant and animal production practices; land use system and
- Natural resource base.

In terms of economy it was referred to as follow:

- Maintenance or enhancement of biological production and productivity;
- Development that meet the needs of future generations;
- Attainment and continued satisfaction of changing human needs;
- Economically viable;
- Makes use of low-cost inputs and less dependence on high inputs;
• More dependence on intensive management;
• Use of the very best of the technology in a balanced and well managed system;
• Make efficient management of renewable, non-renewable and human resources;
• Steady state between what is harvested and what is replenished;
• Maintains soil fertility; and
• Capacity to recover from stresses and disturbances.

In terms of ecology it was referred to as follow:
• Conserves land, water, plant and animal genetic resources;
• Development without compromising the ability of future generations to meet their own needs;
• Maintains soil fertility;
• Conserves man-made resources; is environmentally non-degradable;
• Ecologically sound;
• Enhance the integrity, diversity of the managed agricultural ecosystem;
• Maintains a steady state between what is harvested and what is replenished;
• Utilizes natural biological cycles and controls;
• Minimizes dependence of production on external inputs; and resilience of resource base or capacity to recover from stresses and disturbances.

A few authors have referred sustainable agriculture in terms of social benefits also viz. socially acceptable, socially just, culturally adapted, equity of resource access and integrating into existing social organization.

It can be seen that benefits of farm diversification (Farming system) and the conditions to be fulfilled for a system to be pronounced as sustainable are similar.

The criteria used by the authors while defining sustainable agriculture are as follows:
• Maintenance or constant;
• Enhancement; and
• Long term;

Based on the above analysis, sustainable agriculture is referred to be an agro ecosystem which maintains or enhances biological production and productivity and results in attainment and
continued satisfaction of changing human needs by conserving and efficiently using the renewable, non-renewable and human resources.

**Basic Features of Sustainable Farming Systems**

- The need to maintain or improve soil quality and fertility. This is often attained by increasing the organic matter content of the soil, and by minimizing losses from soil erosion.
- Production programs are designed to improve the efficiency of resource utilization. This will result in the most cost-effective use of water, fertilizers, and pesticides.
- An attempt is made to improve internal nutrient cycles on the farm, which will reduce the dependence on external fertilizers.
- Efforts are made to improve biological diversity on the farm. This will result in improved natural suppression of pests, and may also help to improve internal nutrient cycling within the farm.
- Farm management and marketing programs are designed to minimize overhead costs and to increase returns, often by following alternative marketing schemes.

"Today, sustainable farming practices commonly include:

- crop rotations that mitigate weeds, disease, insect and other pest problems; provide alternative sources of soil nitrogen; reduce soil erosion; and reduce risk of water contamination by agricultural chemicals
- pest control strategies that are not harmful to natural systems, farmers, their neighbours, or consumers. This includes integrated pest management techniques that reduce the need for pesticides by practices such as scouting, use of resistant cultivars, timing of planting, and biological pest controls
- increased mechanical/biological weed control; more soil and water conservation practices; and strategic use of animal and green manures
- use of natural or synthetic inputs in a way that poses no significant hazard to man, animals, or the environment."
"This approach encompasses the whole farm, relying on the expertise of farmers, interdisciplinary teams of scientists, and specialists from the public and private sectors."

**The evolution of thinking on sustainability**

In 1798 Thomas Malthus first put forth the observation that, if unrestrained, population growth would eventually overtake the ability to produce food leading to starvation and war (Malthus, 1798). But, since the mid-20th century, rising food demand has led to improved agricultural technologies so that the so-called Malthusian trap has been avoided, at least for the time being. However, environmental concerns about limits to growth began to emerge in the 1950s and 1960s, stimulating different debates about future scenarios. In the 1960s, concerns were voiced about the environmental risks caused by agriculture, driven in particular by Rachel Carson’s book *Silent Spring* (Carson, 1963). In the 1970s, the Club of Rome’s controversial report on “Limits to Growth” (Meadows et al, 1972) identified the economic problems that societies would face when environmental resources were overused, depleted or harmed, and pointed to the need for different types of policies to generate sustainable economic growth. In the 1980s, the World Commission on Environment and Development, chaired by Gro Harlem Brundtland, published *Our Common Future*, the first serious attempt to link poverty alleviation to natural resource management and the state of the environment (World Commission on Environment and Development, 1987). Sustainable development was defined as “meeting the needs of the present without compromising the ability of future generations to meet their own needs”. The concept implied both limits to growth and the idea of different patterns of growth. In 1992, the UN Conference on Environment and Development held in Rio de Janeiro, raised the international profile of threats to agricultural sustainability.

**The concept of agricultural sustainability – three dimensions**

Many different terms have been used to imply greater sustainability in agricultural systems than in prevailing systems (both pre-industrial and industrialized). Each emphasizes different values, priorities and practices (Pretty, 1995, 2002).

One interpretation of sustainable agriculture focuses on types of technology in particular settings, especially strategies that reduce reliance on non-renewable or environmentally harmful inputs. These include ecoagriculture, permaculture, organic, ecological, low-input, biodynamic,
environmentally-sensitive, community-based, farm-fresh and extensive strategies. There is intense debate, however, about whether agricultural systems using some of these terms actually qualify as “sustainable”.

A second and broader interpretation focuses more on the concept of agricultural sustainability, and goes beyond particular farming systems. Sustainability in agricultural systems is viewed in terms of resilience (the capacity of systems to buffer shocks and stresses) and persistence (the capacity of systems to carry on). It implies the capacity to adapt and change as external and internal conditions change. The conceptual parameters have broadened from an initial focus on environmental aspects to include first economic and then wider social and political dimensions (Cernea, 1991; DFID, 2002):

- **Ecological** – the core concerns are to reduce negative environmental and health externalities, to enhance and use local ecosystem resources, and preserve biodiversity. More recent concerns include broader recognition for positive environmental externalities from agriculture.

- **Economic** – economic perspectives on agricultural sustainability seek to assign value to ecological assets, and also to include a longer time frame in economic analysis. They also highlight subsidies that promote the depletion of resources or unfair competition with other production systems.

- **Social and political** – there are many concerns about the equity of technological change. At the local level, agricultural sustainability is associated with farmer participation, group action and promotion of local institutions, culture and farming communities. At the higher level, the concern is for enabling policies that target poverty reduction.

The relative values that people place on different trade-offs between these three dimensions vary over time and place. Achieving a balance between them is one of the greatest challenges to operationalising the concept of agricultural sustainability. Environmental and social sustainability of productive resources depend in part on economic profitability that must provide for reinvestment in the maintenance of these resources (including the natural environment) and on a satisfactory standard of living for owners and employees involved in the production process. In turn, economic sustainability is dependent on a productive workforce and productive natural resources.
Key features of agricultural sustainability include an acceptance of the fact that agricultural strategies should be based on more than simple productivity criteria, that externalities are of great importance, and that intra- and inter-generational equity are key parameters in assessing agricultural change (DFID, 2002).

**Agricultural growth and resource implications**

In most developing countries, agricultural and industrial revolutions did not begin until well into the twentieth century. In the last half century, rapid technological progress in the production of the major staple foods across much of the developing world has brought impressive results.

Since the 1960s, land in agricultural use (arable land and land under permanent grass and tree crops) in the world has increased by 12% to about 1.5 billion ha (FAO, 2004). This amounts to 11% of the Earth’s surface.

Over the past three decades, the area of land under irrigation has doubled and fertilizer use has increased 18-fold, resulting in a 20% increase in per capita food production (Conway, 1997).

Between 1950 and 2000, world production of grain nearly tripled, and average grain yields have risen from the 1–2 to the 6–8 metric tonnes per hectare range (Ruttan, 2002).

In the past four decades, total world food production grew by 145%. In Africa, it is up by 140%, in Latin America by almost 200%, and in Asia by a remarkable 280%. The greatest increases have been in China, with an extraordinary 5-fold increase, mostly occurring in the 1980s and 1990s (Pretty, 2003). But in recent years, growth in per capita food production has fallen back (Table 1).

Increased agricultural productivity and lower unit costs of food production have led to a sharp decline in real prices of cereals in world markets.

**Table 1. Global production per person of grain, beef and mutton, and seafood (1950–2000)**

<table>
<thead>
<tr>
<th>Food</th>
<th>Growth period</th>
<th>Growth (%)</th>
<th>Decline period</th>
<th>Decline (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grain</td>
<td>1950–84</td>
<td>+38</td>
<td>1984–2000</td>
<td>-11</td>
</tr>
</tbody>
</table>

Source: FAOSTAT
The major ingredients for boosting crop yields through the Green Revolution were public investments in irrigation and roads, public research on high-yielding varieties and reliable supplies of fertilizers and pesticides. Most of the successful breakthroughs in productivity have, however, occurred in more favoured agroecological zones, such as India, and bypassed most of sub-Saharan Africa. Advances in animal production have come from genetic improvements and advances in animal nutrition.

All of this progress in agricultural productivity over recent decades has, however, been associated with costs to the environment in many parts of the world. Agriculture can negatively affect the environment through overuse of natural resources as inputs or through their use as a sink for pollution. Experience has shown that agriculture based on intensive use of inputs is prone to mismanagement that leads to environmental degradation, particularly where the system of incentives is inappropriate (Conway, 1997).

Agricultural intensification and extension have had negative impacts in four critical areas:

- **Land degradation.** Land degradation threatens the productivity of existing farmland and pastures. In many developing countries, agricultural land has soil that is low quality or prone to degradation. About 1.2 billion hectares (almost 11% of the Earth’s vegetated surface) has been degraded by human activity over the past 45 years. An estimated 5–12 million hectares are lost annually to severe degradation in developing countries (Pretty and Koohafkan, 2002). Causes of degradation include water and wind erosion, contamination from industry and agriculture (including pesticides and fertilizers), and overuse of irrigation water causing salinisation. Soil degradation appears to be most extensive in Africa, where it affects 65% of the area used as cropland, compared with 51% in Latin America and 38% in Asia.

- **Water use and availability.** Irrigated agriculture is a major user of water and is crucial to the world’s food supplies. One fifth of the world’s cropland is irrigated, and this produces 40% of the world’s food. In South Asia, over 80% of water resources are now used in agriculture. Despite great investment, water use efficiency in irrigation is generally very low and there are major concerns regarding resource depletion and persistent conflicts over water rights. Unsustainable exploitation of groundwater may lead to unforeseen problems such as arsenic contamination of drinking water. And, in
large areas of India, water tables are already falling as demand is exceeding the sustainable yield of aquifers.

- **Loss of biodiversity.** Diverse agricultural systems and landscapes are resilient to shocks and stresses, with various plants, insects and animals helping to control pests and keep soils fertile. Many of the world’s modern agricultural systems have become highly-simplified, and no longer making the best use of this “beneficial” biodiversity.

- **Declining genetic diversity in agriculture itself.** Only 150 plant species are cultivated for food worldwide, and only 3 (rice, wheat and maize) supply 60% of the world’s calories. Genetic diversity in crops has been spiralling downwards – some 30,000 varieties of rice were grown in India fifty years ago; now only 10 varieties cover 75% of the all the rice-growing area. Reductions in agrobiodiversity increase disease and pest problems (Pretty, 2005).

Such effects are called negative externalities because they are usually non-market effects and therefore their costs are not included in market prices. As the polluter is not paying the full cost of his actions, there is no rational incentive to reduce negative externalities (Pretty et al., 2000, 2003a; Waibel et al., 1999). Many agricultural systems also suffer by undermining key natural assets that they require to be successful.

Externalities in the agricultural sector have four features:

1. Costs are often neglected;
2. They often occur with a time lag;
3. They can affect groups whose interests are not well represented in political or decision-making processes; and
4. The identity of the source of the externality is not always known (Baumol and Oates, 1988).

Agriculture is also associated with positive externalities. Sustainable agriculture is multifunctional within landscapes and economies (Pretty, 2003). It not only produces food and other goods for farm families and markets, but it also contributes to a range of public goods, such as providing clean water, maintaining biodiversity, carbon sequestration in soils, groundwater recharge, and flood protection. Sustainable agricultural systems can have many positive side effects including helping to build natural capital, strengthen social capital and develop human capacities (Pretty, 2003; Ostrom, 1990).
Policy and practice for agricultural sustainability

Researchers have identified eight key factors which appear to condition poverty–environment interactions and outcomes in relation to agriculture (McNeely and Scherr, 2001) which highlight key areas for policy response. These are:

1. The characteristics of the natural resource base and farming systems of the poor
2. Farmers’ awareness and assessment of the importance of environmental degradation
3. The availability of sustainable production technologies and their suitability for the poor
4. Farmers’ capacity to mobilize investment resources through their own assets and networks
5. Economic incentives for conservation management or investment
6. Security of tenure and rights of access to resources by the poor
7. The level of institutional capacity within communities to support adaptive responses by the poor
8. The degree of political inclusion of the rural poor in decisions affecting resource policies.

Macroeconomic and sectoral policies influence poverty–environment interactions by shifting these factors; thus macro policy typically has diverse impacts on different groups of poor people, the environments they use and their scope for positive adaptation. As an illustration of policy impacts, price pressure due to the expansion of supermarket buyer-driven chains can force farmers into unsustainable practices in order to sustain family income on a fixed land base.

<table>
<thead>
<tr>
<th>Key policy issues affecting agricultural sustainability</th>
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<tr>
<td>• input subsidies encourage excessive use</td>
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<tr>
<td>• minimum support prices for cereals discourage diversification</td>
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<tr>
<td>• electricity or fuel subsidies encourage groundwater depletion</td>
</tr>
<tr>
<td>• subsidized milk/dairy imports discourage local production</td>
</tr>
<tr>
<td>• fuel or machinery subsidies discourage conservation tillage</td>
</tr>
<tr>
<td>• insecure property rights mean no incentive for long term investments.</td>
</tr>
</tbody>
</table>

There has clearly been increasing global recognition of the need for policies to support agricultural sustainability. The main agreement of the 1992 Earth Summit was Agenda 21, which set out priorities and practices in all economic and social sectors and how these should relate to the environment (see Box below). The Agenda 21 chapter on “Promoting sustainable agriculture
and rural development” is a call for governments to initiate or strengthen programmes of research, extension and land tenure primarily aimed at sustaining production through conservation and management of natural resources and germplasm.

Extract from Agenda 21 of the 1992 Earth Summit

“Major adjustments are needed in agricultural, environmental and macroeconomic policy, at both national and international levels, in developed as well as developing countries, to create the conditions for sustainable agriculture and rural development. The major objective of sustainable agriculture and rural development is to increase food production in a sustainable way and enhance food security. This will involve education initiatives, utilization of economic incentives and the development of appropriate and new technologies, thus ensuring stable supplies of nutritionally adequate food, access to those supplies by vulnerable groups, and production for markets; employment and income generation to alleviate poverty; and natural resource management and environmental protection.

Efficient Farming Systems

The use of land, labour and energy

Nearly 50% of the world labour force is employed in agriculture. Distribution in the late 1980's ranged from 64% of the economically active in Africa to less than 4% in America and Canada. In Asia the figure was 61%; South America, 24%; Eastern Europe and Russia 15%; Western Europe 7%.

Understanding Efficiency

Many people believe that agriculture in this country (and in the other industrialized countries) is getting more and more efficient. They perhaps get this impression on account of the fact that yields of crops are going up all the time. They may also be influenced in their thinking by the fact that farming is getting increasingly mechanized and requires less and less labour. Nowadays one person can farm hundreds of acres of arable land, whereas fifty years ago they might only be able to farm twenty acres.

But these facts do not in any way indicate greater efficiency. What they do show is an increase in productivity, which is a very different thing. Productivity means the amount produced per unit area of land or per person employed. There is no doubt that both these indices of agricultural production have increased enormously in the last half century. But efficiency has actually gone down over the same period.

This apparent paradox arises because of a misunderstanding about the meaning of the word efficiency. It has nothing to do with productivity. The efficiency of a system means the ratio between the work or energy got out of it and the work or energy put into it. The more energy we get out per unit amount we put in, the more efficient the system is. Theoretically the maximum efficiency is when the energy put in is equal to the energy got out – such a system has an efficiency of 1 (or 100%). But in practice it is impossible to have efficiency as high as 1, because that would mean a perfect mechanism which had no energy losses at all.

Calculating Energy

In agricultural systems the energy inputs are of two kinds. On the one hand there is the sun’s energy, which is absolutely necessary for plant growth and which is virtually inexhaustible, freely available and generally beyond our control. On the other hand there is all the rest of the
energy used, usually referred to as the support energy, which is under our control, has a cost and is exhaustible.

This support energy consists of such things as the energy used by people and draught animals in their work, the energy used to manufacture farming tools and machinery, the fossil fuels used to power the machinery, the energy used by the chemical industry to produce the fertilizers, pesticides, herbicides, plastics, etc., the energy used in food processing and the fuel used to transport the produce to the consumer.

Not all of these energy inputs are taken into consideration in comparing the efficiency of different food production systems. The sun’s energy is usually left out of the calculations because it is assumed that, in a given place, it is constant, whatever the farming methods being used. Labour energy is sometimes left out as being negligible, but more often put in as a nominal value equal to the energy used in the worker’s muscles. Energy consumed in processing food and transporting it to the consumer is normally left out because it is not considered relevant. Only energy consumed within the boundaries of the farm is put into the calculations.

The merits of the arguments for and against including these inputs in the calculation are discussed later. For now it is convenient to leave out all of them apart from a nominal value for labour and settle on a simplified index of agricultural efficiency called the output/input ratio (To confuse things some authors use the input/output ratio, which is just the reciprocal of the output/input ratio), which is the ratio of the energy in the crops produced to the energy consumed on the farm to produce them. Most of this input energy is in the form of fossil fuels, which are used either directly to power tractors etc. or indirectly in the manufacture of goods, such as fertilizers and machinery, that are bought in.

**Comparative Farming Systems**

It is important to realize that output/input ratio is not exactly the same as efficiency. However, for any set of agricultural systems the output/input ratio is proportional to the efficiency, so we can use the ratio to compare the efficiency of one system with another. Here we are going to use it to compare farming in this country years ago with farming today, farming in rich countries with that in poor countries, primitive food production with modern industrialized agriculture, organic with conventional farming and animal rearing with stockless (vegan) farming.

Another value of the output/input ratio is that it is a good measure of the extent to which an agricultural system is using up the earth’s resources. It relates the energy put out in the form of
crops to the energy put in as fossil fuels, etc. If the former is less than the latter, energy is being lost and so the earth’s resources are being used up. In other words, if the output/input ratio is less than one, the system is using up the earth’s energy supply and so is not sustainable. A sustainable system must have an output/input ratio equal to or greater than one.

Let us look, as the first example, at how the efficiency of agriculture has changed in this country over the last century and a half. Bayliss-Smith, 1982) calculated the output/input ratio for English agriculture in 1826 to be 40.3. In 1971, according to the same author, it had fallen to 2.1 – a twenty-fold decline in efficiency. Uhlin (1997) arrived at a ratio for Swedish agriculture in 1972 that was even worse – 0.76. However, according to his calculations, the ratio had increased to 1.14 by 1993.

These figures indicate that, with the increasing mechanization and chemicalisation of agriculture, agricultural efficiency in Europe declined steeply up to the nineteen seventies. The decline then bottomed out and the ratio has risen again very slightly since then, which is confirmed by Bonny’s (1993) study of cereal production in France.

This slight rise, which brings agricultural efficiency back to where it was in the fifties, is probably due to increased industrial efficiency, more efficient machinery and more prudent use of agricultural chemicals. But the overall conclusion is that Western European agriculture is now barely sustainable, even when the enormous energy costs of transport and food processing are not included.

**Countries Compared**

As another example of the use of output/input ratios we can look at a comparison of agriculture in different countries carried out by Conforti and Giampietro (1997). They excluded from their calculations all energy inputs other than fossil fuels. In most cases this is a good approximation, because fossil fuels constitute over 90% of total energy inputs. They compared the output/input ratios of 75 countries world-wide and found that the value of the ratio varied from 156 to 0.41.

The countries with the most inefficient agriculture (those with output/input ratios of 2 and below) included most of the rich countries of the world – Western Europe, USA, Israel, Japan, Australia and New Zealand. The countries with the most efficient agriculture on this scale (with ratios from 30 upwards) included Ghana, the Central African Republic, Niger and Uganda [This result may seem incredible to many people, for whom the names of the sub-Saharan countries of Africa are associated with hunger and, at times, starvation. The point is, it is not inefficient
agriculture that leads to starvation – it is caused principally by wars, acts of genocide and foreign interference in the economy]. These results speak for themselves.

Even more eloquent are comparisons of output/input ratios of primitive and industrialized agricultural systems. Steinhart and Steinhart (1974) worked out output/input ratios for shifting agriculture (like slash-and-burn) as about 28 and for hunting and gathering as 4. Leach (1976) gives 4.5 for hunting and gathering, which compares with his figure of 3.35 for intensive wheat production in the UK.

The same author puts subsistence farming in the range of 11 to 61, as compared with 0.35 (unsustainable!) for UK agriculture as a whole. Potato production in the UK has an output/input ratio of 1.57 and rice in the USA of 1.3 – both barely sustainable. He gives two figures for shifting agriculture in two different countries (New Guinea and Congo) – 20 and 65, respectively. So primitive farming, and even hunting and gathering, is far more efficient than modern industrialized agriculture.

**Beef Farming - The Most Inefficient**

Particularly interesting are two figures that Leach gives for maize production in Guatemala – one for purely manual work and the other for oxen power. The output/input ratio for the manual cultivation is 14 and the one with oxen is only 4. This shows the efficiency of manual work and calls into question whether animal power is of any advantage. Very little work has been done on the relative efficiency of conventional and organic cultivation. The only relevant published results are those of Kopke and Haas (1996), who studied energy use and carbon dioxide emissions on conventional and organic farms in West Germany.

According to them organic farming used only about a third of the energy per unit area of land than conventional farming did. Their work does not deal with outputs, but, even if we make a very conservative estimate and say that on organic farms the yields are only two thirds of what they are on conventional farms, we still find that organic farms are far more efficient than conventional ones – about twice as efficient, in fact.

Finally, we can use output/input ratios to compare the efficiency of animal farming with that of crop production. Here the results are not so clear cut. It very much depends on what kind of animal farming we are talking about. Intensive beef production, as practised in the UK, is probably about the most inefficient form of farming there is, having an output/input ratio of about 0.08 (Steinhart and Steinhart 1974). On the other hand, nomadic herding is relatively very
Recent Advances in Integrated Farming Systems

Gomez and Daniel (1977) have done a study of sheep rearing in the western USA and has shown that, with the decline of transhumance [The practice of alternating the grazing, according to the season, between two different areas, often very far apart. In the south of Europe/Indian subcontinent this was, until recently, the normal practice in sheep husbandry. The sheep were grazed in the mountains in the summer and in the lowlands in the winter and had to walk sometimes hundreds of kilometres between the two] and the change to more settled forms of grazing, the efficiency drops substantially.

**Lies, Damn Lies and Statistics**

It must be emphasized that all the figures on efficiency quoted above are in a sense provisional results and should be treated with a certain amount of caution. Agroecology is still not an exact science. Its practitioners have not even agreed yet on the definition of terms or on an appropriate methodology. The disagreement (referred to above) about what to include on the input side is a typical example of this.

Some researchers (especially those who are supporters of modern agriculture) are reluctant to include any inputs beyond the farm gate, believing that they are irrelevant to agriculture. That is why they disregard the energy cost of food transport and processing. But this can lead to very misleading results, because in the industrialized countries those costs represent nearly two thirds of the total energy consumed in food production (Steinhart and Steinhart 1974); so their inclusion in the calculations can turn what is apparently a sustainable system into one that is completely unsustainable.

Many critics of modern agriculture (e.g. Perelman (1976)) would argue that a large increase in the processing and transport of produce is inseparable from modern farming methods. In primitive agriculture farmers grew a wide range of crops to satisfy most of the needs of their own community. Consequently a large part of their produce was consumed locally. With the introduction of industrialized methods of farming, involving specialization in a few crops, it became necessary to process the food and transport it to great distances. One region specializing, for example, in cereal production could not satisfy all the food requirements of the local population, so other produce such as vegetables had to be transported in from other regions.

**Labour Costs**

Another broad area of disagreement in agroecology (which has been well reviewed by Fluck and Baird (1980)) is the energy value of human labour in farming. Many researchers take it as being
equal to the energy consumed by the human body in carrying out the physical work involved, which means that in all systems the labour energy per unit of time worked would be roughly the same. However, this may be an oversimplification, because it leaves out the energy cost of the reproduction of labour and that varies enormously from one society to another. In a primitive society most of the labour energy is consumed in food production and in domestic tasks like home making and bringing up children.

But in an advanced industrial society we must add to that all the energy consumed in support services like health services, social services and education, not to speak of the huge entertainment industry. In fact some researchers have gone as far as to suggest that the energy cost of labour is equal to the total gross national product of a country divided by the number of workers. This would give a figure up to ten times greater than the simple calculation of the energy expended by a person in the work itself. And if we applied this inflated figure for the energy cost of human labour to countries like Ethiopia and Tanzania, their agriculture would probably appear very much less efficient than previously stated.

So the relatively high efficiency of agriculture in poor countries could have something to do with the low energy requirements of their agricultural workers. This point needs more research. But there could be an important lesson for us in all this – that the only way to make food production more efficient and hence sustainable is to simplify our lives and greatly reduce our material standard of living.

Agricultural systems entail costs for society which the farmer usually does not have to take into account. These not only include transfer payments in the form of subsidies which farmers receive, either paid for by the taxpayer or the consumer in the form of higher food prices. They also include the costs of putting right environmental problems caused by farming practices. The costs of ensuring clean water supplies without excessive levels of nitrates, the costs of monitoring foodstuffs for pesticide residues or cleaning up water courses after accidents at agrochemical plants, the costs of conserving threatened habitats and environmentally threatened areas to name but a few.

**The Treadmill of Higher Productivity**

Some people, who might otherwise agree with the idea of a simpler life, may feel that the exclusive emphasis on efficiency as the main goal in farming is playing into the hands of our
opponents. They may feel that it is precisely the emphasis on efficiency that leads to the dehumanisation of human activities and that turns work into a treadmill. Not so. This misconception again arises from confusion between efficiency and productivity. It is the pressure for greater productivity of labour that gives rise to the treadmill. Efficiency in agriculture, as practised in less developed societies, leads to more leisure time and more time for cultural activities in the broadest sense. Hunter gatherers, for example, need to spend only 25% of their waking time to satisfy their whole food needs (Leach 1976). The rest of the time is available for domestic and social tasks and creative artistic activities.

“The Earth’s total resources cannot accommodate the spread of the West’s high energy consumption…. of oil and other minerals (which) is out of all proportion to its percentage of the world’s population.” Richard Norton Taylor.

It is when we take a very long term view that the paramount importance of agricultural efficiency becomes apparent. The only process in the world that actually adds to the world’s net energy and order is photosynthesis, which takes the sun’s energy and stores it in plant tissues like wood (Glasby 1988). Even fossil fuels were originally produced in this way. Nature is highly efficient by our definition and stored a lot more energy than was needed. So a vast reserve of energy was built-up over millennia. It is this reserve that we are now living off. When it is gone, there will only be the current energy of photosynthesis to live off.

**Why Vegan Agriculture Is Imperative**

In other words, we will have used up all the energy capital that we can and will be back to living off the interest again. In that situation, with no reserves, it will be imperative that essential human activities, such as food production, yield more energy as food than the support energy they use. If not they will quickly use up the world’s remaining energy reserves and the result will be starvation.

It would be wrong to suggest, by the way, that energy supply will be the only constraint on agriculture in the future. As the human population of the earth increases, shortage of land may also become a problem. In this case, the reversion to primitive farming, which the energy shortage will necessitate, will not help, because it will result in lower yields of food per unit area of land. The answer lies in the fact that at present a large proportion of agricultural land is given over to animal rearing, which is a very unproductive use of the land. Crop production could yield up to ten times more food than animal rearing. So, in the words of John Ikerd et al. (1997),
“much of…… our food supply problems could be solved by eating lower on the food chain”, or, in other words, by a move towards a vegan diet. However, this opens up a whole new area of debate.

**A note about “efficiency” and “output/input ratio”**

The efficiency of a system is the ratio of all the work or energy got out of it to all the energy or work put into it. So, for example, if you put 10,000 calories of work into a system, but only get 5000 calories out, the efficiency is 5000/10,000 = 0.5. We get the real efficiency of the system when we include in this calculation all the energy inputs and outputs. But we may not always want to do that. We may want to compare two farming systems but omit some of the inputs. There are two main reasons why we might want to do that. In one case a particular input might be exactly the same for both systems and hence makes no difference to their relative efficiency. For example, if we are comparing the efficiency of two neighbouring farms, one organic and the other conventional, we can assume that the intensity of solar radiation that they receive is the same. So it is usual to omit solar radiation from the inputs in such cases. Another reason for omitting a particular input is if it is considered to be relatively so small as to be insignificant. Some researchers have omitted the energy of human labour on these grounds (although human labour is, in fact, the biggest input of all).

But, if we have omitted some of the energy inputs, we can no longer call the quantity that we calculate the efficiency of the system, so we give it another name – output/input ratio. As long as we consistently omit the same inputs for one of the above reasons, the output/input ratio will be roughly proportional to the efficiency, so we can use it to compare the efficiencies of different farming systems.

However, there is one noticeable difference between the figures for efficiency and those for output/input ratio. Efficiency is always less than 1, because you can never get more energy out of a system than you put in. In an ideal system there would be no wastage at all, so all the energy put in is converted into useful work or energy. In this case the output would exactly equal the input, so the efficiency would be 1, but this can never be achieved in practice.

However, as has been explained above, it is customary to omit from the calculation some of the inputs, like solar energy or human labour, so in that case it is quite possible to have a total output that exceeds the total input. In that case the calculated output/input ratio would exceed 1. That is why the figures that have been used to compare different farming systems are greater than 1.
For example, as pointed out that primitive agriculture can have an output/input ratio as high as 60, whereas that of modern agriculture is generally between 1 and 2. If we compare all systems of agriculture in this way, we have to conclude that no-dig vegan-organic cultivation using solely manual methods or intermediate technology is the most efficient food production system there can be.
Natural resources - identification and management

Natural resources are derived from the environment. A natural resource is often characterized by amounts of biodiversity and geo-diversity existent in various ecosystems. Some of them are essential for our survival while most are used for satisfying our wants. Natural resources are materials and components (something that can be used) that can be found within the environment. Every man-made product is composed of natural resources (at its fundamental level). A natural resource may exist as a separate entity such as fresh water, and air, as well as a living organism such as a fish, or it may exist in an alternate form which must be processed to obtain the resource such as metal ores, oil, and most forms of energy.

There is much debate worldwide over natural resource allocations, this is partly due to increasing scarcity (depletion of resources) but also because the exportation of natural resources is the basis for many economies.

Some Natural resources can be found everywhere such as sunlight and air, when this is so the resource is known as an ubiquitous (existing or being everywhere) resource. However, most resources are not ubiquitous. They only occur in small sporadic areas; these resources are referred to as localized resources. There are very few resources that are considered inexhaustible (will not run out in foreseeable future) – these are solar radiation, geothermal energy, and air (though access to clean air may not be). The vast majority of resources are however exhaustible, which means they have a finite quantity, and can be depleted if managed improperly. The natural resources are materials, which living organisms can take from nature for sustaining their life or any components of the natural environment that can be utilized by man to promote his welfare is considered as natural resources.

Classification

There are various methods of categorizing natural resources, these include source of origin, stage of development, and by their renewability. On the basis of origin, resources may be divided into:

- Biotic – Biotic resources are obtained from the biosphere (living and organic material), such as forests, animals, birds, and fish and the materials that can be obtained from them. Fossil fuels such as coal and petroleum are also included in this category because they are formed from decayed organic matter.
Abiotic – Abiotic resources are those that come from non-living, non-organic material. Examples of abiotic resources include land, fresh water, air and heavy metals including ores such as gold, iron, copper, silver, etc.

Considering their stage of development, natural resources may be referred to in the following ways:

- **Potential Resources** – Potential resources are those that exist in a region and may be used in the future. For example, petroleum may exist in many parts of India, having sedimentary rocks but until the time it is actually drilled out and put into use, it remains a potential resource.
- **Actual Resources** – Actual resources are those that have been surveyed, their quantity and quality determined and are being used in present times. The development of an actual resource, such as wood processing depends upon the technology and the cost.
- **Reserve Resources** – The part of an actual resource which can be developed profitably in the future is called a reserve resource.
- **Stock Resources** – Stock resources are those that have been surveyed but cannot be used by organisms due to lack of technology. For example: hydrogen.

Renewability is a very popular topic and many natural resources can be categorized as either renewable or non-renewable:

- **Renewable resources** are ones that can be replenished naturally. Some of these resources, like sunlight, air, wind, etc., are continuously available and their quantity is not noticeably affected by human consumption. Though many renewable resources do not have such a rapid recovery rate, these resources are susceptible to depletion by over-use. Resources from a human use perspective are classified as renewable only so long as the rate of replenishment/recovery exceeds that of the rate of consumption.
- **Non-renewable resources** are resources that form extremely slowly and those that do not naturally form in the environment. Minerals are the most common resource included in this category. By the human perspective, resources are non-renewable when their rate of consumption exceeds the rate of replenishment/recovery; a good example of this are...
fossil fuels, which are in this category because their rate of formation is extremely slow (potentially millions of years), meaning they are considered non-renewable. Some resources actually naturally deplete in amount without human interference, the most notable of these being radio-active elements such as uranium, which naturally decay into heavy metals. Of these, the metallic minerals can be re-used by recycling them but coal and petroleum cannot be recycled.

**Extraction**

Resource extraction involves any activity that withdraws resources from nature. This can range in scale from the traditional use of preindustrial societies, to global industry. Extractive industries are, along with agriculture, the basis of the primary sector of the economy. Extraction produces raw material which is then processed to add value. Examples of extractive industries are hunting and trapping, mining, oil and gas drilling, and forestry. Natural resources can add substantial's to a country's wealth, however a sudden inflow of money caused by a resource boom can create social programs including inflation harming other industries ("Dutch disease") and corruption, leading to inequality and underdevelopment, this is known as the "resource curse".

**Depletion**

In recent years, the depletion of natural resources has become a major focus of governments and organizations such as the United Nations (UN). This is evident in the UN’s Agenda 21 Section Two which outlines the necessary steps to be taken by countries to sustain their natural resources. The depletion of natural resources is considered to be a sustainable development issue. The term sustainable development has many interpretations, most notably the Brundtland Commission’s ‘to ensure that it meets the needs of the present without compromising the ability of future generations to meet their own needs’, however in broad terms it is balancing the needs of the planet's people and species now and in the future. In regards to natural resources, depletion is of concern for sustainable development as it has the ability to degrade current environments and potential to impact the needs of future generations.

Depletion of Natural Resources is associated with social inequity. Considering most biodiversity are located in developing countries, depletion of this resource could result in losses of ecosystem services for these countries. Some view this depletion as a major source of social unrest and conflicts in developing nations.
At present, there is particular concern for rainforest regions which hold most of the Earth's biodiversity. According to Nelson deforestation and degradation affect 8.5% of the world’s forests with 30% of the Earth’s surface already cropped. If we consider that 80% of people rely on medicines obtained from plants and ¾ of the world’s prescription medicines have ingredients taken from plants, loss of the world’s rainforests could result in a loss of finding more potential life saving medicines.

The depletion of natural resources is caused by ‘direct drivers of change’ such as Mining, petroleum extraction, fishing and forestry as well as ‘indirect drivers of change’ such as demography, economy, society, politics and technology. The current practice of Agriculture is another factor causing depletion of natural resources. For example, the depletion of nutrients in the soil, due to excessive use of nitrogen and desertification. The depletion of natural resources is a continuing concern for society.

**Protection**

In 1982 the UN developed the World Charter for Nature in which it recognised the need to protect nature from further depletion due to human activity. They state the measures needed to be taken at all societal levels, from international right down to individual, to protect nature. They outline the need for sustainable use of natural resources and suggest that the protection of resources should be incorporated into the law system at state and international level. To look at the importance of protecting natural resources further. The World Ethic of Sustainability, developed by the IUCN, WWF and the UNEP in 1990 which set out eight values for sustainability, include the need to protect natural resources from depletion. Since these documents, there have been many measures taken to protect natural resources, some of these ways include Conservation biology and Habitat Conservation.

Conservation biology is the scientific study of the nature and status of Earth's biodiversity with the aim of protecting species, their habitats, and ecosystems from excessive rates of extinction. It is an interdisciplinary subject drawing on sciences, economics, and the practice of natural resource management.

Habitat conservation is a land management practice that seeks to conserve, protect and restore, habitat areas for wild plants and animals, especially conservation reliant species, and prevent their extinction, fragmentation or reduction in range.
Natural resource management

**Natural resource management** refers to the management of natural resources such as land, water, soil, plants and animals, with a particular focus on how management affects the quality of life for both present and future generations (stewardship).

Natural resource management deals with managing the way in which people and natural landscapes interact. It brings together land use planning, water management, biodiversity conservation, and the future sustainability of industries like agriculture, mining, tourism, fisheries and forestry. It recognises that people and their livelihoods rely on the health and productivity of our landscapes, and their actions as stewards of the land play a critical role in maintaining this health and productivity.

Natural resource management is also congruent with the concept of sustainable development, a scientific principle that forms a basis for sustainable global land management and environmental governance to conserve and preserve natural resources.

Natural resource management specifically focuses on a scientific and technical understanding of resources and ecology and the life-supporting capacity of those resources. Environmental management is also similar to natural resource management. In academic contexts, the sociology of natural resources is closely related to, but distinct from, natural resource management.

**Ownership regimes**

Natural resource management approaches can be categorized according to the kind and right of stakeholders, natural resources:

- State Property Regime
- Private Property Regime
- Common Property Regime
- Non-property Regimes (open access)
- Hybrid Regimes

**State Property Regime**

Ownership and control over the use of resources is in hands of the state. Individuals or groups may be able to make use of the resources, but only at the permission of the state. National forest, National parks and military reservations are some US examples. Water access entitlements are an example from Australia.
Private Property Regime
Any property owned by a defined individual or corporate entity. Both the benefit and duties to the resources fall to the owner(s). Private land is the most common example.

Common Property Regimes
It is a private property of a group. The group may vary in size, nature and internal structure e.g. indigenous tribe, neighbours of village. Some examples of common property are community forests and water resources.

Non-property Regimes (open access)
There is no definite owner of these properties. Each potential user has equal ability to use it as they wish. These areas are the most exploited. It is said that "Everybody's property is nobody’s property". An example is a lake fishery. This ownership regime is often linked to the tragedy of the commons.

Hybrid Regimes
Many ownership regimes governing natural resources will contain parts of more than one of the regimes described above, so natural resource managers need to consider the impact of hybrid regimes. An example of such a hybrid is native vegetation management in NSW, Australia, where legislation recognises a public interest in the preservation of native vegetation, but where most native vegetation exists on private land.

Management approaches
Natural resource management issues are inherently complex as they involve the ecological cycles, hydrological cycles, climate, animals, plants and geography etc. All these are dynamic and inter-related. A change in one of them may have far reaching and/or long term impacts which may even be irreversible. In addition to the natural systems, natural resource management also has to manage various stakeholders and their interests, policies, politics, geographical boundaries, economic implications and the list goes on. It is very difficult to satisfy all aspects at the same time. This results in conflicting situations.

After the United Nations Conference for the Environment and Development (UNCED) held in Rio de Janeiro in 1992, most nations subscribed to new principles for the integrated management of land, water, and forests. Although program names vary from nation to nation, all express similar aims.

The various approaches applied to natural resource management include:
Recent Advances in Integrated Farming Systems

- Top-down or Command and control
- Bottom-Up (regional or community based NRM)
- Adaptive management
- Precautionary approach
- Integrated approach (INRM)

**Regional or Community Based NRM**

The community based NRM approach combines conservation objectives with the generation of economic benefits for rural communities. The three key assumptions being that: locals are better placed to conserve natural resources, people will conserve a resource only if benefits exceed the costs of conservation, and people will conserve a resource that is linked directly to their quality of life. When a local people’s quality of life is enhanced, their efforts and commitment to ensure the future well-being of the resource are also enhanced. Regional and community based natural resource management is also based on the principle of subsidiary.

The United Nations advocates community based NRM in the Convention on Biodiversity and the Convention to Combat Desertification. Unless clearly defined, decentralised NRM can result an ambiguous socio-legal environment with local communities racing to exploit natural resources while they can e.g. forest communities in central Kalimantan (Indonesia).

A problem of community based NRM is the difficulty of reconciling and harmonising the objectives of socioeconomic development, biodiversity protection and sustainable resource utilisation. The concept and conflicting interests of community based NRM, show how the motives behind the participation are differentiated as either people-centred (active or participatory results that are truly empowering) or planner-centred (nominal and results in passive recipients). Understanding power relations is crucial to the success of community based NRM. Locals may be reluctant to challenge government recommendations for fear of losing promised benefits.

Community based NRM is based particularly on advocacy by nongovernmental organizations working with local groups and communities, on the one hand, and national and transnational organizations, on the other, to build and extend new versions of environmental and social advocacy that link social justice and environmental management agendas with both direct and indirect benefits observed including a share of revenues, employment, diversification of livelihoods and increased pride and identity. CBNRM has raised new challenges, as concepts of
community, territory, conservation, and indigenous are worked into politically varied plans and programs in disparate sites. Warner and Jones address strategies for effectively managing conflict in CBNRM.

The capacity of indigenous communities to conserve natural resources has been acknowledged by the Australian Government with the Caring for Country Program. Caring for our Country is an Australian Government initiative jointly administered by the Australian Government Department of Agriculture, Fisheries and Forestry and the Department of the Environment, Water, Heritage and the Arts. These Departments share responsibility for delivery of the Australian Government’s environment and sustainable agriculture programs, which have traditionally been broadly referred to under the banner of ‘natural resource management’.

These programs have been delivered regionally, through 56 State government bodies, successfully allowing regional communities to decide the natural resource priorities for their regions.

Governance is seen as a key consideration for delivering community-based or regional natural resource management. In the State of NSW, the 13 catchment management authorities (CMAs) are overseen by the Natural Resources Commission (NRC), responsible for undertaking audits of the effectiveness of regional natural resource management programs.

**Adaptive Management**

The primary methodological approach adopted by catchment management authorities (CMAs) for regional natural resource management in Australia is adaptive management.

This approach includes recognition that adaption occurs through a process of ‘plan-do-review-act’. It also recognises seven key components that should be considered for quality natural resource management practice:

- Determination of scale
- Collection and use of knowledge
- Information management
- Monitoring and evaluation
- Risk management
- Community engagement
- Opportunities for collaboration.
Integrated natural resource management (INRM)
A process of managing natural resources in a systematic way, which includes multiple aspects of natural resource use (biophysical, socio-political, and economic) meet production goals of producers and other direct users (e.g., food security, profitability, risk aversion) as well as goals of the wider community (e.g., poverty alleviation, welfare of future generations, environmental conservation). It focuses on sustainability and at the same time tries to incorporate all possible stakeholders from the planning level itself, reducing possible future conflicts. The conceptual basis of INRM has evolved in recent years through the convergence of research in diverse areas such as sustainable land use, participatory planning, integrated watershed management, and adaptive management. INRM is being used extensively and been successful in regional and community based natural management.

Frameworks and modelling
There are various frameworks and computer models developed to assist natural resource management.

Geographic Information Systems (GIS)
GIS is a powerful analytical tool as it is capable of overlaying datasets to identify links. A bush regeneration scheme can be informed by the overlay of rainfall, cleared land and erosion. In Australia, Metadata Directories such as NDAR provide data on Australian natural resources such as vegetation, fisheries, soils and water. These are limited by the potential for subjective input and data manipulation.

Natural Resources Audit Framework
The NSW Government in Australia has published an audit framework for natural resource management, to assist the establishment of a performance audit role in the governance of regional natural resource management. This audit framework builds from other established audit methodologies, including performance audit, environmental audit and internal audit. Audits undertaken using this framework have provided confidence to stakeholders, identified areas for improvement and described policy expectations for the general public.

Other elements

Biodiversity Conservation
The issue of biodiversity conservation is regarded as an important element in natural resource management. What is biodiversity? Biodiversity is a comprehensive concept, which is a
description of the extent of natural diversity. Gaston and Spicer point out that biodiversity is "the variety of life" and relate to different kinds of "biodiversity organization". According to Gray, the first widespread use of the definition of biodiversity, was put forward by the United Nations in 1992, involving different aspects of biological diversity.

**Precautionary Biodiversity Management**

The "threats" wreaking havoc on biodiversity include: habitat fragmentation, putting a strain on the already stretched biological resources; forest deterioration and deforestation; the invasion of "alien species" and "climate change". Since these threats have received increasing attention from environmentalists and the public, the precautionary management of biodiversity becomes an important part of natural resources management. According to Cooney, there are material measures to carry out precautionary management of biodiversity in natural resource management.

**Concrete "policy tools"**

Cooney claims that the policy making is dependent on "evidences", relating to "high standard of proof", the forbidding of special "activities" and "information and monitoring requirements". Before making the policy of precaution, categorical evidence is needed. When the potential menace of "activities" is regarded as a critical and "irreversible" endangerment, these "activities" should be forbidden. For example, since explosives and toxicants will have serious consequences to endanger human and natural environment, the South Africa Marine Living Resources Act promulgated a series of policies on completely forbidding to "catch fish" by using explosives and toxicants.

**Administration and guidelines**

According to Cooney, there are 4 methods to manage the precaution of biodiversity in natural resources management: 1."Ecosystem based Management" including "more risk-averse and precautionary management" ,where "given prevailing uncertainty regarding ecosystem structure, function, and inter-specific interactions, precaution demands an ecosystem rather than single-species approach to management". 2."Adaptive management" is "a management approach that expressly tackles the uncertainty and dynamism of complex systems". 3."Environmental impact assessment" and exposure ratings decrease the "uncertainties" of precaution, even though it has deficiencies, and 4."Protectionist approaches", which "most frequently links to" biodiversity conservation in natural resources management.
Land management

In order to have a sustainable environment, understanding and using appropriate management strategies is important. In terms of understanding, Young emphasises some important points of land management:

- Comprehending the processes of nature including ecosystem, water, soils
- Using appropriate and adapting management systems in local situations
- Cooperation between scientists that have knowledge and resources and local people that have knowledge and skills

Dale et al. (2000) study has shown that there are five fundamental and helpful ecological principles for the land manager and people who need them. The ecological principles relate to time, place, species, disturbance and the landscape and they interact in many ways. It is suggested that land managers could follow these guidelines:

- Examine impacts of local decisions in a regional context.
- Plan for long-term change and unexpected events.
- Preserve rare landscape elements and associated species.
- Avoid land uses that deplete natural resources.
- Retain large contiguous or connected areas that contain critical habitats.
- Minimize the introduction and spread of non-native species.
- Avoid or compensate for the effects of development on ecological processes.
- Implement land-use and land-management practices that are compatible with the natural potential of the area.
Production potential of different components of farming systems

The potential enterprises which are important in farming system in the way of making a significant impact of farm by generating adequate income and employment and providing livelihood security are as follows:

1. Crop Production

Crop production is an integral part of farm activities in the country. Cropping systems based on climate, soil and water availability have to be evolved for realizing the potential production levels through efficient use of available resources. The cropping system should provide enough food for the family, fodder to the cattle and generate sufficient cash for domestic and cultivation expenses. These objectives could be achieved by adopting intensive cropping (multiple cropping and intercropping). Intensive cropping may pose some practical difficulties such as shorter turn-around time lapse for land preparation before the succeeding crop and labour shortage at peak periods of agricultural activities. These practical handicaps can easily be overcome by making modifications in the cropping techniques. Alteration of crop geometry may help to accommodate intercrops without losing the base crop population.

(I) Sequential Cropping Systems: In sequential cropping, the preceding crop has considerable influence on the succeeding crop. This includes the complementary effects such as release of N from the residues of the previous crop, particularly legume, to the following crops and carries over effects of fertilizer applied to preceding crops. The adverse effects include allelopathy, temporary immobilization of N due to wide C/N ratio of the residues and carry over effect of pest and diseases.

In India, food crop is predominantly grown in most suitable seasons and thus particular food crop is basic to the cropping system followed by the farmers. Accordingly the cropping systems are usually referred to as:

(i) Rice-based cropping system
(ii) Sorghum-based cropping system
(iii) Pearl millet-based cropping system
(iv) Wheat and gram-based cropping system
Some of the cropping systems based on commercial crops are (i) cotton-based, (ii) groundnut-based, (iii) sugarcane-based, (iv) plantation crop-based and (v) vegetable-based cropping system. The grain production potential in different regions of the country under intensive cropping ranges from 11-18 t/ha. In maize-potato or toria-wheat-moong system followed at IARI, New Delhi, it was possible to produce 14-15 tonnes of food per ha per annum without impairing the soil health. The results of multiple cropping demonstrations under irrigated conditions showed that production potential can be as high as 19.8 t/ha in cereal-based cropping system of rice-rice-rice. The yield potential of multiple cropping varies from region to region depending upon the physical and socio-economic conditions.

(II) Multi-tier Cropping: The practice of growing different crops of varying height, rooting pattern and duration is called ‘multi-tier cropping’ or multi-storied cropping. Multi-storied cropping is mostly prevalent in plantation crops like coconut and areca nut. There is scope for intercropping in coconut garden up to the age of 8 years and after 25 years. During this period there is adequate light transmission to the ground, which permits cultivation of intercrops. The objective of this system of cropping is to utilize the vertical space more effectively. In this system, the leaf canopies of intercrop components occupy different vertical layers. The tallest components have foliage tolerant of strong light and high evaporative demand and the shorter component(s) with foliage requiring shade and on relatively high humidity e.g. coconut + black pepper + cocoa + pineapple.

In this system, coconut is planted with a spacing of 7.5 m. Rooted cuttings of black pepper are planted on either side of coconut about 75 cm away from the base. On the coconut trunk at a height of about one meter from the ground level, the vines of pepper are trailed. A single row of cacao is planted at the center of space between coconut rows. Pineapple is planted in the inter-space.

Coconut growing to a height of more than 10 m occupies the top floor. Black pepper growing to about 6-8 m height forms the second floor. Cacao with its pruned canopy of about 2.5 m height and pine apple growing to about 1 m height form the first and ground floors, respectively.

In another multi-tier system in coconut, ginger or turmeric and partial shade loving vegetables form the first tier, banana in second, pepper in third and coconut or areca nut in the final tier. In the areca nut plantation, tuber crops are predominantly intercropped. Elephant yam, tapioca, greater yam and sweet potato are common intercrops in humid tropics. Banana and pine apple
are also cultivated as intercrops in areca nut gardens. In coffee based multi-tier cropping system, first tier is with pine apple, second tier with coffee, third tier with cacao/mandarin and final tier with fast growing shade trees necessary for coffee plantation (e.g., dadaps and silver oak).

2. Dairy Farming
Dairy farming is an important source of income to farmers. Besides producing milk and/or draft power, the dairy animals are also good source of farm yard manure, which is good source of organic matter for improving soil fertility. The farm byproducts in turn are gainfully utilized for feeding the animals. Though the total milk production in the country as per current estimates have crossed 90 million tonnes/annum, the per capita availability is still about 220 g/day against the minimum requirement of 250 g/day as recommended by Indian Council of Medical Research.

The dairy sector in India is characterized by very large number of cattle and buffaloes population with very low productivity. Around 70% of Indian cows and 60% of buffaloes have very low productivity. This sector is highly livelihood intensive and provides supplementary incomes to over 70% of all rural and quite a few urban households. The sector is highly gender sensitive and over 90% of the households dairy enterprise is managed by family’s women folk.

(a) Cattle Rearing: Cattle rearing in India is carried out under a variety of adverse climatic and environmental conditions. The cattle are broadly classified into three groups.

(i) Draft breeds: The bullocks of these breeds are good draft animals, but the cows are poor milkers, e.g. Nagore, Hallikar, Kangeyam, Mali.

(ii) Dairy breeds: The cows are high milk yielders, but the bullocks are of poor draft quality, e.g., Sahiwal, Sindhi, Gir.

(iii) Dual purpose: The cows are fairly good milkers and the bullocks are with good draft work capacity, e.g., Hariana, Ongole and Kankrej.

Exotic breeds: The exotic breeds are high milk yielder e.g., Jersey, Holstein-Friesian, Aryshire, Brown Swiss and Guernsey.

(b) Buffaloes: Important dairy breeds of buffalo are Murrah, Nili Ravi (which has its home tract in Pakistan), Mehsana, Suti, Zafarabadi, Godavari and Bhadawari. Of these Godavari has been evolved through crossing local buffaloes in coastal regions of Andhra Pradesh with Murrah.
(i) **Housing:** Each cow requires 12 to 18 m$^2$ space and the buffaloes need 12 to 15 m$^2$. It is important to provide good ventilation and an open shed of housing is always preferable. Dairy building should be located at an elevated place to facilitate easy drainage. The floor should be rough and have gradient of 2.5 cm for every 25 cm length.

(ii) **Breeding and Maintenance:** The cows remain in milk for 9-10 months, the average calving interval being 16-18 months. A cow does not require more than 6-8 weeks of dry period. From the economic point of view, cow should ordinarily be bred during the second and third months after calving. In weak animals and heavy milkers, breeding may be delayed by 1 or 2 months. Cattle come to heat in more or less regular cycles of about 21 days which lasts for about a day. The best time to serve a cow is during the last stage of heat. If artificially inseminated, it is better to inseminate for 3 days continuously to have better probability to conceive. The gestation period varies with individual cows and breeds and normally it is about 280 days.

In the case of buffaloes, the lactation period last for 7-9 months. She buffalo comes to heat every 21-23 days. The gestation period is 310 days. Calf rearing is very important in the case of buffalo maintenance. Since they require abundant water, wallowing is required. Regular de-worming is needed for buffalo maintenance.

Under Indian conditions, cattle commonly mature at the age of about three years. This period can, however, be reduced by six months under well-managed herd.

(iii) **Feeding:** Cattle feed generally contains fibrous, coarse, low nutrient straw material called roughage and concentrates as well as green fodder round the calendar year to harvest potential yield.

**Roughages:** Dairy cattle are efficient user of the roughages and convert large quantities of relatively inexpensive roughage into milk. Roughages are basic for cattle ratio and include legumes, non-legume hays, straw and silage of legume and grasses.

**Concentrates:** Grains and byproducts of grains and oilseeds constitute the concentrates. They are extensively used in dairy cattle ration. These include cereals (maize, sorghum, oats, barley), cotton seeds, industrial wastes (bran or wheat, rice, gram husk) and cakes of oilseeds (groundnut, sesame, rapeseed, soybean, linseed).

**Vitamins and mineral mixtures:** It is advisable to feed a supplement containing vitamins A and D. Mineral mixtures containing salt, Ca, Mg and P should also be provided in the ration.
The ration per animal per day includes concentrate @ 1 kg for 2 litres of milk yield, green fodder (20-30 kg), straw (5-7 kg) and water (32 litres).

3. Goat and Sheep Rearing

The system of sheep and goat rearing in India is different from that adopted in the developed countries. In general, smaller units are mostly maintained as against large scale in fenced areas in the developed countries.

(i) Goat Rearing: In India, activity of goat rearing is sustained in different kinds of environments, including dry, hot, wet and cold, high mountains or low lying plains. The activity is also associated with different systems such as crop or animal-based, pastoral or sedentary, single animal or mixed herd, small or large scale. Goat is mainly reared for meat, milk, hide and skin. Goat meat is the preferred meat in the country. A goat on hoof (live goat) fetches a better price than a sheep on hoof.

Housing: Goats can be maintained under stall-fed conditions. Successful goat rearing depends on the selection of site. Goats do not thrive on marshy or swampy ground. Goats are to be provided with a dry, comfortable, safe and secure place, free from worms and affording protection from excessive heat and inclement weather. The Kitts are kept under large inverted baskets until they are old enough to run along with their mothers. Males and females are generally kept together. The space requirement for a goat is 4.5 to 5.4 m$^2$.

Breeding and Maintenance: Goat matures in about 6-7 months. Breeding is allowed for buck at one year and doe after 10 months of age. Gestation period is 145-155 days. It gives birth to 1-3 Kitts per time. Number of evings is three per 2 years. The Kitts can be weaned after 30-45 days. Mother can be allowed for mating 45-60 days after evings. Once in five years, the buck can be changed to avoid deterioration due to inbreeding. When the young ones attain a body weight of about 25-30 kg in about nine months, they can be sold.

Feeding: The requirement of nutrients per head in respect of goats is relatively low. Hence, they are suitable for resource poor small farmers with marginal grazing lands. They are essentially browsers and eat plants, which any other animals won’t touch. Goats eat 4-5 times that of their body weight. Since the profit depends on weight addition, adequate proteins and calorie should be given to goats. They eat more of tree fodder and hence 40-50% of green fodder should contain tree leaf fodder and the rest with other grass species. Goats should be fed with concentrates of maize, wheat, horsegram, groundnut cake, fish meal and wheat bran. Common salt and vitamin
mixtures should also be added. Abundant clean fresh water should be made available to goats. Water should be changed every morning and evening. Fresh water is required for digestion, blood circulation and removal of waste from the body. Water is also required for regulation of the body temperature.

(ii) Sheep Rearing: Sheep are well adapted to many areas. They are excellent gleaners and make use of much of the waste feed. They consume large quantities of roughage, converting a relatively cheap food into a good cash product. Housing need not be elaborate or expensive. However, to protect the flock from predatory animals, the height of the fencing should be raised to two meters.

Breeds of Indian Sheep: There are three types of sheep in India based on the geographical division of the country.

(i) The Temperate Himalayan Region: Gurez, Karanah, Bhakarwal, Gaddi, Rampur-Bushair.

(ii) Dry Western Region: Lohi, Bikaneri, Marwari, Kutchi, Kathiawari

(iii) Southern Region: Deccani, Nellore, Bellary, Mandya, Bandur

Breeding and Maintenance: One ram can be maintained for 40-50 ewes. Rams are liable to fight when two or more of them are put in a pen. Unlike other farm animals, ewes in general do not come in heat at regular intervals throughout the year but are seasonal in this respect. The duration of the heat period will range from 1-3 days and 75% of the ewes remain in heat for 21-39 hours. The optimum time of service is towards the end of heat period. Average heat interval is 18 days during the breeding season. The gestation period will vary from 142-152 days with an average of 147 days. A normal ram is in full vigour for breeding from the age of 2½-5 years. Sheep grow fully at two years of age when the ewe is ready for breeding. Under average range conditions, ewes may be expected to produce about five crops of lambs.

Feeding: A sheep requires about 1-2 kg of leguminous hay per day depending on the age of sheep and its body weight. Proteins may be supplied through concentrates such as groundnut cake, sesame cake or safflower cake when the pastures are poor in legumes or when scarcity conditions prevail. Normally 110-225 g of cake is sufficient to maintain an average sheep in
good condition. Feeding a mixture of common salt, ground limestone and sterilized bone meal in equal parts is required to alleviate deficiency of minerals in the feed.

4. Piggery

Pigs are maintained for the production of pork. They are fed with inedible feeds, forages, certain grain byproducts obtained from mills, meat byproducts damaged feeds and garbage. Most of these feeds are either not edible or not very palatable to human beings. The pig grows fast and is a prolific breeder, farrowing 10 to 12 piglets at a time. It is capable of producing two litters per year under good management conditions. The carcass return is high at 65-70% of the live weight.

**Breeds:** Imported breeds of Large White Yorkshire and Landrace are being used widely. Yorkshire is the most extensively used exotic breed in India. It is a prolific breed having good carcass quality, growth rate and feed conversion ability. For a small breeding farm or unit, the selection of a herd boar is extremely important. A good boar weighs 90 kg in about 5-6 months and is strong on feet and legs. The mother of the pig to be selected should have large litters of eight piglets or more.

**Housing:** Housing should provide maximum comfort to pigs so that their growth is optimum. There should not be dampness, draft and over heating. Locally available materials can be used for housing. One pig requires about 2.7 sq.m. with a wall of 1.2 m height. Eight boars can be kept in 2.7-4.5 m$^2$ area with 2.4-6.0 m$^2$ open space.

**Feeding:** Feed plays an important role in successful pig production. Pigs are the most rapidly growing livestock and suffer more from nutritional deficiencies than the ruminants. Protein, carbohydrates, fats, minerals, vitamins and ample good water form a complete diet for pig. Pigs have a simple stomach; therefore, they must be fed with maximum of concentrates and minimum of roughage. The main ingredients of swine ration are cereals and millets and their byproducts. The fibre content in swine ration should be very low (around 5-6%) for better feed utilization efficiency. Mixed ration should also contain 0.5% of added salt. Swine requires comparatively higher percentage of Ca and P than do cattle or sheep. When pigs are maintained with agricultural/kitchen waste or fish and slaughterhouse waste, the cost of production remains low. On an average, the consumption of feed is 3.5% of total weight. Feed allowance is calculated as 2.5-3.0 kg/100 kg body weight + 0.25 kg feed per piglet with the lactating mothers.
Management: As a general rule, well-developed gilts weighing about 100 kg, when 12-14 months old, may be used for breeding. The body weight is more important than age at breeding. Sows with low body weight show higher rate of fetal and pre-weaning mortality and have been proved as mothers with poor nursing ability. The gestation period is on an average 114 days. Litter size at birth may be 1-16 numbers with the body weight of 1-25 kg. Normal period between birth of piglets is 10-20 minutes. Time taken for the whole process of farrowing ranges from 1.5 to 4.0 hours. Sows are weaned after 40 days. It is advantageous to cull the sow after fifth or sixth litter in a commercial herd. Weaned sows come into heat in 3-10 days after weaning and may be allowed to breed. The boar-sow ratio should be 1:15. It is profitable to raise two litters from each sow each year. Mortality in piglets is an important cause of heavy economic loss leading to failure of pig industry. In general, one fourth of piglets farrowed die before they are weaned. Another one tenth is also categorized into stunt or unprofitable group due to disease or parasite infection. Thus about 60-65% of the piglets farrowed perform as healthy piglets at slaughter age. Death rate is high during farrowing and the first week after farrowing. The farrowing season also determines mortality rate. Mortality in newborn piglets is maximum when farrowing takes place in acute cold or hot climate. Therefore, mating should be planned in such a way that farrowing could be avoided in such seasons.

5. Poultry

Poultry is one of the fastest growing food industries in the world. Poultry meat accounts for about 27% of the total meat consumed worldwide and its consumption is growing at an average of 5% annually. Poultry industry in India is relatively a new agricultural industry. Till 1950, it was considered a back yard profession in India. In the sixties, the growth rate of egg production was about 10% and it increased to 25% in the seventies. The growth rate came down to 7-8% by 1990 due to price-rise in poultry feed. By 2000, the total egg production may reach up to 5000 crores. Broiler production is increasing at the rate of 15% per year. It was 31 million in 1981 and increased up to 300 million in 1995 (Singh, 1997). Nearly 330 thousand tonnes of broiler meat are currently produced. The average global consumption is 120 eggs per person per year and in India, it is only 32-33 eggs per capita year. As per the nutritional recommendation, the per capita consumption is estimated at 180 eggs/year and 9 kg meat/year.
BREEDS: Specific poultry stocks for egg and broiler production are available. A majority of the stocks used for egg production are crosses involving the strains or inbred lines of white Leghorn. To a limited extent, other breeds like Rhode Island Red, California Grey and Australop are used. Heavy breeds such as white Plymouth Rock, White Cornish and New Hampshire are used for crossbred broiler chickens. Hence, it is essential to consider the strain within the breed at the time of purchase. Several commercial poultry breeders are selling day old chicks in India. It is best to start with the day old chicks.

HOUSING: Adequate space should be provided for the birds. Floor area of about 0.2 m$^2$ per adult bird is adequate for light breeds such as white Leghorn. About 0.3-0.4 m$^2$ per bird is required for heavy breeds. The house should have good ventilation and reasonably cool in summer and warm during winter. It should be located on well-drained ground, safe from flood waters.

FEED: The feed conversion efficiency of the bird is far superior to other animals. About 60-70% of the total expenditure on poultry farming is spent on the poultry feed. Hence, use of cheap and efficient ration will give maximum profit. Ration should be balanced containing carbohydrates, fats, minerals and vitamins. Some of the common feed stuffs used for making poultry ration in India are:

- **Cereals**: Maize, barley, oats, wheat, pearl millet, sorghum, rice-broken.
- **Cakes/meal**: Oil cakes, maize-gluten-meal, fish meal, meat meal, blood meal.
- **Minerals/salt**: Limestone, Oyster shell, salt, manganese

From the day old to 4 weeks of age, birds are fed on starter ration and thereafter finisher ration, which contains more energy and 18-20% protein. Feed may be given 2-3 times in a day. In addition to the foodstuffs, antibiotics and drugs may also be added to the poultry ration. Laying hens are provided with oyster shell or ground limestone. Riboflavin is particularly needed.

MAINTENANCE: The chicks must be vaccinated against Ranikhet diseases with F$_1$ Strain vaccine within the first 6-7 days of age. One drop of vaccine may be administered in the eye and nostril. When chicks get the optimum body weight of 1.0-1.5 kg around six weeks, they can be marketed for broiler. Hens may be retained upto the age of about 1½ years for egg production. One hen is capable of laying 180-230 eggs in a year starting from the six month. In addition, a laying hen produces about 230 g of fresh droppings (75% moisture) daily.
6. Duck Rearing

Ducks account for about 7% of the poultry population in India. They are popular in states like West Bengal, Orissa, Andhra Pradesh, Tamil Nadu, Kerala, Tripura and Jammu and Kashmir. Ducks are predominantly of indigenous type and reared for egg production on natural foraging. They have a production potential of about 130-140 eggs/bird/year. Ducks are quite hardy, more easily brooded and resistant to common avian diseases. In places like marshy riverside, wetland and barren moors where chicken or any other type of stock do not flourish, duck rearing can be better alternative.

**Breeds:** The important Indian breeds are Sylhet Mete and Nageswari, which are mostly found in the Eastern region of the country. Their annual production of 150 eggs/bird/year. Improved breeds for egg and meat production are available. Khaki Campbell and Indian Runner are the most popular breeds for egg laying. Khaki Campbell has a production of 300 eggs/bird/year. Indian Runner is the second best producer. White Pekin, Muscovy and Aylesbury are known for meat production. White Pekin is the most popular duck in the world. It is fast growing and has low feed consumption with fine quality of meat. It attains about 3 kg of body weight in 40 days. Indigenous types, however, still continue to dominate in duck farming. Desi ducks are robust, well adapted to local conditions and free of diseases.

**Housing:** Ducks prefer to stay outside day and night even during winter or rains. In mild climate, it is possible to raise ducks without artificial shelter. A light fence of at least 1.2 m high enclosing the yard is enough to stop any predators. One nest of size 0.3 x 0.3 x 0.45 m to every 3 ducks is sufficient. In case of laying birds, a mating ratio of 1 drake: 6-7 ducks and in meat type 1:4-5 is allowed. The duck house should be well ventilated, dry, leaf and rat proof. The roof may be of thatched or asbestos sheeted. A water channel of 0.5 m wide and 0.20 m deep is constructed at the far end on both sides parallel to the night shelter in the rearing or layer house.

**Feeding:** Ducks normally require lesser attention. They supplement their feed by foraging, eating fallen grains in harvested paddy fields, small fishes and other aquatic materials in lakes and ponds. However, for intensive rearing, pellet feeding may be given. Ducks prefer wet mash due to difficulties in swallowing the dry mash. Hence, ducks should never have access to feed without water. During the first 8 weeks, birds should always have an access to feed. Later on they must be fed twice a day in the morning and late afternoon.
**Maintenance**: The general management of ducks is similar to that of the chickens. The incubation period is 28 days. A broody duck or hen may be used for small scale hatching and incubator for large scale hatching. During the early part of the life, newly hatched ducklings require warm temperature under the natural or village conditions. A duck or broody hen can take care of 10-15 ducklings. Artificial brooding may be resorted for large number of ducklings. High egg-laying strains of duck come into production at 16-18 weeks of age. Ducks are resistant to common avian diseases. Some of the common diseases in duck are duck plague, duck virus hepatitis, duck cholera and aflatoxicosis.

**7. Apiculture**

Apiculture is the science and culture of honeybees and their management. Apiculture is a subsidiary occupation and it is a additional source of income for farm families. It requires low investments and so can be taken up by small, marginal and landless farmers and educated unemployed youth.

**Species**: There are two bee species, which are most commonly grown in India. They are *Apis cerana indica* and *A. mellifera*, are complementary to each other but have different adaptations. *A. cerana* is known as Indian bees, while *A mellifera* is known as European/western bee.

*Apis cerana*: serves commercial bee keeping in most parts of the country and is reared mostly in ISI- A Type bee-hive. *Apis cerana* has instinctive behaviour of swarming and absconding. Its honey yield varies from 12 to 15 kg/hive/annum with foraging range between 0.8 and 1.0 km.

*Apis mellifera*: This species has achieved a great success in northwestern states of India. Its worker cell is 5.3 mm in width and drone cell is 1-3 times larger. Average honey production from this species is between 30 and 40 kg/hive/annum with foraging range extending up to 2-3 km.

**Management**: The beekeeper should be familiar with the source of nectar and pollen within his locality. Bee flora species are specific to different areas and have micro regional habitats. Under subtropical climates of India, nectar and pollen sources are available for most part of the year, but continuous succession throughout the year is lacking in some localities. Flowers of large number of plants species are visited by honeybees for nectar and pollen. The most important sources of nectar and pollen are maize, mustard, sunflower and palm, litchi, pongamia, coconut, sesamum etc. The beginner should start with 2 and not more than 5 colonies. A minimum of 2
colonies is recommended because in the event of some mishap, such as the loss of the queen occurring in one, advantage may be taken with the other.

The hive consists of bottom-board, brood chamber, brood chamber frames, super chamber, super chamber frames, top cover, inner cover, and entrance rod. These parts can easily be separated. The hive may be double walled or single walled. The single walled hive is light and cheap. The most suitable time for commencing bee keeping in a locality is the arrival of the swarming season. Swarming is a natural tendency of bees to divide their colonies under conditions that are generally favourable for the survival of both parent colony and the swarm. This occurs during the late spring or early summer.

**Honey collection:** Honey is a sweet viscous fluid produced by honeybees mainly from the nectar of the flowers. Honey should have good quality to meet the national and international standards. Qualities such as aroma, colour, consistency and floral sources are important. Proper honey straining and processing are needed to improve the quality of the produce. Honey varies in the proportion of its constituents owing to the differences in the nectar produced by different plants. The nectar collected by bees is processed and placed in comb cells for ripening. During the ripening, sucrose is converted into glucose and fructose by an enzyme called invertase, which is added to it by the bees. Honey is an excellent energy food with an average of about 3500 calories per kg. It is directly absorbed into the human blood stream, requiring no digestion.

**8. Fishery**

Ponds serve various useful purposes, viz., domestic requirement of water, supplementary irrigation source to adjoining crop fields and pisciculture. With the traditional management, farmers obtain hardly 300-400 kg of wild and culture fish per ha annually. However, composite-fish culture with the stocking density of 5000-7500 fingerlings/ ha and supplementary feeding can boost the total biomass production.

**Pond:** The depth of the pond should be 1.5-2.0 m. This depth will help for effective photosynthesis and temperature maintenance for the growth of zoo and phytoplankton. Clay soils have higher water retention capacity and hence are best suited for fish rearing. Pond water should have appropriate proportion of nutrients, phosphate (0.2-0.4 ppm), nitrate (0.06-0.1 ppm) and dissolved oxygen (5.0-7.0 ppm). Water should be slightly alkaline (pH 7.5-8.5). If the pH is less
than 6.5, it can be adjusted with the addition of lime at regular interval of 2-3 days. Higher pH (>8.5) can be reduced with the addition of gypsum. Application of fresh dung may also reduce high pH in the water.

Soil of the pond should be tested for N and P content. If the nutrient content is less, nitrogenous fertilizers like ammonium sulphate and urea and phosphatic fertilizer like super phosphate can be added. Organic manures such as FYM and poultry droppings may also be applied to promote the growth of phyto and zooplanktons.

**Species of fish:**

(i) Among the Indian major carps, Catla (*Catla catla*) is the fast growing fish. It consumes a lot of vegetation and decomposing higher plants. It is mainly a surface and column feeder.

(ii) Rohu (*Labeo rohita*) is a column feeder and feeds on growing fish. It consumes a lot of vegetation and decomposing higher plants. It is mainly a column and surface feeder.

(iii) Calbasu (*Labeo calbasu*) is a bottom feeder on detritus. Mrigal (*Cirrhinus mrigala*) is also a bottom feeder, taking detritus to large extent, diatoms, filamentous and other algae and higher plants. Common carp (*Cyprinus carpio*) is a bottom feeder and omnivorous.

(iv) Silver carp (*Hypophthalmichthys molitrix*) is mainly a surface and phytoplankton-feeder and also feeds on micro-plants.

(v) Grass carp (*Ctenopharyngodon idella*) is a specialized feeder on aquatic plants, cut-grass and other vegetable matter. It is also a fast growing exotic fish.

**Composite Fish Culture:** The phytophagous fish (Catla, Rohu and Mrigal) can be combined with omnivorous (Common carp), plankton-feed (Silver carp) and mud-eaters (Mrigal and Calbasu) in a composite fish culture system.

**Management:** For higher productivity fish are to be provided with supplementary feeding with rice bran and oilseed cakes. This will enable faster growth and better yield. Each variety of carps could be stocked to 500 fingerlings with the total 5000-8000 per ha. This stocking density will enable to get a maximum yield of 2000 to 5000 kg/ha of fish annually under good management practices.
9. Sericulture

Sericulture is defined as a practice of combining mulberry cultivation, silkworm rearing and silk reeling. Sericulture is a recognized practice in India. India occupies second position among silk producing countries in the world, next to China. The total area under mulberry is 188 thousand ha in the country. It plays an important role in socio-economic development of rural poor in some areas. In India more than 98% of mulberry-silk is produced from five traditional sericultural states, viz., Karnataka, Andhra Pradesh, West Bengal, Tamil Nadu, and Jammu and Kashmir.

The climatic conditions in India are favourable for luxuriant growth of mulberry and rearing and silkworms throughout the year. The temperature in Karnataka state, major silk producing state in India, ranges from 21.2 to 30 °C. Climatic conditions in Kashmir are favourable to silk worm from May to October.

**Moriculture:** Cultivation of mulberry plants is called as ‘moriculture’. There are about 20 species of mulberry, of which four are commonly cultivated. They are *Morus alba, M. indica, M. serrata* and *M. latifolia*. The crop can yield well for 12 years, after which they are pulled out and fresh planting is done. Yield of mulberry leaves is 30-40 t/ha/year.

**Silk worm rearing:** There are four types of silk worm viz. (i) Mulberry silk worm – *Bombyx mori* (ii) Eri silk worm – *Philosamia ricini* (iii) Tassar silk worm – *Antheraea mylitta* (iv) Muga silk worm – *Antheraea assami*

**Rearing and Maintenance:** The fertilized moth is covered with an inverted funnel or cellule and eggs are allowed to be laid over a cardboard. Parasites may be removed by brushing the egg masses with a fine brush. This will also enable to obtain a uniform hatch. In a bamboo tray rice husk is spread. Tender chopper mulberry leaves are added to the tray. The hatched out larvae are transferred to the leaves. Leaves are changed after every 2-3 hours during the first 2-3 days.

The cocoon is constructed with a single reelable thread of silk. If the moths are allowed to emerge from the cocoons, the silk thread is cut into pieces. Hence the pupa are killed 2-3 days before the emergence of moth and processed. The cocoons required for further rearing are kept separately and moths are allowed to emerge from them.
10. Mushroom Cultivation

Mushroom is an edible fungus with great diversity in shape, size and colour. Essentially mushroom is a vegetable that is cultivated in protected farms in a highly sanitized atmosphere. Just like other vegetables, mushroom contains 90% moisture with high in quality protein. Mushrooms are fairly good source of vitamin C and B complex. The protein have 60-70% digestibility and contain all essential amino acids. It is also rich source of minerals like Ca, P, K and Cu. They contain less fat and CHO and are considered good for diabetic and blood pressure patients.

Species: There are three types of mushrooms popularly cultivated in India. They are (i) Oyster mushroom – *Pleurotus sp.* (ii) Paddy straw mushroom – *Volvariella volvacea* (iii) White bottom mushroom – *Agaricus bisporus*

Method of production

**Oyster Mushroom:** Take fresh paddy straw and cut into small pieces of 3-5 cm length. Soak them in water for 4-6 hours and then boil for half an hour. Drain the water and dry the straw in shade till it is neither too dry nor wet. Take polythene bags of 60 x 30 cm size and make two holes of one cm diameter in the center of the bag such that they face opposite sides. Tie the bottom of the bag with a thread to make a flat bottom. Fill the bag with paddy straw to 10 cm height. Then inoculate with the spawn. Likewise prepare 4-5 layers of straw and spawn alternatively. The last layer ends up in straw of 10 cm height. Keep this in a spawn running room maintained at a temperature of about 22-28 °C and with RH 85-90%. After 15-20 days when the spawn running is completed, cut open the polythene bag and take it to cropping room and allow it to grow for 7 days and harvest the mushroom. Mushroom yield is around 0.5-1.0 kg/bag.

**Paddy straw Mushroom:** Cut the straw into long pieces of 60-90 cm and soak in water for 12 hours and sterilize 15 minutes. Arrange the straw in bundles. Lay the moistened straw bundles on the slightly raised concrete floor or on wooden platform in layers of four bundles width. Spawn or seed the beds simultaneously in each layer either by broadcasting or placing the grain spawn at different spots. Sprinkle grain dhal over each layer on the spawn. Don’t spawn below the topmost layer. Maintain it at 30-35 °C. Harvesting is ready after 25-30 days. Yield is around 1-1.5 kg/bed.
**Botton Mushroom:** It requires a complex method of preparing compost, which is used as a substrate for mushroom production. Spawning is done by three methods, viz., surface spawning, layer spawning and trough spawning. Fill the trays with compost and do spawning. After spawning, compost is pressed hard to make it compact. The trays are arranged in the cropping room in tiers and cover with newspaper sheet sprayed with 2% formalin. The temperature of 20-25 °C and RH of 90-95% should be maintained. After spawn running is completed in 15-20 days and do casing. Pin heads appear within 10-15 days after casing. Cropping continues for 60-75 days. Mushrooms can be harvested at button stage. Yield ranges from 6-7 kg/m$^2$.

11. **Agroforestry**

Agroforestry is a collective name for land use systems and technologies, in which woody perennials (trees, shrubs, palms, bamboos etc) are deliberately combined on the same land-management unit as agricultural crops and/or animals, either in some form of spatial arrangement or in a temporal sequence. In agroforestry systems, there are ecological and economical interactions among different components. That implies that: (i) agroforestry normally involves two or more species of plants (or plants and animals) at least one of which is woody perennials; (ii) an agroforestry system always has two or more outputs; (iii) the cycle of an agroforestry system is always more than one year; and (iv) even the simplest agroforestry system is structurally, functionally, and socio-economically more complex than a monocropping system. Agroforestry is important for meeting fodder, fuel wood and small timber of farmers, conserving soil and water, maintenance of soil fertility, controlling salinity and water logging, positive environment impact and alternate land use for marginal and degraded lands. Selection of proper land use systems conserve biophysical resources of non-arable land besides providing day-to-day needs of farmer and livestock within the farming system.

The different commonly followed agro-forestry systems in India are: (1) Agri-silviculture (crops + trees), which is popularly known as farm forestry (2) Agri-horticulture (crops + fruit trees); (3) Silvi-pasture (Trees + pasture + animals); (4) Agri-horti-silviculture (crops + fruit trees + MPTS + pasture); (5) Horti-silvi-pasture (fruit trees + MPTs + Pasture); (6) Agri-silvi-pasture (crops + trees + Pasture); (7) Homestead agroforestry (multiple combination of various components); (8) Silvi-apiculture (trees + honey bees); (9) Agri-pisci-silviculture (crops + fish + MPTS); (10) Pisci-silviculture (Fish + MPTs) etc.
**Agri-silvicultural Systems:** This system emphasizes raising of trees and cultivation of field crops and/or fodder crops in the available space between the trees. In arid and semi-arid regions hardy trees like *Prosopis cineraria* (Khejri), *Eucalyptus sp.*, *Acacia tortilis*, *Hardwickia binata* (Anjan), *Azadirachta indica* (Neem), *Ailanthes excelsa*, *Ziziphus jujuba* etc. could be grown along with dry land crops such as pulses (pigeonpea, blackgram), millets (finger millet, sorghum) etc. This is practiced mostly on arable lands, wherein multipurpose trees used for fuel and fodder can be grown with crops in the fields as alley farming. The hedges follow contour and compromise trees and shrubs like *Leucaena* or pigeonpea. Leguminous perennials are more suitable due to fixation of nitrogen.

**Agri-horti-silviculture:** In this system fruit trees are grown along with crops and multipurpose trees (MPTs). Under rainfed situation hardy fruit trees like ber, aonla, pomegranate, guava could be grown along with dryland crops like pigeonpea, til, mothbean, mustard etc. Grafted ber (Var., Gola, Seb, Mundiya, Banarasi Kasak) may be planted at 6 x 6 m with 2 plants of subabul in between. Under partial irrigation, Guava, pomegranate, Lemon, Kinnow have been successfully grown at 6 x 5 m along with crop like wheat, groundnut and subabul (200 pl/ha) for quick leaf fodder and fuel wood production. For further protecting fruit crops from desiccating hot summer and cold winter planting of subabul/sesbania at every 2 m apart as wind breaks. Alternate plants of subabul/sesbania could be harvested for quick fodder and fuel wood production every 3rd year. Relative grain yield was 70-85% even in 3rd and 4th year.

**Silvi-Pastoral system:** In the silvi-pastoral system, improved pasture species are introduced with tree species. In this system grasses or grass legume mixture is grown along with the woody perennial simultaneously on the same unit of land. In the marginal, sub-marginal and other degraded lands silvipastoral system has been found to be most economic agroforestry system especially in arid and semi-arid regions. It involves lopping trees and grazing understorey grasses and bushes in forests or plantations. It helps in reduction of the cost of concentrated feed to animal during lean period. A number of fodder trees like *Leucaena latisiliqua*, *Bauhinia variegata*, *Albizia labbek*, *Albizia amara*, *Moringa olerifera*, *Sesbania sesban*, *S. grandiflora*, *Hardwickia binata* are identified for different regions of the country for silvi pastoral systems. Trees provide fuel and timber in the extreme dry season and lean periods, animal graze on pastures and feed on the leaves of nutritious trees and shrubs. Multilayered vegetation covers are very effective in controlling run-off and soil loss from erosion prone areas.


**Horti-Pastoral system:** It involves integration of fruit trees with pasture. In the degraded arid and semi arid rangeland regimes number of over grazed plants of *Ziziphus nummularis* are found which could be successfully budded with improved variety of ber (viz., Gola, Seb, Umran, Banaras, Kaska) besides planting MPTs like anjan, Subabul, Khejri along grasses and legumes like *Cenchrus*, *Lasiurus*, *Chrysopogon*, *Stylosanthes*, *Sirato* etc.

**Agri-silvi-pasture:** It is a combination of agri-silviculture and silvi-pastoral system. In arid degraded lands of Rajasthan, Gujarat and Haryana often dryland crops viz. bajra, moth, urad, til etc. are grown in strips along with grass strips to avoid shifting sand reaching cropped area. MPTs could be introduced both in the pasture strips as well as in the crop strips, which besides protecting the crops from desiccating hot and cold wind would also provide leaf fodder, timber etc. besides pasture when there is a crop failure. Woody plants could be *Acacia Senegal*, ber, anjan, neem etc. Grasses like *Cenchrus*, *Lasiurus* and legume *Stylo sp.*

**Pastoral silvicultural system:** Integrated crop farming is practiced to meet the requirements of grasses and fodder for livestock. The pastoral silvicultural system is the practice in which grazing is the main component with scattered trees grown in the area. This practice is adopted in semi-arid regions of the country comprising the states of Andhra Pradesh, Tamil Nadu, Karnataka, Maharashtra and Madhya Pradesh. The cultivators leave the fields fallow with existing trees and protect the same. *Dichanthium annulatum* is an important grass under this system. The important planted trees in the system are *Eucalyptus* hybrid, *Casuarina equisetifolia*, *Borassus flabellifera* and *phoenix sylvestris*. Generally trees are lopped for fuel and fodder. Custard apple, mango, *Zizyphus* and tamarind fruits are used for domestic consumption.

**12. Biogas**

A biogas unit is an asset to a farming family. It produces good manure and clean fuel and improves sanitation. Biogas is a clean, unpolluted and cheap source of energy, which can be obtained by a simple mechanism and little investment. The gas is generated from the cow dung during anaerobic decomposition. Biogas generation is a complex biochemical process. The celluloitic material is broken down to methane and carbondioxide by different groups of microorganisms. It can be used for cooking purpose, burning lamps, running pumps etc.
Selection of a model: The two main designs of biogas plants are the floating gas holder and fixed-dome types. The merits and demerits of each design need to be considered while selecting a model.

(i) Float dome type: Different models are available in this category e.g., KVIC vertical and horizontal, Pragati model, Ganesh model.

(ii) Fixed dome type: The gas plant is dome shaped underground construction. The masonry gasholder is an integral part of the digester called dome. The gas produced in the digester is collected in dome at vertical pressure by displacement of slurry in inlet and outlet. The entire construction is made of bricks and cement. The models available in this category are Janata and Deen-Bandhu.

The selection of a particular type depends on technical, climatological, geographical and economic factors prevailing in a given area.

Selection of Size: The size of the biogas plant is decided by the number of family members and the availability of dung. One cubic metre capacity plant will need two to three animals and 25 kg of dung. The gas produced will meet the requirement of a family of 4-6 members. It would suffice to have a 2 cubic metre plant to cater to the needs of a family of 6-10 members.

Site selection and management: The site should be close to the kitchen or the place of use. It will reduce the cost of gas distribution system. It should also be nearer to the cattle shed to reduce the cost of transport of cattle dung. Land should be leveled and slightly above the ground level to avoid inflow or run-off of water. Plant should get clear sunshine during most part of the day. Generation of dung has a direct bearing on the quantity of gas generated. The amount of gas production is considerably higher in summer followed by rainy and winter seasons. Gas production would be maximum at a temperature between 30 to 35 °C. If the ambient temperature falls below 10 °C gas production is reduced drastically.

Biogas slurry: Slurry is obtained after the production of bio-gas. It is enriched manure. Another positive aspect of this manure is that even after weeks of exposure to the atmosphere, the slurry does not attract fleas and worms.
**Mechanism of different production factors and their interaction**

**Factors of Production:** These are the various resources which contribute to generation of goods or services. They fall into four main groups – **land** (including all natural resources), **labour** (including all human resources), **capital** (including all man-made resources) and **Enterprise** (which brings all the previous resources together for production) or **entrepreneurship**. These factors are classified also as management, machines, materials, and money (this, the 4 Ms), or other such nomenclature. More recently, knowledge has come to be recognized as distinct from labour, and as a factor of production in its own right. In economics, factors of production mean inputs and finished goods mean output.

Input determines the quantity of output i.e. output depends upon input. Input is the starting point and output is the end point of production process and such input-output relationship is called a production function. All factors of production like land, labour, capital and entrepreneur are required in combination at a time to produce a commodity. In economics, production means creation or an addition of utility. Factors of production (or productive 'inputs' or 'resources') are any commodities or services used to produce goods and services.

The number and definition of factors varies, depending on theoretical purpose, empirical emphasis, or school of economics. 'Factors of production' may also refer specifically to the 'primary factors', which are stocks including land, labour (the ability to work), and capital goods applied to production. The primary factors facilitate production but neither become part of the product (as with raw materials) nor become significantly transformed by the production process (as with fuel used to power machinery). 'Land' includes not only the site of production but natural resources above or below the soil. The factor land may, however, for simplification purposes be merged with capital in some cases (due to land being of little importance in the service sector and manufacturing). Recent usage has distinguished human capital (the stock of knowledge in the labour force) from labour. Entrepreneurship is also sometimes considered a factor of production. Sometimes the overall state of technology is described as a factor of production.
**Historical schools and factors**

In the interpretation of the currently dominant view of classical economic theory developed by neoclassical economists, the term "factors" did not exist until after the classical period and is not to be found in any of the literature of that time.

Differences are most stark when it comes to deciding which factor is the most important. For example, in the Austrian view—often shared by neoclassical and other "free market" economists—the primary factor of production is the time of the entrepreneur, which, when combined with other factors, determines the amount of output of a particular good or service. However, other authors argue that "entrepreneurship" is nothing but a specific kind of labour or human capital and should not be treated separately. The Marxian school goes further, seeing labour (in general, including entrepreneurship) as the primary factor of production, since it is required to produce capital goods and to utilize the gifts of nature. But this debate is more about basic economic theory (the role of the factors in the economy) than it is about the definition of the factors of production.

**Physiocracy**

In French Physiocracy, the main European school of economics before Adam Smith, the productive process is explained as the interaction between participating classes of the population. These classes are therefore the factors of production within physiocracy: capital, entrepreneurship, land, and labour.

- *The farmer* labours on land (sometimes using "crafts") to produce
- *The landlord* is only a consumer of food and crafts and produces nothing at all.
- *The merchant* labours to export food in exchange for foreign imports.

**Classical**

The classical economics of Adam Smith, David Ricardo, and their followers focuses on physical resources in defining its factors of production, and discusses the distribution of cost and value
among these factors. Adam Smith and David Ricardo referred to the "component parts of price" as the costs of using:

- Land or natural resource — naturally-occurring goods such as water, air, soil, minerals, flora and fauna that are used in the creation of products. The payment for use and the received income of a land owner is rent.
- Labour — human effort used in production which also includes technical and marketing expertise. The payment for someone else's labour and all income received from ones own labour is wages. Labour can also be classified as the physical and mental contribution of an employee to the production of the good(s).
- The capital stock — human-made goods (or means of production), which are used in the production of other goods. These include machinery, tools, and buildings.

The classical economists also employed the word "capital" in reference to money. Money, however, was not considered to be a factor of production in the sense of capital stock since it is not used to directly produce any good. The return to loaned money or to loaned stock was styled as interest while the return to the actual proprietor of capital stock (tools, etc.) was styled as profit.

The Chapman Effect also known as diminished return, occurs when an employee is at fault for impeding the projected return of a company. Meaning that this employee distracts others, which causes output to decline (classical output function).

**Marxian**

Marx considered the "elementary factors of the labour-process" or "productive forces" to be:

- Labour ("work itself")
- The subject of labour (objects transformed by labour)
- The instruments of labour (or means of labour).

The "subject of labour" refers to natural resources and raw materials, including land. The "instruments of labour" are tools, in the broadest sense. They include factory buildings,
infrastructure, and other human-made objects that facilitate labour's production of goods and services.

This view seems similar to the classical perspective described above. But unlike the classical school and many economists today, Marx made a clear distinction between labour actually done and an individual's "labour power" or ability to work. Labour done is often referred to nowadays as "effort" or "labour services." Labour-power might be seen as a stock which can produce a flow of labour.

Labour, not labour power, is the key factor of production for Marx and the basis for Marx's labour theory of value. The hiring of labour power only results in the production of goods or services ("use-values") when organized and regulated (often by the "management"). How much labour is actually done depends on the importance of conflict or tensions within the labour process.

**Neoclassical economics**

Neoclassical economics, one of the branches of mainstream economics, started with the classical factors of production of land, labour, and capital. However, it developed an alternative theory of value and distribution. Many of its practitioners have added various further factors of production (see below).

**Further distinctions**

Further distinctions from classical and neoclassical microeconomics include the following:

- **Capital** — This has many meanings, including the financial capital raised to operate and expand a business. In much of economics, however, "capital" (without any qualification) means goods that can help produce other goods in the future, the result of investment. It refers to machines, roads, factories, schools, infrastructure, and office buildings which humans have produced in order to produce goods and services.

- **Fixed capital** — This includes machinery, factories, equipment, new technology, factories, buildings, computers, and other goods that are designed to increase the
productive potential of the economy for future years. Nowadays, many consider computer software to be a form of fixed capital and it is counted as such in the National Income and Product Accounts of the United States and other countries. This type of capital does not change due to the production of the good.

- **Working capital** — This includes the stocks of finished and semi-finished goods that will be economically consumed in the near future or will be made into a finished consumer good in the near future. These are often called inventories. The phrase "working capital" has also been used to refer to liquid assets (money) needed for immediate expenses linked to the production process (to pay salaries, invoices, taxes, interests...) Either way, the amount or nature of this type of capital usually changed during the production process.

- **Financial capital** — This is simply the amount of money the initiator of the business has invested in it. "Financial capital" often refers to his or her net worth tied up in the business (assets minus liabilities) but the phrase often includes money borrowed from others.

- **Technological progress** — For over a century, economists have known that capital and labour do not account for all of economic growth. This is reflected in total factor productivity and the Solow residual used in economic models called production functions that account for the contributions of capital and labour, yet have some unexplained contributor which is commonly called technological progress. Ayres and Warr (2009) present time series of the efficiency of primary energy (exergy) conversion into useful work for the US, UK, Austria and Japan revealing dramatic improvements in model accuracy. With useful work as a factor of production they are able to reproduce historical rates of economic growth with considerable precision and without recourse to exogenous and unexplained technological progress, thereby overcoming the major flaw of the Solow Theory of economic growth.

**A fourth factor?**

As mentioned, recent authors have added to the classical list. For example, J.B. Clark saw the co-ordinating function in production and distribution as being served by entrepreneurs; Frank Knight introduced managers who co-ordinate using their own money (financial capital) and the
financial capital of others. In contrast, many economists today consider "human capital" (skills and education) as the fourth factor of production, with entrepreneurship as a form of human capital. Yet others refer to intellectual capital. More recently, many have begun to see "social capital" as a factor, as contributing to production of goods and services.

**Entrepreneurship**

Consider entrepreneurship as a factor of production, leaving debate aside. In markets, entrepreneurs combine the other factors of production, land, labour, and capital in order to make a profit. Often these entrepreneurs are seen as innovators, developing new ways to produce and new products. In a planned economy, central planners decide how land, labour, and capital should be used to provide for maximum benefit for all citizens. Of course, just as with market entrepreneurs, the benefits may mostly accrue to the entrepreneurs themselves.

The word has been used in other ways. The sociologist C. Wright Mills refers to "new entrepreneurs" who work within and between corporate and government bureaucracies in new and different ways. Others (such as those practicing public choice theory) refer to "political entrepreneurs," i.e., politicians and other actors.

Much controversy rages about the benefits produced by entrepreneurship. But the real issue is about how well institutions they operate in (markets, planning, bureaucracies, government) serve the public. This concerns such issues as the relative importance of market failure and government failure.

**Non tangible forms of capital**

**Human capital**

Contemporary analysis distinguishes tangible, physical, or nonhuman capital goods from other forms of capital such as human capital. Human capital is embodied in a human being and is acquired through education and training, whether formal or on the job. Human capital is important in modern economic theory. Education is a key element in explaining economic growth over time (see growth accounting). It is also often seen as the solution to the "Leontief paradox" in international trade.
Intellectual capital

A more recent coinage is intellectual capital, used especially as to information technology, recorded music, written material. This intellectual property is protected by copyrights, patents, and trademarks.

This view posits a new Information Age, which changes the roles and nature of land, labour, and capital. During the Information Age (circa 1971–1991), the Knowledge Age (circa 1991 to 2002), and the Intangible Economy (2002–present) many see the primary factors of production as having become less concrete. These factors of production are now seen as knowledge, collaboration, process-engagement, and time quality.

According to economic theory, a "factor of production" is used to create value and allow economic performance. As the four "modern-day" factors are all essentially abstract, the current economic age has been called the Intangible Economy. Intangible factors of production are subject to network effects and the contrary economic laws such as the law of increasing returns.

Social capital

Social capital is often hard to define, but to one textbook - Microeconomics in Context - it is: the stock of trust, mutual understanding, shared values, and socially held knowledge that facilitates the social coordination of economic activity.

Knowledge, ideas, and values, and human relationships are transmitted as part of the culture. This type of capital cannot be owned by individuals and is instead part of the common stock owned by humanity. But they are often crucial to maintaining a peaceful society in which normal economic transactions and production can occur.

Another kind of social capital can be owned individually. This kind of individual asset involves reputation, what accountants call "goodwill", and/or what others call "street cred," along with fame, honor, and prestige. It fits with Pierre Bourdieu’s definition of "social capital" as: an attribute of an individual in a social context. One can acquire social capital through purposeful actions and can transform social capital into conventional economic gains. The ability to do so, however, depends on the nature of the social obligations, connections, and networks, available to you.

This means that the value of individual social assets that Bourdieu points to depend on the current "social capital" as defined above.
Natural resources
Ayres and Warr (2009) are among the economists who criticize orthodox economics for overlooking the role of natural resources and the effects of declining resource capital.

Energy
Energy can be seen as individual factor of production, with an elasticity larger than labour. A co-integration analysis support results derived from linear exponential (LINEX) production functions.

Production theory
Production theory is the study of production, or the economic process of converting inputs into outputs. Production uses resources to create a good or service, that is suitable for use, gift-giving in a gift economy, or exchange in a market economy. This can include manufacturing, storing, shipping, and packaging. Some economists define production broadly as all economic activity other than consumption. They see every commercial activity other than the final purchase as some form of production.

Production is a process, and as such it occurs through time and space. Because it is a flow concept, production is measured as a “rate of output per period of time”. There are three aspects to production processes:

1. the quantity of the good or service produced,
2. the form of the good or service created,
3. the temporal and spatial distribution of the good or service produced.

A production process can be defined as any activity that increases the similarity between the pattern of demand for goods and services, and the quantity, form, shape, size, length and distribution of these goods and services available to the market place.

Neoclassical Theory of Production
The inputs or resources used in the production process are called factors of production by economists. The myriad of possible inputs are usually grouped into five categories. These factors are: Raw materials, Machinery, Labour services, Capital goods and Land. In the “long run”, all of these factors of production can be adjusted by management. The “short run”, however, is defined as a period in which at least one of the factors of production is fixed. A fixed factor of production is one whose quantity cannot readily be changed. Examples include major pieces of equipment, suitable factory space, and key managerial personnel. A variable factor of production
is one whose usage rate can be changed easily. Examples include electrical power consumption, transportation services, and most raw material inputs. In the short run, a firm’s “scale of operations” determines the maximum number of outputs that can be produced. In the long run, there are no scale limitations.

**Total, average, and marginal product**

![Total Product Curve](image)

The total product (or total physical product) of a variable factor of production identifies what outputs are possible using various levels of the variable input. This can be displayed in either a chart that lists the output level corresponding to various levels of input, or a graph that summarizes the data into a “total product curve”. The diagram shows a typical total product curve. In this example, output increases as more inputs are employed up until point A. The maximum output possible with this production process is Qm. (If there are other inputs used in the process, they are assumed to be fixed.)

The average physical product is the total production divided by the number of units of variable input employed. It is the output of each unit of input. If there are 10 employees working on a production process that manufactures 50 units per day, then the average product of variable labour input is 5 units per day.
Average and Marginal Physical Product Curves
The average product typically varies as more of the input is employed, so this relationship can also be expressed as a chart or as a graph. A typical average physical product curve is shown (APP). It can be obtained by drawing a vector from the origin to various points on the total product curve and plotting the slopes of these vectors.

The marginal physical product of a variable input is the change in total output due to a one unit change in the variable input (called the discrete marginal product) or alternatively the rate of change in total output due to an infinitesimally small change in the variable input (called the continuous marginal product). The discrete marginal product of capital is the additional output resulting from the use of an additional unit of capital (assuming all other factors are fixed). The continuous marginal product of a variable input can be calculated as the derivative of quantity produced with respect to variable input employed. The marginal physical product curve is shown (MPP). It can be obtained from the slope of the total product curve.

Because the marginal product drives changes in the average product, we know that when the average physical product is falling, the marginal physical product must be less than the average. Likewise, when the average physical product is rising, it must be due to a marginal physical product greater than the average. For this reason, the marginal physical product curve must intersect the maximum point on the average physical product curve.

Notes: MPP keeps increasing until it reaches its maximum. Up until this point every additional unit has been adding more value to the total product than the previous one. From this point onwards, every additional unit adds less to the total product compared to the previous one – MPP is decreasing. But the average product is still increasing till MPP touches APP. At this point, an additional unit is adding the same value as the average product. From this point onwards, APP starts to reduce because every additional unit is adding less to APP than the average product. But
the total product is still increasing because every additional unit is still contributing positively. Therefore, during this period, both, the average as well as marginal products, are decreasing, but the total product is still increasing. Finally we reach a point when MPP crosses the x-axis. At this point every additional unit starts to diminish the product of previous units, possibly by getting into their way. Therefore the total product starts to decrease at this point. This is point A on the total product curve. (Courtesy: Dr. Shehzad Inayat Ali).

**Diminishing returns**

Diminishing returns can be divided into three categories: 1. **Diminishing Total returns**, which implies reduction in total product with every additional unit of input. This occurs after point A in the graph. 2. **Diminishing Average returns**, which refers to the portion of the APP curve after its intersection with MPP curve. 3. **Diminishing Marginal returns**, refers to the point where the MPP curve starts to slope down and travels all the way down to the x-axis and beyond. Putting it in a chronological order, at first the marginal returns start to diminish, then the average returns, followed finally by the total returns.

**Diminishing marginal returns**

These curves illustrate the principle of **diminishing marginal returns to a variable input** (not to be confused with diseconomies of scale which is a long term phenomenon in which all factors are allowed to change). This states that as you add more and more of a variable input, you will reach a point beyond which the resulting increase in output starts to diminish. This point is illustrated as the maximum point on the marginal physical product curve. It assumes that other factor inputs (if they are used in the process) are held constant. An example is the employment of labour in the use of trucks to transport goods. Assuming the number of available trucks (capital) is fixed, then the amount of the variable input labour could be varied and the resultant efficiency determined. At least one labourer (the driver) is necessary. Additional workers per vehicle could be productive in loading, unloading, navigation, or around the clock continuous driving. But at some point the returns to investment in labour will start to diminish and efficiency will decrease. The most efficient distribution of labour per piece of equipment will likely be one driver plus an additional worker for other tasks (2 workers per truck would be more efficient than 5 per truck).
Resource allocations and distributive efficiencies in the mix of capital and labour investment will vary per industry and according to available technology. Trains are able to transport much more in the way of goods with fewer "drivers" but at the cost of greater investment in infrastructure. With the advent of mass production of motorized vehicles, the economic niche occupied by trains (compared with transport trucks) has become more specialized and limited to long haul delivery.

P.S.: There is an argument that if the theory is holding everything constant, the production method should not be changed, i.e., division of labour should not be practiced. However, the rise in marginal product means that the workers use other means of production method, such as in loading, unloading, navigation, or around the clock continuous driving. For this reason, some economists think that the “keeping other things constant” should not be used in this theory.

**Many ways of expressing the production relationship**

The total, average, and marginal physical product curves mentioned above are just one way of showing production relationships. They express the quantity of output relative to the amount of variable input employed while holding fixed inputs constant. Because they depict a short run relationship, they are sometimes called short run production functions. If all inputs are allowed to be varied, then the diagram would express outputs relative to total inputs, and the function would be a long run production function. If the mix of inputs is held constant, then output would be expressed relative to inputs of a fixed composition, and the function would indicate long run economies of scale.

Rather than comparing inputs to outputs, it is also possible to assess the mix of inputs employed in production. An isoquant (see below) relates the quantities of one input to the quantities of another input. It indicates all possible combinations of inputs that are capable of producing a given level of output.

Rather than looking at the inputs used in production, it is possible to look at the mix of outputs that are possible for any given production process. This is done with a production possibilities frontier. It indicates what combinations of outputs are possible given the available factor endowment and the prevailing production technology.
Isoquants

An isoquant represents those combinations of inputs, which will be capable of producing an equal quantity of output; the producer would be indifferent between them. The isoquants are thus contour lines, which trace the loci of equal outputs. As the production remains the same on any point of this line, it is also called equal product curve. Let $Q_0 = f(L,K)$ be a production factor, where $Q_0 = A$ is a fixed level of production.

$L = \text{Length}$

$K = \text{Capital}$

If three combinations of labour and capital $A$, $B$ and $C$ produces 10 units of product, then the isoquant will be like Figure 1.

Here we see that the combination of $L_1$ labour and $K_3$ capital can produce 10 units of product, which is $A$ on the isoquant. Now to increase the labour keeping the production the same the organization has to decrease capital. In Figure 1 B is the point where capital decreases to $K_2$, consistent with the diagram.
while labour increases to L2. Similarly, 10 units of product may be produced at point C on the isoquant with capital K1 and labour L3. Each of the factor combinations A, B and C produces the same level of output, 10 units.

**The marginal rate of technical substitution**

*Marginal Rate of Technical Substitution*

Isoquants are typically convex to the origin reflecting the fact that the two factors are substitutable for each other at varying rates. This rate of substitutability is called the “marginal rate of technical substitution” (MRTS) or occasionally the “marginal rate of substitution in production”. It measures the reduction in one input per unit increase in the other input that is just sufficient to maintain a constant level of production. For example, the marginal rate of substitution of labour for capital gives the amount of capital that can be replaced by one unit of labour while keeping output unchanged.

To move from point A to point B in the diagram, the amount of capital is reduced from Ka to Kb while the amount of labour is increased only from La to Lb. To move from point C to point D, the amount of capital is reduced from Kc to Kd while the amount of labour is increased from Lc to Ld. The marginal rate of technical substitution of labour for capital is equivalent to the absolute slope of the isoquant at that point (change in capital divided by change in labour). It is equal to 0 where the isoquant becomes horizontal, and equal to infinity where it becomes vertical.
The opposite is true when going in the other direction (from D to C to B to A). In this case we are looking at the marginal rate of technical substitution capital for labour (which is the reciprocal of the marginal rate of technical substitution labour for capital).

It can also be shown that the marginal rate of substitution labour for capital, is equal to the marginal physical product of labour divided by the marginal physical product of capital.

In the unusual case of two inputs that are perfect substitutes for each other in production, the isoquant would be linear (linear in the sense of a function $Y = a - bx$). If, on the other hand, there is only one production process available, factor proportions would be fixed, and these zero-substitutability isoquants would be shown as horizontal or vertical lines.

**Productivity**

Productivity is a measure of the efficiency of production. Productivity is a ratio of production output to what is required to produce it (inputs). The measure of productivity is defined as a total output per one unit of a total input.

These definitions are short but too general and insufficient to make the phenomenon productivity understandable. A more detailed theory of productivity is needed, which explains the phenomenon productivity and makes it comprehensible. In order to obtain a measurable form of productivity, operationalization of the concept is necessary. In explaining and operationalizing a set of production models are used. A production model is a numerical expression of the production process that is based on production data, i.e. measured data in the form of prices and quantities of inputs and outputs.

It is most advisable to examine any phenomenon whatsoever only after defining the entity the phenomenon under review forms part of. Then it will be possible to analyse the phenomenon as part of such an entity. Hence, productivity cannot be examined as a phenomenon independently but it is necessary to identify the entity it belongs to. Such an entity is defined as production process. Productivity is a critical factor of production process in one way or another. To define the way is the object of this article.
The benefits of high productivity are manifold. At the national level, productivity growth raises living standards because more real income improves people’s ability to purchase goods and services, enjoy leisure, improve housing and education and contribute to social and environmental programs. Productivity growth is important to the firm because more real income means that the firm can meet its (perhaps growing) obligations to customers, suppliers, workers, shareholders, and governments (taxes and regulation), and still remain competitive or even improve its competitiveness in the market place.

**Characteristics of production**

Economic well-being is created in a production process. Production means, in a broad sense, all economic activities that aim directly or indirectly to satisfy human needs. The degree to which the needs are satisfied is often accepted as a measure of economic well-being.

The satisfaction of needs originates from the use of the commodities which are produced. The need satisfaction increases when the quality-price-ratio of the commodities improves and more satisfaction is achieved at less cost. Improving the quality-price-ratio of commodities is to a producer an essential way to enhance the production performance but this kind of gains distributed to customers cannot be measured with production data.

Economic well-being also increases due to the growth of incomes that are gained from the more efficient production. The most important forms of production are market production, public production and production in households. In order to understand the origin of the economic well-being we must understand these three processes. All of them have production functions of their own which interact with each other. Market production is the prime source of economic well-being and therefore the “primus motor” of the economy. Productivity is in this economic system the most important feature and an essential source of incomes.

**Main processes of a producing company**

A producing company can be divided into sub-processes in different ways; yet, the following five are identified as main processes, each with a logic, objectives, theory and key figures of its
own. It is important to examine each of them individually, yet, as a part of the whole, in order to be able to measure and understand them. The main processes of a company are as follows:

Main processes of a producing company (Saari 2006,3)

- real process
- income distribution process
- production process
- monetary process
- market value process

Productivity is created in the real process, productivity gains are distributed in the income distribution process and these two processes constitute the production process. The production process and its sub-processes, the real process and income distribution process occur simultaneously, and only the production process is identifiable and measurable by the traditional accounting practices. The real process and income distribution process can be identified and measured by extra calculation, and this is why they need to be analysed separately in order to understand the logic of production performance.
Real process generates the production output from input, and it can be described by means of the production function. It refers to a series of events in production in which production inputs of different quality and quantity are combined into products of different quality and quantity. Products can be physical goods, immaterial services and most often combinations of both. The characteristics created into the product by the manufacturer imply surplus value to the consumer, and on the basis of the price this value is shared by the consumer and the producer in the marketplace. This is the mechanism through which surplus value originates to the consumer and the producer likewise. It is worth noting that surplus values to customers cannot be measured from any production data. Instead the surplus value to a producer can be measured. It can be expressed both in terms of nominal and real values. The real surplus value to the producer is a result of the real process, real income, and measured proportionally it means productivity.

Income distribution process of the production refers to a series of events in which the unit prices of constant-quality products and inputs alter causing a change in income distribution among those participating in the exchange. The magnitude of the change in income distribution is directly proportionate to the change in prices of the output and inputs and to their quantities. Productivity gains are distributed, for example, to customers as lower product sales prices or to staff as higher income pay.

Davis has deliberated the phenomenon of productivity, measurement of productivity, distribution of productivity gains, and how to measure such gains. He refers to an article suggesting that the measurement of productivity shall be developed so that it “will indicate increases or decreases in the productivity of the company and also the distribution of the ‘fruits of production’ among all parties at interest”. According to Davis, the price system is a mechanism through which productivity gains are distributed, and besides the business enterprise, receiving parties may consist of its customers, staff and the suppliers of production inputs. In this article, the concept of “distribution of the fruits of production” by Davis is simply referred to as production income distribution or shorter still as distribution.

The production process consists of the real process and the income distribution process. A result and a criterion of success of the owner is profitability. The profitability of production is the share of the real process result the owner has been able to keep to himself in the income distribution process. Factors describing the production process are the components of profitability, i.e., returns and costs. They differ from the factors of the real process in that the components of
profitability are given at nominal prices whereas in the real process the factors are at periodically fixed prices.

Monetary process refers to events related to financing the business. Market value process refers to a series of events in which investors determine the market value of the company in the investment markets.

**Economic growth**

Economic growth is defined as a production increase of an output of a production process. It is usually expressed as a growth percentage depicting growth of the real production output. The real output is the real value of products produced in a production process and when we subtract the real input from the real output we get the real income. The real output and the real income are generated by the real process of production from the real inputs.

The real process can be described by means of the production function. The production function is a graphical or mathematical expression showing the relationship between the inputs used in production and the output achieved. Both graphical and mathematical expressions are presented and demonstrated. The production function is a simple description of the mechanism of economic growth. Real economic growth consists of two components. These components are an increase in production input and an increase in productivity.

Components of economic growth (Saari 2006,2)

The figure illustrates an economic growth process (exaggerated for clarity). The Value T2 (value at time 2) represents the growth in output from Value T1 (value at time 1). Each time of measurement has its own graph of the production function for that time (the straight lines). The output measured at time 2 is greater than the output measured at time one for both of the
components of growth: an increase of inputs and an increase of productivity. The portion of
growth caused by the increase in inputs is shown on line 1 and does not change the relation
between inputs and outputs. The portion of growth caused by an increase in productivity is
shown on line 2 with a steeper slope. So increased productivity represents greater output per unit
of input.

Production is a process of combining various material inputs and immaterial inputs (plans, know-
how) in order to make something for consumption (the output). The methods of combining the
inputs of production in the process of making output are called technology. Technology can be
depicted mathematically by the production function which describes the relation between input
and output. The production function can be used as a measure of relative performance when
comparing technologies.

In the case of a single production process (described above) the output is defined as an economic
value of products and services produced in the process. When we want to examine an entity of
many production processes we have to sum up the value-added created in the single processes.
This is done in order to avoid the double accounting of intermediate inputs. Value-added is
obtained by subtracting the intermediate inputs from the outputs. The most well-known and used
measure of value-added is the GDP (Gross Domestic Product). It is widely used as a measure of
the economic growth of nations and industries.

**Production performance**

Economic growth measures the growth of production output and, therefore, it is only a rough
indicator of economic welfare. It does not reveal anything about the performance of the
production process. The performance of production measures production’s ability to generate
income. Because the income from production is generated in the real process, we call it the real
income. Similarly, as the production function is an expression of the real process, we could also
call it “income generated by the production function”.

The real income generation follows the logic of the production function. Two components can
also be distinguished in the income change: the income growth caused by an increase in
production input (production volume) and the income growth caused by an increase in
productivity. The income growth caused by increased production volume is determined by
moving along the production function graph. The income growth corresponding to a shift of the
production function is generated by the increase in productivity. The change of real income so signifies a move from the point 1 to the point 2 on the production function (above). When we want to maximize the production performance we have to maximize the income generated by the production function.

The production performance can be measured as a relative or an absolute income. Expressing performance both in relative (rel.) and absolute (abs.) quantities is helpful for understanding the welfare effects of production. For measurement of the relative production performance, we use the known productivity ratio.

Average and marginal productivity (Saari 2011,8)

1) Real output / Real input.

The absolute income of performance is obtained by subtracting the real input from the real output as follows:

- Real income (abs.) = Real output – Real input

The growth of the real income is the increase of the economic value which can be distributed between the production stakeholders. With the aid of the production model we can perform the relative and absolute accounting in one calculation. Maximizing production performance requires using the absolute measure, i.e. the real income and its derivatives as a criterion of production performance.

The differences between the absolute and relative performance measures can be illustrated by the following graph showing marginal and average productivity. The figure is a traditional
expression of average productivity and marginal productivity. The maximum for production performance is achieved at the volume where marginal productivity is zero. The maximum for production performance is the maximum of the real incomes. In this illustrative example the maximum real income is achieved, when the production volume is 7.5. The maximum average productivity is reached when the production volume is 3.0. It is worth noting that the maximum average productivity is not the same as the maximum of real income.

Figure above is a somewhat exaggerated depiction because the whole production function is shown. In practice, decisions are made in a limited range of the production functions, but the principle is still the same; the maximum real income is aimed for. An important conclusion can be drawn. When we try to maximize the welfare effects of production we have to maximize real income formation. Maximizing productivity leads to a suboptimum. Maximizing productivity also leads to the phenomenon called "jobless growth" This refers to economic growth as a result of productivity growth but without creation of new jobs.

A practical example illustrates the case. When a jobless person obtains a job in market production we may assume it is a low productivity job. As a result average productivity decreases but the real income per capita increases. Furthermore the well-being of the society also grows. This example reveals the difficulty to interpret the total productivity change correctly. The combination of volume increase and total productivity decrease leads in this case to the improved performance because we are on the “diminishing returns” area of the production function. If we are on the part of “increasing returns” on the production function, the combination of production volume increase and total productivity increase leads to improved production performance. Unfortunately we do not know in practice on which part of the production function we are. Therefore a correct interpretation of a performance change is obtained only by measuring the real income change.

**Production models**

A production model is a numerical description of the production process and is based on the prices and the quantities of inputs and outputs. There are two main approaches to operationalize the concept productivity. We can use mathematical formulae, which are typically used in macroeconomics (in growth accounting) or arithmetical models, which are typically used in
microeconomics and management accounting. We do not present the former approach here but refer to the survey “Growth accounting” by Hulten 2009.

We use here arithmetical models because they are like the models of management accounting, illustrative and easily understood and applied in practice. Furthermore they are integrated to management accounting, which is a practical advantage. A major advantage of the arithmetical model is its capability to depict productivity as a part of production process. Consequently productivity can be understood, measured, and examined as a part of production process.

There are different production models according to different interests. Here we use a production income model, a productivity model and a growth accounting model in order to demonstrate productivity as a phenomenon and a measurable quantity.

**Production income model**

<table>
<thead>
<tr>
<th></th>
<th>Period 1</th>
<th></th>
<th>Period 2</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Quantity</td>
<td>Price</td>
<td>Value</td>
<td>Quantity</td>
</tr>
<tr>
<td>Product 1</td>
<td>210.00</td>
<td>7.20</td>
<td>1512.00</td>
<td>247.25</td>
</tr>
<tr>
<td>Product 2</td>
<td>200.00</td>
<td>7.00</td>
<td>1400.00</td>
<td>195.03</td>
</tr>
<tr>
<td>Output</td>
<td>2912</td>
<td></td>
<td></td>
<td>3150</td>
</tr>
<tr>
<td>Labour</td>
<td>100.00</td>
<td>7.50</td>
<td>750.00</td>
<td>115.00</td>
</tr>
<tr>
<td>Materials</td>
<td>80.00</td>
<td>8.60</td>
<td>688.00</td>
<td>79.20</td>
</tr>
<tr>
<td>Energy</td>
<td>400.00</td>
<td>1.50</td>
<td>600.00</td>
<td>428.00</td>
</tr>
<tr>
<td>Capital</td>
<td>160.00</td>
<td>3.80</td>
<td>608.00</td>
<td>164.80</td>
</tr>
<tr>
<td>Input</td>
<td></td>
<td></td>
<td>2646</td>
<td></td>
</tr>
<tr>
<td>Surplus value</td>
<td>265.00</td>
<td></td>
<td></td>
<td>265.12</td>
</tr>
<tr>
<td>Surplus value</td>
<td>1.101</td>
<td></td>
<td></td>
<td>1.100</td>
</tr>
</tbody>
</table>

Profitability of production measured by surplus value (Saari 2006,3)

The scale of success run by a going concern is manifold, and there are no criteria that might be universally applicable to success. Nevertheless, there is one criterion by which we can generalise the rate of success in production. This criterion is the ability to produce surplus value. As a criterion of profitability, surplus value refers to the difference between returns and costs, taking into consideration the costs of equity in addition to the costs included in the profit and loss statement as usual. Surplus value indicates that the output has more value than the sacrifice made for it, in other words, the output value is higher than the value (production costs) of the used inputs. If the surplus value is positive, the owner’s profit expectation has been surpassed.
The table presents a surplus value calculation. We call this set of production data a basic example and we use the data through the article in illustrative production models. The basic example is a simplified profitability calculation used for illustration and modelling. Even as reduced, it comprises all phenomena of a real measuring situation and most importantly the change in the output-input mix between two periods. Hence, the basic example works as an illustrative “scale model” of production without any features of a real measuring situation being lost. In practice, there may be hundreds of products and inputs but the logic of measuring does not differ from that presented in the basic example.

In this context we define the quality requirements for the production data used in productivity accounting. The most important criterion of good measurement is the homogenous quality of the measurement object. If the object is not homogenous, then the measurement result may include changes in both quantity and quality but their respective shares will remain unclear. In productivity accounting this criterion requires that every item of output and input must appear in accounting as being homogenous. In other words the inputs and the outputs are not allowed to be aggregated in measuring and accounting. If they are aggregated, they are no longer homogenous and hence the measurement results may be biased.

Both the absolute and relative surplus value have been calculated in the example. Absolute value is the difference of the output and input values and the relative value is their relation, respectively. The surplus value calculation in the example is at a nominal price, calculated at the market price of each period.

**Productivity model**
Productivity model (Saari 2006,4)
The next step is to describe a productivity model by help of which it is possible to calculate the results of the real process, income distribution process and production process. The starting point is a profitability calculation using surplus value as a criterion of profitability. The surplus value calculation is the only valid measure for understanding the connection between profitability and productivity or understanding the connection between real process and production process. A valid measurement of total productivity necessitates considering all production inputs, and the surplus value calculation is the only calculation to conform to the requirement. If we omit an input in productivity accounting, this means that the omitted input can be used unlimitedly in production without any impact on accounting results.

The process of calculating is best understood by applying the term *ceteris paribus*, i.e. "all other things being the same," stating that at a time only the impact of one changing factor be introduced to the phenomenon being examined. Therefore, the calculation can be presented as a
process advancing step by step. First, the impacts of the income distribution process are calculated, and then, the impacts of the real process on the profitability of the production.

The first step of the calculation is to separate the impacts of the real process and the income distribution process, respectively, from the change in profitability (285.12 – 266.00 = 19.12). This takes place by simply creating one auxiliary column (4) in which a surplus value calculation is compiled using the quantities of Period 1 and the prices of Period 2. In the resulting profitability calculation, Columns 3 and 4 depict the impact of a change in income distribution process on the profitability and in Columns 4 and 7 the impact of a change in real process on the profitability.

The accounting results are easily interpreted and understood. We see that the real income has increased by 58.12 units from which 41.12 units come from the increase of productivity growth and the rest 17.00 units come from the production volume growth. The total increase of real income (58.12) is distributed to the stakeholders of production, in this case 39.00 units to the customers and to the suppliers of inputs and the rest 19.12 units to the owners. Here we can make an important conclusion. The income change created in a real process is always distributed to the stakeholders as economic values within the review period. Accordingly the changes in real income and income distribution are always equal in terms of economic value.

This model demonstration reveals the fundamental character of the phenomenon total productivity. Total productivity is that part of real income change which is caused by the shift of the production function. Accordingly any productivity measure is valid only when it indicates correctly enough this kind of income change.

Another productivity model (Saari 2011, 14) also gives details of the income distribution. Because the accounting techniques of the two models are different, they give differing, although complementary, analytical information. The accounting results are, however, identical. We do not present the model here in detail but we only use its detailed data on income distribution, when the objective functions are formulated in the next section.

**Growth accounting model**

Growth accounting model is used in economics to account the contribution of different factors of production to economic growth. The idea of growth accounting is to decompose the growth rate of economy's total output into that which is due to increases in the amount of inputs used and
that which cannot be accounted for by observable changes in input utilization. The unexplained part of growth is then taken to represent increases in productivity.

The growth accounting model is normally expressed in the form of the exponential growth function. It can also be expressed in the form of the arithmetical model, which way is used here because it is more descriptive and understandable. The principle of the accounting model is simple. The weighted growth rates of inputs (factors of production) are subtracted from the weighted growth rates of outputs. Because the accounting result is obtained by subtracting it is often called a “residual”. The residual is often defined as the growth rate of output not explained by the share-weighted growth rates of the inputs (Hulten 2009, 6).

We can use the real process data of the productivity model (above) in order to show the logic of the growth accounting model and identify possible differences in relation to the productivity model. When the production data is the same in the model comparison the differences in the accounting results are only due to accounting models. We get the following growth accounting from the production data.

![Growth accounting model](https://via.placeholder.com/150)

Growth accounting model (Saari 2012)

The growth accounting procedure proceeds as follows. First is calculated the growth rates for the output and the inputs by dividing the Period 2 numbers with the Period 1 numbers. Then the weights of inputs are computed as input shares of the total input (Period 1). Weighted growth rates (WG) are obtained by weighting growth rates with the weights. The accounting result is obtained by subtracting the weighted growth rates of the inputs from the growth rate of the output. In this case the accounting result is 0.015 which implies a productivity growth by 1.5%.

We note that the productivity model reports a 1.4% productivity growth from the same production data. The difference (1.4% versus 1.5%) is caused by the different production volume used in the models. In the productivity model the input volume is used as a production volume
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measure giving the growth rate 1.063. In this case productivity is defined as follows: output volume per one unit of input volume. In the growth accounting model the output volume is used as a production volume measure giving the growth rate 1.078. In this case productivity is defined as follows: input consumption per one unit of output volume. The case can be verified easily with the aid of productivity model using output as a production volume.

The accounting result of the growth accounting model is expressed as an index number, in this example 1.015, which depicts the average productivity change. As demonstrated above we cannot draw correct conclusions based on average productivity numbers. This is due to the fact that productivity is accounted as an independent variable separated from the entity it belongs to, i.e. real income formation. Hence, if we compare in a practical situation two accounting results of the same production process we do not know which one is better in terms of production performance.

This kind of mistake of wrong analysis level has been recognized and described long ago (Vygotsky 1934). Vygotsky cautions against the risk of separating the issue under review from the total environment, the entity of which the issue is an essential part. By studying only this isolated issue we are likely to end up with incorrect conclusions. A practical example illustrates this warning. Let us assume we are studying the properties of water in putting out a fire. If we focus the review on small components of the whole, in this case the elements oxygen and hydrogen, we come to the conclusion that hydrogen is an explosive gas and oxygen is a catalyst in combustion. Therefore, their compound water could be explosive and unsuitable for putting out a fire. This incorrect conclusion arises from the fact that the components have been separated from the entity. (Saari 2011, 10)

Growth accounting based productivity models were introduced in the 1980s (Loggerenberg van, 1982, Bechler, 1984) to be used in management accounting but they did not gain on as management tools.

**Analyses**

The production models used here are illustrative tools because they show explicitly how the accounting results are computed from the production data. Clarity and understanding can be
increased with additional summaries, analyses and objective function formulations. Some typical cases are presented below.

**Objective functions**

An efficient way to improve the understanding of production performance is to formulate different objective functions according to the objectives of the different interest groups. Formulating the objective function necessitates defining the variable to be maximized (or minimized). After that other variables are considered as constraints. The most familiar objective function is profit maximization which is also included in this case. Profit maximization is an objective function that stems from the owner’s interest and all other variables are constraints in relation to maximizing of profits.

<table>
<thead>
<tr>
<th>INCOME FORMATION - changes between two periods</th>
</tr>
</thead>
<tbody>
<tr>
<td>Income generation</td>
</tr>
<tr>
<td>+/- Productivity:</td>
</tr>
<tr>
<td>+41.12</td>
</tr>
<tr>
<td>+/- Volume</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Real income: +58.12</td>
</tr>
<tr>
<td>TOTAL GENERATION:</td>
</tr>
</tbody>
</table>

Summary of objective function formulations (Saari 2011,17)

The procedure for formulating different objective functions, in terms of the production model, is introduced next. In the income formation from production the following objective functions can be identified:

- Maximizing the real income
- Maximizing the producer income
- Maximizing the owner income.

These cases are illustrated using the numbers from the basic example. The following symbols are used in the presentation: = signifies the starting point of the computation or the result of computing and + / - signifies a variable that is to be added or subtracted from the function. A producer means here the producer community, i.e. labour force, society and owners.

Objective function formulations can be expressed in a single calculation which concisely illustrates the logic of the income generation, the income distribution and the variables to be maximized.
The calculation resembles an income statement starting with the income generation and ending with the income distribution. The income generation and the distribution are always in balance so that their amounts are equal. In this case it is 58.12 units. The income which has been generated in the real process is distributed to the stakeholders during the same period. There are three variables which can be maximized. They are the real income, the producer income and the owner income. Producer income and owner income are practical quantities because they are addable quantities and they can be computed quite easily. Real income is normally not an addable quantity and in many cases it is difficult to calculate.

Here we have to add that the change of real income can also be computed from the changes in income distribution. We have to identify the unit price changes of outputs and inputs and calculate their profit impacts (i.e. unit price change x quantity). The change of real income is the sum of these profit impacts and the change of owner income. This approach is called the dual approach because the framework is seen in terms of prices instead of quantities (ONS 3, 23).

The dual approach has been recognized in growth accounting for long but its interpretation has remained unclear. The following question has remained unanswered: “Quantity based estimates of the residual are interpreted as a shift in the production function, but what is the interpretation of the price-based growth estimates?” (Hulten 2009, 18). We have demonstrated above that the real income change is achieved by quantitative changes in production and the income distribution change to the stakeholders is its dual. In this case the duality means that the same accounting result is obtained by accounting the change of the total income generation (real income) and by accounting the change of the total income distribution.

**Illustration of the real and income distribution processes**
Variables of production performance (Saari 2006,5)
Measurement results can be illustrated by models and graphic presentations. The following figure illustrates the connections between the processes by means of indexes describing the change. A presentation by means of an index is illustrative because the magnitudes of the changes are commensurate. Figures are from the above calculation example of the production model. (Loggerenberg van et al. 1982,90. Saari 2006,5).

The nine most central key figures depicting changes in production performance can be presented as shown in Figure. Vertical lines depict the key figures of the real process, production process and income distribution process. Key figures in the production process are a result of the real process and the income distribution process. Horizontal lines show the changes in input and output processes and their impact on profitability. The logic behind the figure is simple. Squares in the corners refer to initial calculation data. Profitability figures are obtained by dividing the output figures by the input figures in each process. After this, the production process figures are obtained by multiplying the figures of the real and income distribution process.

**Depicting the development by time series**

![Graph](https://via.placeholder.com/150)

Productivity and income distribution development (Saari 2006,5)
Development in the real process, income distribution process and production process can be illustrated by means of time series. (Kendrick 1984,64. Saari 2006,5) The principle of a time series is to describe, for example, the profitability of production annually by means of a relative surplus value and also to explain how profitability was produced as a consequence of
productivity development and income distribution. A time series can be composed using the chain indexes as seen in the following.

Now the intention is to draw up the time series for the ten periods in order to express the annual profitability of production by help of productivity and income distribution development. With the time series it is possible to prove that productivity of the real process is the distributable result of production, and profitability is the share remaining in the company after income distribution between the company and interested parties participating in the exchange.

The graph shows how profitability depends on the development of productivity and income distribution. Productivity figures are fictional but in practice they are perfectly feasible indicating an annual growth of 1.5 per cent on average. Growth potentials in productivity vary greatly by industry, and as a whole, they are directly proportionate to the technical development in the branch. Fast-developing industries attain stronger growth in productivity. This is a traditional way of thinking. Today we understand that human and social capitals together with competition have a significant impact on productivity growth.

In any case, productivity grows in small steps. We cannot trace these small improvements correctly with the relative measure (output/input) but we have to use the absolute measure real income and its derivatives. By the accurate measurement of real income and its derivatives, it is possible to appreciate these small changes and create an organisation culture where continuous improvement is a common value.

**National productivity**

In order to measure productivity of a nation or an industry, it is necessary to operationalize the same concept of productivity as in a production unit or a company, yet, the object of modelling is substantially wider and the information more aggregate. The calculations of productivity of a nation or an industry are based on the time series of the SNA, System of National Accounts. National accounting is a system based on the recommendations of the UN (SNA 93) to measure total production and total income of a nation and how they are used. (Saari 2006, 9)

Productivity is considered a key source of economic growth and competitiveness and, as such, is basic statistical information for many international comparisons and country performance assessments. There are different measures of productivity and the choice between them depends either on the purpose of the productivity measurement and/or data availability. One of the most
widely used measures of productivity is Gross Domestic Product (GDP) per hour worked. (OECD 2008,11)

Another productivity measure is so called multi factor productivity (MFP) also known as total factor productivity (TFP). It measures the residual growth that cannot be explained by the rate of change in the services of labour, capital and intermediate outputs, and is often interpreted as the contribution to economic growth made by factors such as technical and organisational innovation. (OECD 2008,11)

Productivity measures are key indicators of economic performance and there is strong interest in comparing them internationally. The OECD publishes an annual Compendium of Productivity Indicators that includes both labour and multi-factor measures of productivity. Several statistical offices publish productivity accounting handbooks and manuals with detailed accounting instructions and definitions. For example the following:

- Measuring Productivity - OECD Manual
- Office for National Statistics (UK) Productivity handbook
- Bureau of Labour Statistics, Productivity Statistics (U.S.)

**Labour productivity**

![Productivity in the OECD 2017](image)

Comparison of average labour productivity levels between the OECD member states. Productivity is measured as GDP per hour worked. Blue bars = higher than OECD-average productivity. Yellow bars = lower than average.
OECD’s definition

Labour productivity is a revealing indicator of several economic indicators as it offers a dynamic measure of economic growth, competitiveness, and living standards within an economy. It is the measure of labour productivity (and all that this measure takes into account) which helps explain the principal economic foundations that are necessary for both economic growth and social development. (Freeman 2008,5)

Although the ratio used to calculate labour productivity provides a measure of the efficiency with which inputs are used in an economy to produce goods and services, it can be measured in various ways. Labour productivity is equal to the ratio between a volume measure of output (gross domestic product or gross value added) and a measure of input use (the total number of hours worked or total employment). (Freeman 2008,5)

- labour productivity = volume measure of output / measure of input use

The volume measure of output reflects the goods and services produced by the workforce. Numerator of the ratio of labour productivity, the volume measure of output is measured either by gross domestic product (GDP) or gross value added (GVA). Although these two different measures can both be used as output measures, there is normally a strong correlation between the two. (Freeman 2008,5)

The measure of input use reflects the time, effort and skills of the workforce. Denominator of the ratio of labour productivity, the input measure is the most important factor that influences the measure of labour productivity. Labour input is measured either by the total number of hours worked of all persons employed or total employment (head count). (Freeman 2008,5)

There are both advantages and disadvantages associated with the different input measures that are used in the calculation of labour productivity. It is generally accepted that the total number of hours worked is the most appropriate measure of labour input because a simple headcount of employed persons can hide changes in average hours worked, caused by the evolution of part-time work or the effect of variations in overtime, absence from work or shifts in normal hours. However, the quality of hours-worked estimates is not always clear. In particular, statistical establishment and household surveys are difficult to use because of their varying quality or hours-worked estimates and their varying degree or international comparability. (Freeman 2008,5)
In contrast, total employment is easier to measure than the total number of hours worked. However, total employment is less recommended as a measure of labour productivity because it neither reflects changes in the average work time per employee nor changes in multiple job holdings and the role of self-employed persons (nor in the quality of labour). (Freeman 2008, 5)

**Validity**

Validity is a characteristic of the measure which is used in measuring. Validity implies how exact information the used measure can generate from the phenomenon. We need to understand the phenomenon, the measure and the possible difference between them. Often when we aim at simplicity and understandability in measuring, we have to lower the requirements for validity. For this reason it is important to evaluate the validity of the measurements used, case by case. Good measuring presupposes that those responsible for measuring are familiar with the validity of the measurements and also keep users informed of the validity.

The Gross Domestic Product (GDP) is a technical quantity of national accounts that measures the value-added generated by a nation (or other economic entity). Value added is equivalent to output less outside purchases (of materials and services). According to OECD, Gross Domestic Product per capita measures economic activity or income per person and is one of the core indicators of economic performance. GDP per capita is a rough measure of average living standards or economic well-being. (OECD 2008, 14)

GDP is, for this purpose, only a very rough measure. Maximizing GDP, in principal, also allows maximizing capital usage. For this reason GDP is systematically biased in favour of capital intensive production at the expense of knowledge and labour intensive production. The use of capital in the GDP-measure is considered to be as valuable as the production’s ability to pay taxes, profits and labour compensation. The bias of the GDP is actually the difference between the GDP and the producer income. (Saari 2011, 10, 16)

Another labour productivity measure output per worker is often seen as a proper measure of labour productivity like here “Productivity isn't everything, but in the long run it is almost everything. A country's ability to improve its standard of living over time depends almost entirely on its ability to raise its output per worker”. This measure (output per worker) is, however, more problematic than the GDP or even invalid because this measure allows maximizing all supplied inputs, i.e. materials, services, energy and capital at the expense of producer income.
Multifactor productivity

The multifactor productivity model is an application of the growth accounting model depicted above. Multifactor productivity is the ratio of the real value of output to the combined input of labour and capital. Multi-factor productivity (MFP) is also known as total factor productivity (TFP) and it measures the residual growth that cannot be explained by the rate of change in the services of labour, capital and intermediate outputs, and is often interpreted as the contribution to economic growth made by factors such as technical and organisational innovation. (OECD 2008,11). Historically there is a correlation of TFP with energy conversion efficiency.

Multifactor productivity (MFP) is the name given to the Solow residual in the BLS productivity program, replacing the term “total factor productivity” (TFP) used in the earlier literature, and both terms continue in use (usually interchangeably) (Hulten 2009,7). The MFP measure can be compactly introduced with an accounting procedure in the following calculation.

We can use the fixed price values of the real process in the productivity model above to show the accounting procedure. Fixed price values of the real process depict commensurate volumes of the outputs and inputs. When we subtract from the output so called intermediate inputs we obtain the value-added. Value-added is used as an output in MFP measure. The principle is to compare the growth of the value-added to the growth of labour and capital input. The formula of the MFP growth is as follows (Schreyer 2005,7):
change of MFP = change of output (1.119)
minus change of labour input x cost share of labour (1.150 x 0.475 = 0.546)
minus change of capital input x cost share of capital (1.030 x 0.525 = 0.541)

As an accounting result the MFP growth is 1.119-0.546-0.541=0.032 or 3.2 \%.

It is somewhat unclear what phenomenon is measured with this measure. According to the
definition above “MFP is often interpreted as the contribution to economic growth made by
factors such as technical and organisational innovation” (OECD 2008,11). The most famous
description is that of Solow’s (1957): 'I am using the phrase 'technical change’ as a shorthand
expression for any kind of shift in the production function. Thus slowdowns, speed ups,
 improvements in the education of the labour force and all sorts of things will appear as 'technical
change' ‘. Yet another opinion: In practice, TFP is a measure of our ignorance, as Abramovitz
(1956) put it, precisely because it is a residual. This ignorance covers many components, some
wanted (like the effects of technical and organizational innovation), others unwanted
(measurement error, omitted variables, aggregation bias, model misspecification) (Hulten
2000,11).

The original MFP model (Solow 1957) involves several assumptions: that there is a stable
functional relation between inputs and output at the economy-wide level of aggregation, that this
function has neoclassical smoothness and curvature properties, that inputs are paid the value of
their marginal product, that the function exhibits constant returns to scale, and that technical
change has the Hicks’n neutral form (Hulten, 2009,5). However no instructions have been given
how these assumptions should be taken into account in practical situations when the accounting
results are interpreted.

Validity

In order to evaluate validity of any measure we need to understand the phenomenon, the measure
and the possible difference between them. In the case of MFP we cannot make this evaulation in a
traditional way because the phenomenon intended to measure is somewhat unclear. Instead we
can identify the differences between MFP model and total productivity model. As seen from the
accounting results the MFP model and the total productivity model report differing accounting
results from the same production data. MFP-model reports a productivity change of 3.2\% which
is more than double compared to the result of the total productivity model, the change of 1.4\%. 

The difference between the models can be explained with the modifications made to the MFP model.
In the MFP model the Value Added (Output – Intermediate Inputs) is used as an output instead of Total Output. Value added is also used as a measure of production volume instead of input volume. As a result of these modifications production volume change in the MFP model is 1.119 instead of 1.078 in the total productivity model.
The real income (227.00 units) which is the measure of production performance is totally eliminated in the MFP model. Actually real income is replaced in the MFP model with the capital usage by making the following assumption: \( \text{Real income} = \text{Capital usage} \). The reason of this modification is not known nor argued but for sure it will weaken the validity of the measure. It is clear that due to these modifications the models report differing accounting results from the same production data.

**Importance of national productivity growth**

Productivity growth is a crucial source of growth in living standards. Productivity growth means more value is added in production and this means more income is available to be distributed.

At a firm or industry level, the benefits of productivity growth can be distributed in a number of different ways:

- to the workforce through better wages and conditions;
- to shareholders and superannuation funds through increased profits and dividend distributions;
- to customers through lower prices;
- to the environment through more stringent environmental protection; and
- to governments through increases in tax payments (which can be used to fund social and environmental programs).

Productivity growth is important to the firm because it means that it can meet its (perhaps growing) obligations to workers, shareholders, and governments (taxes and regulation), and still remain competitive or even improve its competitiveness in the market place.

There are essentially two ways to promote growth in output:

- bring additional inputs into production; or
- increase productivity.
Adding more inputs will not increase the income earned per unit of input (unless there are increasing returns to scale). In fact, it is likely to mean lower average wages and lower rates of profit.

But, when there is productivity growth, even the existing commitment of resources generates more output and income. Income generated per unit of input increases. Additional resources are also attracted into production and can be profitably employed.

At the national level, productivity growth raises living standards because more real income improves people's ability to purchase goods and services (whether they are necessities or luxuries), enjoy leisure, improve housing and education and contribute to social and environmental programs. Over long periods of time, small differences in rates of productivity growth compound, like interest in a bank account, and can make an enormous difference to a society's prosperity. Nothing contributes more to reduction of poverty, to increases in leisure, and to the country's ability to finance education, public health, environment and the arts'.

**Sources of productivity growth**

The most famous description of the productivity sources is that of Solow’s (1957): "I am using the phrase 'technical change' as a shorthand expression for any kind of shift in the production function. Thus slowdowns, speed ups, improvements in the education of the labour force and all sorts of things will appear as 'technical change' " Since then more specific descriptions of productivity sources have emerged referring to investment, innovations, skills, enterprise and competition (ONS 3, 20).

**Drivers of productivity growth**

There is a general understanding of the main determinants – or “drivers” – of productivity growth. Certain factors are critical for determining productivity growth. The Office for National Statistics (UK) identifies five drivers that interact to underlie long-term productivity performance: investment, innovation, skills, enterprise and competition. (ONS 3, 20)

*Investment* is in physical capital - machinery, equipment and buildings. The more capital workers have at their disposal, generally the better they are able to do their jobs, producing more and better quality output.

*Innovation* is the successful exploitation of new ideas. New ideas can take the form of new technologies, new products or new corporate structures and ways of working. Such innovations
can boost productivity, for example as better equipment works faster and more efficiently, or better organisation increases motivation at work.  

*Skills* are defined as the quantity and quality of labour of different types available in an economy. Skills complement physical capital, and are needed to take advantage of investment in new technologies and organisational structures.

*Enterprise* is defined as the seizing of new business opportunities by both start-ups and existing firms. New enterprises compete with existing firms by new ideas and technologies increasing competition. Entrepreneurs are able to combine factors of production and new technologies forcing existing firms to adapt or exit the market.

*Competition* improves productivity by creating incentives to innovate and ensures that resources are allocated to the most efficient firms. It also forces existing firms to organize work more effectively through imitations of organizational structures and technology.

**Productivity improving technologies**

In the most immediate sense, productivity is determined by:

- the available technology or know-how for converting resources into outputs desired in an economy; and
- the way in which resources are organized in firms and industries to produce goods and services.

Average productivity can improve as firms move toward the best available technology; plants and firms with poor productivity performance cease operation; and as new technologies become available. Firms can change organizational structures (e.g. core functions and supplier relationships), management systems and work arrangements to take the best advantage of new technologies and changing market opportunities. A nation's average productivity level can also be affected by the movement of resources from low-productivity to high-productivity industries and activities.

With increase pressure from the international or National productivity growth stems from a complex interaction of factors. As just outlined, some of the most important immediate factors include technological change, organizational change, industry restructuring and resource reallocation, as well as economies of scale and scope. Over time, other factors such as research and development and innovative effort, the development of human capital through education,
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and incentives from stronger competition promote the search for productivity improvements and the ability to achieve them. Ultimately, many policy, institutional and cultural factors determine a nation's success in improving productivity.

**Productivity in practice**

Productivity is one of the main concerns of business management and engineering. Practically all companies have established procedures for collecting, analyzing and reporting the necessary data. Typically the accounting department has overall responsibility for collecting and organizing and storing the data, but some data normally originates in the various departments.

**Productivity paradox**

Despite the proliferation of computers, productivity growth was relatively slow from the 1970s through the early 1990s. Although several possible cause for the slowdown have been proposed there is no consensus. The matter is subject to a continuing debate that has grown beyond questioning whether just computers can significantly increase productivity to whether the potential to increase productivity is becoming exhausted.

**Partial productivity**

Measurement of partial productivity refers to the measurement solutions which do not meet the requirements of total productivity measurement, yet, being practicable as indicators of total productivity. In practice, measurement in production means measures of partial productivity. In that case, the objects of measurement are components of total productivity, and interpreted correctly, these components are indicative of productivity development. The term of partial productivity illustrates well the fact that total productivity is only measured partially – or approximately. In a way, measurements are defective but, by understanding the logic of total productivity, it is possible to interpret correctly the results of partial productivity and to benefit from them in practical situations.
Stability in Farming Systems

Farmers with limited production resources want to be as sure as possible that their investment of those resources will payoff in substantial production increases. When agricultural development specialists urge a farmer to adopt a particular crop on the basis of its performance in past trials in similar environments, the farmer must decide whether the predicted performance of the crop on his land is worth the risk of a deviation from its past performance. He wants to know how stable the crop is in living up to its promise. The stability, or predictability, of a cropping system and its various components is of the utmost importance to the farmer faced with a decision whether to adopt a new technology, and this factor must therefore be considered by those who design new farming systems.

Stability is inseparable from risk, a familiar economic concept that figures largely in farmers' decisions. The total risk in any proposed innovation is an aggregate of several factors that can be analyzed and dealt with individually. Each is an element of uncertainty, instability, or unpredictability in some aspect of the production system. As farming systems are designed, it is important that stability be built into each element. Factors that will increase the farmer's risk-and thus make the entire system less acceptable to him-must be identified in the planning stage and corrected as much as possible to produce a stable system.

There are various sources of stability in farming systems.

**Biological stability**

The biological stability of a crop-plant or animal-is the measure of its ability to deliver a predictable yield under given environmental and management conditions. A crop with a high degree of biological stability will maintain its expected productivity despite fluctuations in weather conditions and disease and pest incidences.

In the humid tropics, where rainfall is plentiful but erratic, most animal enterprises and tree crops have greater biological stability than annual crops because trees and animals are less affected by short-term weather fluctuations and less susceptible to pests and diseases. In the same environment, a crop like onion has low biological stability because it is very sensitive to water supply. Lowland paddy rice is much more biologically stable than upland rice.
The biological stability of a crop can be increased by breeding and selection to improve such inherent qualities as drought tolerance and resistance to pests and diseases. The new tropical varieties of wheat, rice, and maize have inbred resistance to a broad spectrum of insects and diseases; many also have a genetic tolerance for drought and adverse soil conditions. The deepwater dwarf varieties of rice from Thailand, which elongate their stems rapidly in response to increased water depth, are an excellent example of genetic adaptations that increase the biological stability of a crop for use under uncertain environmental conditions.

The biological stability of a crop can also be increased by proper management. The choice of the optimum time for planting, the proper use of fertilizers, adequate field drainage, and other management practices can markedly improve the predictability of crop performance. Biological stability can also be affected by the diversity of crops. In areas where farmers plant patchworks of different crops in adjacent fields, the biological diversity of the total system usually deters devastating outbreaks of pests or diseases. Severe infestations seldom occur in highly diversified, mixed farming areas.

Such diversification is not always practical in areas devoted to seasonal monocultures of rice, maize, sugarcane, and other staple, commercial crops. Diversity can be introduced, however, by planting varietal mixtures of the single crops, including varieties with different genetic resistances to pests and diseases. Recent research has also demonstrated the efficacy of mixed cropping and intercropping in reducing pest and disease damage, thus increasing biological stability. In selecting the crops for his total enterprise, the farmer often considers the contribution of diversity to biological stability and aims for the maximum overall stability in his system. If he has ready markets for more than one high-value crop, for example, the farmer may forego the increased theoretical efficiency of a single crop in favour of a mixture of crops with complementary sources of biological stability. A farmer might retain coconut trees that are not as profitable as an alternative crop but that are extremely stable, affording him a hedge against a failure of his more profitable but less stable crop. He may also grow cassava, a very stable annual crop; upland rice, which is less stable; and some vegetables, which are highly unstable but potentially highly profitable. One or more animal enterprises add extra stability to the total system. The achievement of a balance among crops with different degrees of biological stability is an important motivation for farmers as they make decisions about intensive mixed farming systems. The biological stability of a crop is reflected in the costs the farmer will have to bear to
grow it. Highly unstable crops, which are often highly profitable in the end, also often cost more to produce than more stable crops because expensive inputs must be used to compensate for their instability. A crop that is biologically unstable because it is extremely susceptible to insect depredations, for example, must be protected with pesticides or other costly measures.

**Management stability**

A second source of crop stability—one that is commonly overlooked or misunderstood by development planners—is the ability and readiness of the farmer to carry through the appropriate management program that will ensure the success of the crop. Many otherwise promising production schemes have failed because of management-induced instability although the failures are almost always ascribed to lack of management.

A clear example of management-induced instability is the combination of mechanical cultivation and hand weeding of upland rice in parts of the Philippines. The method works well under ideal conditions of moderate to low rainfall. When the rainfall is unusually heavy during the first month after planting, however, the farmers cannot get their mechanical equipment into the fields on time and, when they do, the wet soil reduces the effectiveness of the cultivation. Moreover, when this upland management method was modified for direct-seeded lowland rice, a weed control chemical was added in an effort to improve the stability of the crop. The chemical's effectiveness was short-lived, however, while the paddies remained unflooded for up to two months. As a result, the resurgent weeds had a chance to outgrow the dwarf rice. Production on many farms has suffered greatly from this failure of management to improve the stability of the crop. Alternative management methods to increase stability include:

- planting direct-seeded rice only in paddies that can be flooded within 30 days
- using rice varieties that are more competitive with weeds
- using an herbicide with a longer active life
- direct-seeding only in paddies where weed control has previously been good

Thus, as the Philippine example illustrates, the farmer has available a variety of management options that will improve crop stability. Many of these options are pest management methods, which are critical elements in management stability and in the overall success of any crop enterprise. Weed management is perhaps the most important single element needed to improve
crop stability in the humid tropics, and there is an urgent need for new crop varieties that can compete successfully with weeds, as well as for other innovative and effective weed management strategies. In deciding whether to adopt a new management technology, the farmer gives great weight to the stability it will lend his crop. An unstable management technique or package will result in a crop that is difficult to grow, involving techniques that are impractically complex or that leave the crop vulnerable to environmental factors. The high probability of failure with such a management system is likely to discourage the farmer from adopting it. To the farmer, failure may mean not only loss of crop production, but loss of respect as well. It is important for the development planner therefore to recognize the management instability in new technologies and the devise alternative management strategies to eliminate or compensate for it.

Production stability
The overall production stability of a farm is the result of the biological stability and the management stability of each of its component enterprises. The importance of production stability to the farmer depends largely on his economic circumstances. A farmer with extremely limited resources, facing a new with each crop the absolute need for at least a minimum production, cannot afford to endure any more instability than the irreducible minimum. He cannot afford to take a chance on an unstable crop or management technology, even if it promises to repay increased risk with increased production. He will demand the utmost stability on the subsistence portion of his farm; on whatever portion is left for commercial enterprises, he will be more willing to accept some instability for the chance to make money.

Economic stability
In commercial farming, economic stability is a combined measurement of production stability and price stability. The farmer's inability to predict the market prices for his crops, especially when he must also contend with biological and management instabilities, adds to his reluctance to adopt new technologies. Other economic factors—the advantage of off farm income, for example, or the burden of debt—can also affect the economic stability of the farm as a whole. In general, the farmer makes trade-offs between productivity and stability. Many traditional farming systems have evolved a high degree of stability at the cost of only modest productivity losses. As the farmer intensifies his cropping, pushing his resources toward their theoretical limits, he sacrifices some measure of stability. "Nothing ventured, nothing gained," as the old adage puts it.
Nevertheless, carefully designed technologies can combine high productivity with considerable stability. The development of alternative technologies affords the farmer a choice of approaches to his particular needs and circumstances. The rice farmer mentioned in chapter 8, for example, was willing to try the unstable direct-seeding technology with its potential for high yield largely because he had several alternative management technologies to rely on if it failed.

As new technologies are developed for intensified farming, each must be carefully assessed for stability. The biological stability of a new crop variety can be reliably estimated from environmental data combined with performance results of the crop in trials under similar conditions. Management stability, on the other hand, can only be assessed under actual farm conditions. Before a new management technology is recommended to farmers, therefore, it is crucial that it be tested under farmer management. Failures should be analyzed carefully to identify the exact source of the instability.

The importance of farmer participation in the testing of new technologies can hardly be exaggerated. There is a strong temptation to run on-farm tests under the management of researchers to ensure proper controls, but such trials do not reflect the true management characteristics of the technology.

In the final analysis, it is the farmer who will manage the crop.
Eco-physiological approaches in multiple cropping

Multiple cropping describes forms of cropping in which several crops are grown simultaneously, or sole crops are grown in sequence, or a combination of sole and mixed crops are grown in sequence. Multiple cropping for food production is widespread in the developing world because it allows farmers to have a low but steady production. Multiple cropping is found in such areas that receive 300-1000 mm of rainfall.

Ecophysiology

Ecophysiology (from Greek oikos, "house (hold)"; physis, "nature, origin"; and -logia), environmental physiology or physiological ecology is a biological discipline that studies the adaptation of an organism's physiology to environmental conditions. It is closely related to comparative physiology and evolutionary physiology.

or

The study of the interrelationship between an organism's physical functioning and its environment

or

the study of the physiology of organisms with respect to their adaptation to the environment

Plant ecophysiology is concerned largely with two topics: mechanisms (how plants sense and respond to environmental change) and scaling or integration (how the responses to highly variable conditions—for example, gradients from full sunlight to 95% shade within tree canopies—are coordinated with one another, and how their collective effect on plant growth and gas exchange can be understood on this basis.

Ecophysiologists, or physiological ecologists, address ecological questions about the controls over the growth, reproduction, survival, abundance, and geographical distribution of plants, as these processes are affected by interactions between plants with their physical, chemical, and biotic environment. These ecophysiological patterns and mechanisms can help us understand the functional significance of specific plant traits and their evolutionary heritage. The questions addressed by ecophysiologists are derived from a higher level of integration, i.e. from “ecology”
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in its broadest sense, including questions originating from agriculture, horticulture, forestry, and environmental sciences. However, the ecophysiological explanations often require mechanistic understanding at a lower level of integration (physiology, biochemistry, biophysics, molecular biology). It is, therefore, quite essential for an ecophysicist to have an appreciation of both ecological questions and biophysical, biochemical and molecular methods and processes. In addition, many societal issues, often pertaining to agriculture, environmental change, or nature conservation, benefit from an ecophysiological perspective. A modern ecophysicist thus requires a good understanding of both the molecular aspects of plant processes and the functioning of the intact plant in its environmental context.

Given that plant growth and development are directly and indirectly influenced by environmental factors, in order to obtain a successful production it is essential to understand clearly how said factors affect plant physiology. In this context, ecophysiology is the science that studies the interactions between plants and their physical, chemical and biotic environment. Environmental physiology is also important to study both the effect of different environmental stresses (shading, heavy metals, drought and salinity, among others) on growth and development and the way plants compensate the detrimental effects of stress through different mechanisms (stress response, acclimation and adaptation).

Environmental physiology studies have been extensively used to improve the management of certain species or to explain differences among cultivars. Nevertheless, in regions where agriculture is not very modern, or where new horticultural crops are introduced, the information supplied by environmental physiology studies is highly valuable for deciding on the distribution and performance of crops. Knowledge on the responses of crops to environmental factors such as temperature, water availability, light or carbon dioxide (CO₂) concentration is useful to determine the effect of suboptimal environmental conditions and to manage crops for maximum productivity. In addition, a better understanding of the interaction between environmental factors and physiological processes contributes to breeding programs, production sustainability improvement and efficient agricultural zoning.

Plants cannot move away and are unable to escape unfavourable and changing environmental factors such as heat, cold, drought or floods. They, therefore must endure the adverse conditions or perish (animals go places, plants grow places). Plants are therefore phenotypically plastic and
have an impressive array of genes that aid in adapting to changing conditions. It is hypothesized that this large number of genes can be partly explained by plant species’ need to adapt to a wider range of conditions.

Two or more crops in one place result in interactions which can be discussed on the basis of two theories (Vandermeer 1986).

1) **Competitive production principle** – Besides interactions between organisms of the same species (intraspecific interactions), interspecific interactions (interactions between species) influence mixed cropping systems. Intraspecific competition can be measured relatively easy in monocultures through systematic variation of plant densities, whereas measuring interspecific competition depends on planting density, proportion and planting design of the individual crops grown in mixture. The possible mechanism of interactions between species include (1) coexistence (no interaction), (2) one side interactions (one crop facilitate/inhibits the performance of the second crop), (3) antagonism (two-way negative influence), and (4) symbiosis (two-way positive influence).

2) **Competitive exclusion principle** – As per this principle two species having identical demands on growth factors cannot exist side by side. In other words, two populations can coexist when they do not use the same resources. Through formation and occupation of different ecological niches, interspecific competition is avoided and according to the environmental modification principles (Vandermeer 1986) two species are interacting through ‘interference’ which means modification of environmental conditions for one crop by another. Competition can only be regarded as a part of this theory. With reference to mixed culture, the ‘interference production principle’ (Vandermeer 1981) states that a polyculture is more productive than the monoculture of their crops if one crop does not modify the growth factor of the other crop too extensively or in other words if interspecific competition is smaller than intraspecific competition. Examples for avoidance of interspecific competition by use of different niches and superior productivity of mixed cultures over monocrops are:

- Use of different nitrogen sources
- Use of different soil depths
- Use of growth factors at different times
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- Use of different plant heights

Examples of active modification of environmental conditions of one species by another are:

- Weed suppression
- Protection for wind
- Modification of microclimate
- Modification of pest and disease potential
- Modification of nutrient supply
- Modification of water supply
- Modification of soil structure

Light

As with most abiotic factors, light intensity (irradiance) can be both suboptimal and excessive. Light intensity is also an important component in determining the temperature of plant organs (energy budget). The light response curve of net photosynthesis is particularly useful in characterizing a plant's tolerance to different light intensities.

Suboptimal light (shade) typically occurs at the base of a plant canopy or in an understory environment. Shade-tolerant plants have a range of adaptations to help them survive the altered quantity and quality of light typical of shade environments.

Excess light occurs at the top of canopies and on open ground when cloud cover is low and the sun's zenith angle is low, typically this occurs in the tropics and at high altitudes. Excess light incident on a leaf can result in photoinhibition and photodestruction. Plants adapted to high light environments have a range of adaptations to avoid or dissipate the excess light energy, as well as mechanisms that reduce the amount of injury caused.

Light intensity within a plant canopy decreases exponentially (Krug 1991). For use in crop mixtures this implies the importance of combining a tall crop with effective use of high light intensity ($C_4$ plants) and a determinate shade-tolerant second crop. Many early closing crops are able to achieve high light absorption in sole stands, but cannot maintain this rate over their whole life cycle. In this respect, relay intercropping or intercropping is a route to more efficient use of available resources.
Carbon exchange rate (CER) is strongly dependent on irradiance, absorption, and utilization of photon energy. Low irradiance, in as much as it determines insufficient light penetration into the canopy, influences CER directly by reducing photon energy utilization, thus decreasing productivity. Canopy management as a routine activity in horticultural crops is aimed at increasing light interception and productivity, stabilizing yield, and improving fruit quality. Shading (levels of 60% to 90%) affects leaf morphology and anatomy, gas exchange and water relations (water use efficiency, stomatal conductance, and thus photosynthesis). In addition, shade diminishes reproductive potential directly by decreasing flowering, fruit set and fruit size; and indirectly by reducing the vegetative growth that the plant needs to support reproduction. Previous studies have shown the importance of plant response to shading, since this information is useful to determine ideal plant density, cropping systems or growth conditions in greenhouses. Francescangeli et al. (2007) observed that shading increased growth cycle duration and diminished net assimilation rate in broccoli. However, as individual plant relative growth rate (RGR) was almost constant, they concluded that broccoli can be considered as a shade-tolerant plant, thus apt for intercropping systems. Tsubo and Walker (2004) and Nasrullahzadeh et al. (2007) studied the effect of intercropped beans and observed that dry mass was 40% lower in shaded plants (shading was up to 90%). Nevertheless, shading did not have significant effects on yield parameters (number of pods and number of grains per plant, and number of grains per pod). These authors concluded that growing beans in agroforestry or intercropping systems would be advantageous for farmers. Regarding planting distance, close spacing has been observed to have a negative effect on fruit set in tomato, apparently due to an inadequate supply of photosynthates (Papadopoulos and Pararajasingham, 1997). In a 4-year study conducted in tomato by Zahara and Timm (1973), the variables stem diameter, fruit set, number of flowers and number of leaves per plant decreased as plant density was increased up to 96.3 plants/m². Similar results were found by Papadopoulos and Ormrod (1990), who observed that tomato fruit set declined with decreased plant spacing (i.e. 58%, 52% and 13% fruit set at 60 cm, 45 cm and 23 cm spacing, respectively). In horticultural production systems, plants can experience water loss due to high solar radiation levels, often causing irreversible burns (Castilla, 2005). Shading is a useful strategy for reducing leaf temperature, fruit damage or water loss at irradiance peaks; and for growing shade-tolerant species in areas with excessive radiation (Kittas et al., 1999).
Temperature

In response to extremes of temperature, plants can produce various proteins. These protect them from the damaging effects of ice formation and falling rates of enzyme catalysis at low temperatures, and from enzyme denaturation and increased photorespiration at high temperatures. As temperatures fall, production of antifreeze proteins and dehydrins increases. As temperatures rise, production of heat shock proteins increases. Metabolic imbalances associated with temperature extremes result in the build-up of reactive oxygen species, which can be countered by antioxidant systems. Cell membranes are also affected by changes in temperature and can cause the membrane to lose its fluid properties and become a gel in cold conditions or to become leaky in hot conditions. This can affect the movement of compounds across the membrane. To prevent these changes, plants can change the composition of their membranes. In cold conditions, more unsaturated fatty acids are placed in the membrane and in hot conditions more saturated fatty acids are inserted.

Both high and low temperatures, be they temporary or constant, can induce morpho-anatomical, physiological and biochemical changes in plants, leading to profit reduction. Heat stress can be a concern in many regions of the tropics and subtropics, since high temperature can cause significant damage such as sunburns on leaves, branches and stems, anticipated leaf senescence and abscission, shoot and root growth inhibition and fruit discoloration and damage. Reproductive processes are also highly affected by heat stress in most plants. Through observations in strawberry, Ledesma et al. (2008) found that high temperature stress negatively affected the number of inflorescences, flowers and fruits, and that plant response to high temperature stress was cultivar dependent. In tomato, pollen germination and pollen tube growth, ovule viability, stigma and style positions and number of pollen grains retained by the stigma were also seriously affected by high temperature. In cherimoya, warm temperatures determined the production of low-viability pollen; and therefore of asymmetrical and small fruits containing few seeds (Higuchi et al., 1998). However, it has been observed that pollen viability is reduced in papaya when the temperature drops below 20°C.

This condition can also cause problems of sex change and low-sugar content in fruits. In cacao, temperatures above 23°C seem to accelerate vegetative flushing initiation. Regarding anatomical changes, symptoms observed under heat stress conditions are generally similar to those checked under water stress. Plants present reduced cell size, closure of stomata, curtailed water loss,
increased stomatal and trichome densities and greater xylem vessels in both root and shoot. In rose, significant increases in stomatal index and in stomatal and epidermal cell density were observed in plants grown under high temperature.

Plants can avoid overheating by minimising the amount of sunlight absorbed and by enhancing the cooling effects of wind and transpiration. Plants can reduce light absorption using reflective leaf hairs, scales, and waxes. These features are so common in warm dry regions that these habitats can be seen to form a ‘silvery landscape’ as the light scatters off the canopies. Some species, such as *Macroptilium purpureum*, can move their leaves throughout the day so that they are always orientated to avoid the sun (paraheliotropism). Knowledge of these mechanisms has been key to breeding for heat stress tolerance in agricultural plants.

Plants can avoid the full impact of low temperature by altering their microclimate. For example, *Raoulia* plants found in the uplands of New Zealand are said to resemble ‘vegetable sheep’ as they form tight cushion-like clumps to insulate the most vulnerable plant parts and shield them from cooling winds. The same principle has been applied in agriculture by using plastic mulch to insulate the growing points of crops in cool climates in order to boost plant growth.

High temperature induces the acclimation of photosynthesis by changing the photosynthetic capacity, the temperature response of photosynthesis or both. Changes in several photosynthetic characteristics under high temperatures are excellent indicators of plant tolerance to heat stress, which is indeed capable of damaging the thylakoid membranes.

As a consequence, a series of physiological parameters such as chlorophyll fluorescence, variable to maximum fluorescence ratio ($F_{v}/F_{m}$) and base fluorescence ($F_{0}$) can be used to estimate heat tolerance in different species or cultivars. Studies realized by Petkova et al. (2007) indicated that chlorophyll fluorescence induction parameters ($F_{0}$, $F_{m}$, $F_{v}$ and their ratios) are good indicators of heat tolerance in common beans, and can therefore be used to trace characters of interest in breeding programs. Similar results have been reported by Nyarko et al. (2008) in cabbage. Changes in $F_{v}/F_{m}$ ratio under heat stress conditions could also be a good indicator in screening heat-resistant grape cultivars. High temperatures influence photosynthetic capacity and stomatal conductance by decreasing the activation state of rubisco. Furthermore, heat stress diminishes the amount of photosynthetic pigments. In tomato, the latter condition (temperature above 45°C for 2 h) injured the plasma membrane, altered the pigment composition of the photosynthetic apparatus, and caused an important reduction of the net photosynthetic rate due to
affections in the Calvin cycle and the functioning of photosystem II. In citrus species, net CO$_2$ assimilation rate is reduced by partial decrease in both stomatal conductance and instantaneous carboxylation efficiency at temperatures above or below the optimum range (28-32°C). Hence, knowledge about temperature levels is useful in physiological research as well as horticultural crop production. In general, optimum temperature levels have been obtained for many horticultural crops through laboratory and/or field experiments. Understanding the way this factor affects plant physiology is greatly desirable to avoid damages due to unfavorable temperatures during plant ontogeny.

**Water**

Too much or too little water can damage plants. If there is too little water then tissues will dehydrate and the plant may die. If the soil becomes waterlogged then the soil will become anoxic (low in oxygen), which can kill the roots of the plant.

The ability of plants to access water depends on the structure of their roots and on the water potential of the root cells. When soil water content is low, plants can alter their water potential to maintain a flow of water into the roots and up to the leaves (Soil plant atmosphere continuum). This remarkable mechanism allows plants to lift water as high as 120 m by harnessing the gradient created by transpiration from the leaves.

In very dry soil, plants close their stomata to reduce transpiration and prevent water loss. The closing of the stomata is often mediated by chemical signals from the root (i.e., abscisic acid). In irrigated fields, the fact that plants close their stomata in response to drying of the roots can be exploited to ‘trick’ plants into using less water without reducing yields (see partial rootzone drying). The use of this technique was largely developed by Dr Peter Dry and colleagues in Australia.

If drought continues, the plant tissues will dehydrate, resulting in a loss of turgor pressure that is visible as wilting. As well as closing their stomata, most plants can also respond to drought by altering their water potential (osmotic adjustment) and increasing root growth. Plants that are adapted to dry environments (Xerophytes) have a range of more specialized mechanisms to maintain water and/or protect tissues when desiccation occurs.

Drought stress occurs when there is not enough soil water content for successful growth or water supply replenishment. A decline in leaf relative water content (RWC) initially causes stomatal closure, which in turn leads to a decrease in the supply of CO$_2$ to the mesophyll cells and thus
reduces leaf photosynthetic rate. Drought stress also affects processes such as cell division and expansion, ABA synthesis and sugar accumulation, consequently reducing crop yield. Deficit irrigation can enhance fruit quality by raising dry matter percentage and sugar content. Furthermore, controlled water deficit has been used as a technique to stimulate blossoming in crops such as guava or litchi, or to substitute for adequate chilling when temperate crops such as apple are grown in the tropics. Hence, regulated deficit irrigation (RDI) and partial rootzone drying (PRD) techniques have been applied to withhold water during certain periods, thus producing moderate drought stress, which in turn has improved yield, fruit quality and water use efficiency. The results of RDI experiments have been contradictory, but sometimes promising. In experiments conducted in Spain, RDI has increased grape productivity (Faci et al., 2009) and citrus fruit quality (Ballester et al., 2009), although the yield effect has been controversial for some species (Robles et al., 2009). RDI can also be used to delay flowering and harvesting time or to increase flowering and productivity at certain periods of the year when prices are high. Such is the case of the “forzatura”, a traditional practice applied in lemon crops in Sicily, where the summer bloom is accentuated by withholding irrigation until the trees wilt (Barbera et al., 1985). It is necessary, however, to determine the optimum stress level so that the dry period does not have depressing effects on tree vitality, and to understand the interactions among tree water status, crop load and fruit growth, in order to optimize yield under water deficit conditions. For example, high yields can be obtained in peach with deficit irrigation if an appropriate management of fruit thinning is done at stage III of fruit growth. This is so because said management enhances fruit size not only due to a reduction in fruit competition, but to an improvement in tree water status as well.

Many crop mixtures show higher productivity compared with their monocrop counterparts in dry regions (Kass 1978; Reiu et al 1986). There is reason to believe that available water has either been used more efficient, or as result of interference, more water has been made available (e.g. because of deeper penetrating roots of one crop). Many Fabaceae are relatively drought resistant because of their strong, deeply penetrating root system and this is particularly true for soybeans in mixed cultures (Allen and Obura 1976). Intercropping maize with mungbeans (Suwanarit et al 1984) or cowpeas (Ayeni et al 1984) led to lower evaporation rates than sole stands of maize. Soil cover is a key element for interaction between transpiration and evaporation. On the one hand high leaf area per ground are provided by a second crop can reduce water runoff and
facilitate water penetration from surface into ground in particular when heavy rainfall occurs. On the other, a higher leaf area index can facilitate higher transpiration rates. Evaporation exceeds transpiration if leaf area is small and lower crop densities are more suitable for dry seasons with uneven distributed rainfalls. In regions with regular rainfall where evaporation is higher than transpiration (constant wet soil surface), higher crop densities are more favourable because reduced evaporation likely overcompensates higher transpiration.

Waterlogging reduces the supply of oxygen to the roots and can kill a plant within days. Plants cannot avoid waterlogging, but many species overcome the lack of oxygen in the soil by transporting oxygen to the root from tissues that are not submerged. Species that are tolerant of waterlogging develop specialised roots near the soil surface and aerenchyma to allow the diffusion of oxygen from the shoot to the root. Roots that are not killed outright may also switch to less oxygen-hungry forms of cellular respiration. Species that are frequently submerged have evolved more elaborate mechanisms that maintain root oxygen levels, perhaps most notable being the dramatic aerial roots seen in Mangrove forests.

Under flooding conditions, plants show similar symptoms to those they develop under heat or water stress. Plant responses to waterlogging include increased internal ethylene concentration, low stomatal conductance, decrease in leaf, root and shoot development, changes in osmotic potential and nutrient uptake, and reduced chlorophyll content and photosynthesis. Flooding also increases the severity of certain diseases, mainly root-rotting fungi, as reported by De Siva et al. (1999) regarding Phytophthora root rot in blueberry. The decrease of oxygen level in soils affects the bioavailability of nutrients as well as the ability of root systems to uptake and transport water and mineral nutrients. Waterlogging caused inhibition of N uptake from the soil and reduced leaf concentrations of N, P, K, Ca and Mg in avocado (Schaffer and Andersen, 1994) and pea (Rao and Li, 2003). However, for many terminally overwatered houseplants, the initial symptoms of waterlogging can resemble those due to drought. This is particularly true for flood-sensitive plants that show drooping of their leaves due to epinasty (rather than wilting).

**CO₂ concentration**

CO₂ is vital for plant growth, as it is the substrate for photosynthesis. Plants take in CO₂ through stomatal pores on their leaves. At the same time as CO₂ enters the stomata, moisture escapes. This trade-off between CO₂ gain and water loss is central to plant productivity. The trade-off is all the more critical as R-ubisco, the enzyme used to capture CO₂, is efficient only when there is
a high concentration of CO₂ in the leaf. Some plants overcome this difficulty by concentrating CO₂ within their leaves using C₄ carbon fixation or Crassulacean acid metabolism. However, most species used C₃ carbon fixation and must open their stomata to take in CO₂ whenever photosynthesis is taking place.

The concentration of CO₂ in the atmosphere is rising due to deforestation and the combustion of fossil fuels. This would be expected to increase the efficiency of photosynthesis and possibly increase the overall rate of plant growth. This possibility has attracted considerable interest in recent years, as an increased rate of plant growth could absorb some of the excess CO₂ and reduce the rate of global warming. Extensive experiments growing plants under elevated CO₂ using Free-Air Concentration Enrichment have shown that photosynthetic efficiency does indeed increase. Plant growth rates also increase, by an average of 17% for above-ground tissue and 30% for below-ground tissue. However, detrimental impacts of global warming, such as increased instances of heat and drought stress, mean that the overall effect is likely to be a reduction in plant productivity. Reduced plant productivity would be expected to accelerate the rate of global warming. Overall, these observations point to the importance of avoiding further increases in atmospheric CO₂ rather than risking runaway climate change.

Wind
The main impact of wind on plants is through its influence on the canopy, which in turn influences the way leaves regulate moisture, heat, and carbon dioxide. When no wind is present, a layer of still air builds up around each leaf. This is known as the boundary layer and in effect insulates the leaf from the environment, providing an atmosphere rich in moisture and less prone to convective heating or cooling. As wind speed increases, the leaf environment becomes more closely linked to the surrounding environment. It may become difficult for the plant to retain moisture as it is exposed to dry air. On the other hand, a moderately high wind allows the plant to cool its leaves more easily when exposed to full sunlight. Plants are not entirely passive in their interaction with wind. Plants can make their leaves less vulnerable to changes in wind speed, by coating their leaves in fine hairs (trichomes) to break up the air flow and increase the boundary layer. In fact, leaf and canopy dimensions are often finely controlled to manipulate the boundary layer depending on the prevailing environmental conditions.

In areas where very strong winds are common, plants respond by reducing their above ground growth (known as dwarfing) and by strengthening their stems. Trees have a particularly well-
developed capacity to reinforce their trunks when exposed to wind. In the 1960s, this realisation prompted arboriculturalists in the UK to move away from the practice of staking young amenity trees to offer artificial support. In the most extreme cases, plants can be mortally damaged or uprooted by wind. This is a particular problem for agriculture in hurricane-prone regions, such as the banana-growing Windward Islands in the Caribbean. When this type of disturbance occurs in natural systems, the only solution is to ensure that there is an adequate stock of seeds or seedlings to quickly take the place of the mature plants that have been lost—although, in many cases a successional stage will be needed before the ecosystem can be restored to its former state.

**Beneficial effects for succeeding crops**

Compared to mono-crops of non-legumes, mixed systems with legumes have significant positive effects on succeeding crops; in a sugarcane based intercropping system, pulses increased organic carbon, total N and available P content but had no effect on cane yields (Yadav et al 1987). Soybean and blackgram in mixture with maize increased yield of succeeding wheat significantly (Singh and Singh 1984) and soybean used as green manure in mixture with maize favoured corn yields (Pandey and Pendleton 1986). These long term effects of making air nitrogen available for non-legumes depend on the rapidity of rooting legume roots and nodules which in turn depends on climatic conditions (soil water and temperature). In this respect, a slower release of nitrogen from legume biomass can avoid N leaching.

Finally it can be said that knowledge about the interactions between environmental factors and plant physiology facilitates the identification of environmental changes such as lack of light, high temperatures or water deficit. For example, the shading of horticultural crops can reduce photosynthesis rate, transpiration and stomatal density and conductance; and enhance flower abortion. Likewise, high temperatures can affect pollen viability and germination, number of flowers and number of fruits per plant. Finally, ecophysiological information is a tool that can be used in breeding programs to obtain improved cultivars, as well as in strategies of agricultural zoning, thus enhancing productivity.
Recent Advances in Integrated Farming Systems

Simulation models for intercropping
Intercropping is being advocated as a new and improved approach to farming. However, it has been avoided because of the complications of planting and harvesting. Intercropping involves competition for light, water and nutrients. However, intercropping usually benefits from increased light interception, root contact with more soil, increased microbial activity and can act as a deterrent to pests and weeds of the other crop. There is also evidence that suggests intercropping may benefit a non-legume which needs nitrogen if the other crop is a legume, since legumes will fix nitrogen in the soil. Producers and researchers carry out different cropping systems to increase productivity and sustainability by practicing crop rotations, relay cropping, and intercropping of annual cereals with legumes. Intercropping of cereals with legumes has been popular in tropics and rain-fed areas of the world due to its advantages for soil conservation, weed control, lodging resistance, yield increment, hay curing, forage preservation over pure legumes, high crude protein percentage and protein yield, and legume root parasite infections control.

Modelling in Agricultural Systems
Agricultural models are mathematical equations that represent the reactions that occur within the plant and the interactions between the plant and its environment. However, unlike in the fields of physics and engineering, universal models do not exist within the agricultural systems. Models are built for specific purposes and the level of complexity is accordingly adopted. Inevitably, different models are built for different subsystems and several models may be built to simulate a particular crop or a particular aspect of the production system.

Features of crop models
The main aim of constructing crop models is to obtain an estimate of the harvestable (economic) yield. According to the amount of data and knowledge that is available within a particular field, models with different levels of complexity are developed. The most pertinent aspects of crop models are described below.

Empirical model
Empirical models are direct descriptions of observed data and are generally expressed as regression equations (with one or a few factors) and are used to estimate the final yield. Examples of such models include the response of crop yield to fertiliser application and the relationship between leaf area and leaf size in a given plant species. The limitation of this model is that it is site specific, it cannot be used universally.
**Mechanistic model**
A mechanistic model is one that describes the behaviour of the system in terms of lower-level attributes. Hence, there is some mechanism, understanding or explanation at the lower levels. These models have the ability to mimic relevant physical, chemical or biological processes and to describe how and why a particular response results.

**Static and dynamic models**
A static model is one that does not contain time as a variable even if the end-products of cropping systems are accumulated over time, e.g., the empirical models. In contrast dynamic models explicitly incorporate time as a variable and most dynamic models are first expressed as differential equations.

**Deterministic and stochastic models**
A deterministic model is one that makes definite predictions for quantities (e.g., animal live weight, crop yield or rainfall) without any associated probability distribution, variance, or random element. However, variations due to inaccuracies in recorded data and to heterogeneity in the material being dealt with, are inherent to biological and agricultural systems. In certain cases, deterministic models may be adequate despite these inherent variations but in others they might prove to be unsatisfactory e.g. in rainfall prediction. The greater the uncertainty in the system, the more inadequate deterministic models becomes and in contrast to this stochastic models appears.

**Simulation and optimizing models**
Simulation models form a group of models that is designed for the purpose of imitating the behaviour of a system. They are mechanistic and in the majority of cases they are deterministic. Since they are designed to mimic the system at short time intervals (daily time-step), the aspect of variability related to daily change in weather and soil conditions is integrated. The short simulation time-step demands that a large amount of input data (climate parameters, soil characteristics and crop parameters) be available for the model to run. These models usually offer the possibility of specifying management options and they can be used to investigate a wide range of management strategies at low costs. Most crop models that are used to estimate crop yield fall within this category.

Optimizing models have the specific objective of devising the best option in terms of management inputs for practical operation of the system. For deriving solutions, they use decision rules that are consistent with some optimising algorithm. This forces some rigidity into their structure resulting in restrictions in representing stochastic and dynamic aspects of
agricultural systems. Linear and non-linear programming were used initially at farm level for enterprise selection and resource allocation. Later, applications to assess long-term adjustments in agriculture, regional competition, transportation studies, integrated production and distribution systems as well as policy issues in the adoption of technology, industry re-structuring and natural resources have been developed. Optimising models do not allow the incorporation of many biological details and may be poor representations of reality. Using the simulation approach to identify a restricted set of management options that are then evaluated with the optimising models has been reported as a useful option.

MODEL DEVELOPMENT

Strength
The strengths of models in general include the abilities to:

- Provide a framework for understanding a system and for investigating how manipulating it affects its various components
- Evaluate long-term impact of particular interventions
- Provide an analysis of the risks involved in adopting a particular strategy
- Provide answers quicker and more cheaply than is possible with traditional experimentation

Model calibration
Calibration is adjustment of the system parameters so that simulation results reach a predetermined level, usually that of an observation. In many instances, even if a model is based on observed data, simulated values do not exactly comply with the observed data and minor adjustments have to be made for some parameters.

Model validation
The model validation stage involves the confirmation that the calibrated model closely represents the real situation. The procedure consists of a comparison of simulated output and observed data that have not been previously used in the calibration stage. Ideally, all mechanistic models should be validated both at the level of overall system output and at the level of internal components and processes. The latter is an important aspect because due to the occurrence of feedback loops in biological systems, good prediction of system's overall output could be attributed to compensating internal errors. However, validation of all the components is not possible due to lack of detailed datasets and the option of validating only the determinant ones is adopted. For example, in a soil-water-crop model, it is important to
validate the extractable water and leaf area components since biomass accumulated is heavily
dependent on these.

The methodology of model validation is still rudimentary. The main reason is that, unlike the
case of disciplinary experiments, a large set of hypotheses is being tested simultaneously in a
model. Furthermore, biological and agricultural models are reflections of systems for which
the behavior of some components is not fully understood and differences between model
output and real systems cannot be fully accounted for.

The validation of system simulation models at present is further complicated by the fact that
field data are rarely so definite that validation can be conclusive. This results from the fact
that model parameters and driving variables are derived from site-specific situations that
ideally should be measurable and available. However, in practice, plant, soil and
meteorological data are rarely precise and may come from nearby sites. At times, parameters
that were not routinely measured may turn out to be important and they are then arbitrarily
estimated. Measured parameters also vary due to inherent soil heterogeneity over relatively
small distances and to variations arising from the effects of husbandry practices on soil
properties. Crop data reflect soil heterogeneity as well as variation in environmental factors
over the growing period. Finally, sampling errors also contribute to inaccuracies in the
observed data. Validation procedures involve both qualitative and quantitative comparisons.
Before starting the quantitative tests, it is advisable to qualitatively assess time-trends of
simulated and observed data for both internal variables and systems outputs.

Inadequate predictions of model outputs may require "re-fitting" of the regression curves or
fine-tuning of one or more internal variables. This exercise should be undertaken with care
because arbitrary changes may lead to changes in model structure that may limit the use of
the model as a predictive tool. In some cases, it is best to seek more reliable data through
further experimentation than embarking on extensive modification of model parameters to
achieve an acceptable fit to doubtful data. This decision relies on the modeller's expertise and
rigour as well as on human resources and time available to invest in fine-tuning model
predictions.

**Simulation models for intercropping/multispecies systems**

Models of plant mixtures apply to various systems: crops and weeds, mixtures of crop
varieties, intercropping of different crop species, tree and crop mixtures (agroforestry,
treeshelters), and tree species mixtures (mixed forests). The nonlinear behaviour of
multispecies systems cannot be accounted for by simply studying or modelling plant components independently.

**Modelling is the only way to go with multispecies systems**

Design decisions made from the small amount of empirical evidence from the few available trials on multispecies systems are inherently weak, as plant development and productivity in mixtures are site- or weather-specific (Vandermeer, 1989). Land Equivalent Ratio assessments based on a few years of measurements are highly questionable (Vandermeer, 1989). In mixture studies, innovative planting designs have been developed to reduce the land area needed for mixed-species plantation experiments, by focusing on individual plant analysis rather than plot-level analysis (Kelty, 2006). However, the numerous combinations between species, environments and practices are not within reach of traditional factorial experimental approaches. In dynamic systems with heterogeneous structures, a system approach is required to improve understanding of the processes involved, and to evaluate adequate management schemes. There is a need for dynamic modeling tools to evaluate how wide ranges of soil conditions, various weather sequences and different management schemes modify the yield and environmental impact of multispecies systems.

**Modelling interspecific relationships**

All models of multispecies systems simulate interspecific interactions which are key determinants of the structure, the dynamics and the productivity of mixed plant communities. As seen previously, in contrast with sole cropping, multispecies systems have parallels with basic ecological principles. Plant interaction models are categorized as being either empirical, providing only a description of the outcome of competition, or process-based, offering a representation of the physiological processes underlying plant growth. Empirical models are useful for making predictions within the range of data used to parameterise them but are not suitable for extrapolation. Mechanistic models that are based on the behaviour of individual plants are based on “focal plant–neighbour plant” interactions. In contrast to empirical models, process-based models have the ability to make predictions outside the range of data used in their parameterisation, making them the models of choice for designing plant species mixtures. In order to simulate both competition and facilitation, it is necessary to achieve a balance in aboveground and belowground interactions in resource capture by the component species. Moreover, in modelling approaches, a balance needs to be maintained between process and pattern, between temporal and spatial aspects. Multispecies dynamic models for resource partition must include appropriate plasticity mechanisms in the plant models, solve
the resource sharing for multiple resources simultaneously, and couple plant and crop models often built with different concepts (Fig. 1).

**Figure 1.** The three crux of multispecies dynamic models for resource partition: including appropriate plasticity mechanisms in the plant models (1), solving the resource sharing for multiple resources simultaneously (2), and coupling plant models often built with different concepts (3).

**Current multispecies system models**
A comparison of some representative multispecies system models is presented (Table 1). Relatively few models have been developed for mixtures of tree species (Bartelink, 2000; Coates et al., 2003) and mixtures of herbaceous species (Brisson et al., 2004; Caldwell and Hansen, 1993; Carberry et al., 1996; Tsubo et al., 2005), including crop-weed models (Deen et al., 2003), but even fewer for mixtures of trees and crops (García-Barrios and Ong, 2004; Mobbs et al., 1998). Competition models for trees only usually run on a yearly time step, while competition models for crops only, or crops and trees, run on a daily time step.
### Table 1. Comparison of some multispecies models designed for intercropping, agroforestry and forestry.

<table>
<thead>
<tr>
<th>Model</th>
<th>_specific diversity (number of species)</th>
<th>Spatial pattern heterogeneity (horizontal)</th>
<th>Time step and scale</th>
<th>Aboveground interactions</th>
<th>Belowground interactions</th>
<th>Type of system</th>
<th>Objectives</th>
<th>General comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>CROPSYS (Caldwell and Hansen 1993)</td>
<td>2 (crop/crop)</td>
<td>Day time step n cycles</td>
<td>Canopy: 1D, 2 layers Light balance</td>
<td>Soil: 1D, n Water and N competition</td>
<td>Tropical linear intercropping systems</td>
<td>Growth and yields of annual species risk, evaluation/Decisio n making</td>
<td>Dedicated to crop/crop interactions</td>
<td></td>
</tr>
<tr>
<td>STICS-CA (Brisson et al. 2004)</td>
<td>2 (crop/crop) or (tree/crop)</td>
<td>Day time step n cycles</td>
<td>Canopy: 1D, geometric shape Light balance Microclimate feedback implemented</td>
<td>Soil: 1D, n layers Water and N competition Plasticity of root system implemented, but no callostation between shoots and roots</td>
<td>Temperate and tropical linear intercropping systems</td>
<td>Growth and yield of annual and perennial species</td>
<td>Suitable for tree/crop or crop/crop interactions No tree management (pruning)</td>
<td></td>
</tr>
<tr>
<td>GEMINI (Soussana et al., 2000)</td>
<td>2 (crop/crop)</td>
<td>Day time step n cycles</td>
<td>Canopy: 1D, n vertical layers Light balance</td>
<td>Soil: 1D, n vertical layers N uptake</td>
<td>Temperate grasslands</td>
<td>Grasland species coexistence, dynamic and productivity</td>
<td>Simulation of phenotypic plasticity in response to shade, N deprivation Explicit description of the plant shoot and root morphogenesis and architecture Crop management (animal module)</td>
<td></td>
</tr>
<tr>
<td>YieldSAFE (Van der Werf et al., 2007)</td>
<td>2 (tree/crop)</td>
<td>Annual time step Long term productivity dynamic</td>
<td>Canopy: 1D, n vertical layers Light balance</td>
<td>Soil: 1D, n layers Water and N uptake</td>
<td>Temperate linear intercropping systems</td>
<td>Growth and yields of annual and perennials species. Evaluation of profitability of agroforestry systems</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>WaNuLCAS (Van Noordwijk and Lusiana 2000)</td>
<td>16 (tree/crop)</td>
<td>Day time step n cycles Long term productivity dynamic</td>
<td>Canopy: 1D n layers Light balance Microclimate feedback not implemented</td>
<td>Soil: 2D, compartment Water, N and P uptake Tree roots may interact with crop roots in the 16 compartment s N tree fixation Crop roots do not interact each other and are limited in vertical compartment s Plasticity of tree root system</td>
<td>Tropical and circular intercropping systems; sequential agroforestry</td>
<td>Growth and yield of annual and perennial species Evaluation of sustainability and profitability of agroforestry systems</td>
<td>Tree management Sustainability: SOM (century model) Limits of the STELLA programming platform</td>
<td></td>
</tr>
<tr>
<td>Hi+AFE (Dupraz et al., 2007)</td>
<td>Day time step n cycles Medium term productivity</td>
<td>Canopy: 3 D Light balance</td>
<td>Slope included Soil: 3 D Water and N balance</td>
<td>Temperate agroforestry management systems with any design for tree and</td>
<td>Growth and yields of annual and perennial species Carbon, N, and water budgets for environmental</td>
<td>Crop and Tree Unsuitable for long term prediction Plasticity of tree root</td>
<td>-</td>
<td></td>
</tr>
</tbody>
</table>
Multispecies system models can be divided into three groups depending on spatial discretisation of the simulated scene. Most models ignore the spatial heterogeneity of plant mixtures, and simplify the system to a one-dimensional representation. They include CROPSYS (Caldwell and Hansen, 1993), APSIM (Carberry et al., 1996), Yield-sAFe (van der Werf et al., 2007), and GEMINI (Soussana and Lafarge, 1998). Those models mimic sole crop modelling, considering the system to be composed of two species instead of one, and assume that both aboveground and belowground stand components are horizontally homogeneous. In the second group of models, a first level of spatial heterogeneity is introduced through discretisation of the system into some linear or circular areas between which flows of mass or energy occur. Some intercropping models such as STICS-CA (Brisson et al., 2004) and most tree belt-crop models (Huth et al., 2003) follow that approach. The WaNuLCas model (Van Noordwijk and Lusiana, 1998) includes 4 zones of tree-crop interactions with decreasing intensity. The possible schedule of a sequence of crops to be grown over time in each zone makes it possible to encompass a broader range of systems in terms of species diversity and spatial structure. The third group includes spatially explicit models, based on modelling individual plants that interact together. This is most common for trees in mixed stands (Bartelink, 2000; Coates et al., 2003) but those models often ignore belowground interactions and focus on light partitioning between trees. Very few spatially-explicit models have been developed for annual plants; some models deal with grassland mixtures (Soussana and Loiseau, 2002), but most are neighbourhood population dynamic
models that often ignore competition for belowground resources (Stephen et al., 1990). SeXI-FS (Manson et al., 2006; Vincent and Harja, 2002) and Hi-sAFe (Dupraz et al., in prep) are models that explicitly integrate both above- and belowground competition for resources on a plant scale, using a distance-dependent and an individual-based modelling approach. By including demographic processes (mortality, recruitment), SeXI-FS simulates the long-term dynamics of the spatial structure. For belowground interactions, progress has been achieved with the development of 2D mechanistic models that include distributed source-sink functions (Ozier-Lafontaine et al., 1998; Lafolie et al., 1999), and in some cases algorithms to account for minimum energy resolution (Adiku et al., 2000). By coupling structure and function at different levels of complexity, these biophysical models provide a clearer understanding of the importance of the different components involved in water competition, i.e. demand partitioning, soil hydrodynamic properties, root distribution and priority in root water extraction. Time steps in all these models vary from 1 year to one day or less, with possible integration over the course of one or more growing seasons, up to a century for forest models.

The models have not been designed for the same purpose, or for the same users, and a comparison is therefore tricky. They often combine simplicity and complexity: one model might be very simple regarding one mechanism, while being more realistic and close to mechanistic models for simulating other processes. Most of the models are used as research tools rather than management tools. Knowledge gaps have been identified and are discussed in the following section.

**Future directions in modelling plant mixtures**

*Designing an appropriate working environment to deal with spatial and temporal patterns*

One of the main characteristics of multispecies systems is the wide range of spatial arrangements (strip or mixed systems, alley crops with various plant-plant distances, mixtures of annuals and perennials, vertical discontinuities in agroforests, windbreaks, etc.) and temporal arrangements (simultaneous versus sequential) that farmers opt for depending on their agroecological purposes. Such a platform is only partially designed in WaNuLCAS and Hi-sAFe for agroforestry systems.

A real breakthrough is needed in the design of a flexible platform that involves both multi-spatial and temporal management, including annual (intercrops, cover crops) and perennial (agroforests, forests) arrangements. The CAPSIS platform provides an attractive example of such operational platforms designed for the simulation of forest dynamics and productivity.
Dynamic simulation models need to integrate competition for different resources in time and space, so as to predict highly non-linear response patterns. A key point in future modeling challenges remains the need for a link between different models geared towards process levels and, above all, between different spatial and temporal scales. That objective means creating bridges between ecophysiology, population biology and functional ecology.

Table 1 focuses on the modelling of multispecies systems as a whole, but other modelling tools are available and relevant to the analysis of some multispecies system processes or components. For example, radiation models based on 3D architectural mock-ups and ray-tracing can be used to derive parameters of the turbid medium analogy widely applied in multispecies system models (Lamanda et al., 2007). In addition, conceptual population biology models may be helpful in exploring the coexistence of species in mixtures. To that end, use of functional traits and groups used in ecology to characterize and simulate natural ecosystems such as rainforests may be of great interest for simulating complex multispecies systems, such as agroforestry systems in the humid tropics.

Challenges related to the level of process description in mechanistic models

The large number of possible species combinations, management practices and site-dependent interactions in multispecies systems indicates that a pure empirical approach would be unsuitable for most problems to be solved. Although intensive work has been devoted to simulating abiotic interactions (light, water) in multispecies systems, efforts need to be focused on (i) better knowledge of interactions for resources, which requires both suitable discretisation of the above- and belowground environment (voxellisation) and realistic simulation of the physical properties of mass transport laws – simulation of changes in soil physical properties, due to tillage and biological activities, must also receive greater attention (Stockle, 1999) – and (ii) an appropriate understanding and multi-scale representation of the plasticity of roots, shoots and crowns involved in the process of adaptation to heterogeneous and competitive environments. Through its decisive role in resource acquisition and use, physiological and morphological plasticity may alter the sign and magnitude of interactions among plants and, as a consequence, the performance and dynamics of the system (Callaway et al., 2003).

Biotic investigations still remain the poor relation of modeling research on multispecies systems, although many models have been developed to simulate the growth and activity of weed, pest and disease populations (Doyle, 1997; Van Oijen, 1995). As pointed out by Stockle (1999), weed, pest and disease effects are ignored in most comprehensive models, as
a result of the complexity of dealing with a potentially large number of species for each plant of interest. This field of research is particularly dependent on population ecology concepts – population dynamics, epidemiology – and the functional ecology of the soil (role of micro- and macroorganisms).

Assessing the impact of climate change and CO₂ elevation on multispecies system productivity and the environment will continue to be an important field of research, particularly for simulating the ability of species to adapt to changing temperatures, moisture availability, CO₂ concentration and other aspects of climate change, i.e. pest pressure.

It may be conclusively inferred that despite its potential advantages and the huge diversity of multispecies systems existing in world agriculture, mainstream agronomic research has largely focused on monocrop systems, with very little interest in ecological interactions between species in mixed systems. Today, it is barely feasible to simulate multispecies systems and, due to the absence of efficient models, it is difficult to understand the effects of the different factors that interact within those systems. The relevance, but relative limitation of the concepts and existing tools of systemic agronomy in alone representing and simulating multispecies systems and their properties certainly reveal the need to find new representations to account for the particular processes brought into play. As shown here, the numerous mechanisms involved in species mixing highlight the need to deal with their complexity by combining concepts from diverse disciplines (agronomy, ecology, epidemiology, etc.), although the necessary link with ecology largely remains to be constructed.

As emphasized by Gurr et al. (2003), mixing species in cropping systems may lead to a range of benefits that are expressed on various space and time scales, from a short-term increase in crop yield and quality, to longer-term agroecosystem sustainability, up to societal and ecological benefits that include recreation, aesthetics, water and soil quality, and flora and fauna conservation, including endangered species. Understanding such interactions between cropping systems and the environment means working on a broader spatial scale than the farmer’s field and means considering the mosaic of fields that structure the landscape, and its evolution over a longer time scale.

For all these issues, multispecies systems are today a real challenge for agricultural research, and more specifically for systemic agronomy. It is time to understand and integrate their complex functioning and develop an adequate tool-box for checking and ensuring their technological development.
Intercropping is a traditional practice in many parts of Africa, Asia, and Latin America. Maize is a staple food crop in many tropical countries. Farmers have traditionally produced their maize under various intercropping systems with other crops, notably pulses. Beans are the predominant pulses grown with maize in many parts of Africa and Latin America. It is important to remember that traditionally these systems operated virtually without the application of artificial fertilizer. One of the problems is that fertilizer technology, expensive though it is, has been developed for monoculture systems of the developed world but fertilizer research in intercropping systems has been limited. Consequently there are practically no fertilizer recommendations under such cropping systems.

Intercropping is a cropping system that has been described as the simultaneous growing of two or more crops in the same field during the same growing season. Another definition of intercropping have incorporated a measure of _inter-crop_ competition. In this case, two crops growing simultaneously in the same field experience _inter-crop_ competition apart from the _intra-crop_ competition that already exists in sole crops. In some forms of intercropping (sequential, strip, and relay) intercrop competition is greatly reduced. Here, fertilizer recommendations for sole crops may still be applicable. However, in other intercropping systems inter-crop competition is significant and recommendations for such systems are not generally available.

**Nutrient uptake and requirement**

The amounts of fertilizers recommended for application depend largely on the total nutrient requirement of the crop and how much is supplied by the soil. The time of fertilizer application, on the other hand, depends on the pattern of growth of crops in intercropping. In order to design an effective fertilizer scheme one needs to know the amounts of nutrients which a given component crop requires and is able to extract from the soil. But crops differ widely in nutrient requirements and so a given fertility level of a soil may lead to varied crop responses in intercropping. Oelsligle _et al._ (1976) proposed that data on total nutrient removal under intercropping systems would be a good place to start when estimating and determining fertilizer practices for such systems. The rate of nutrient uptake varies with component crops as well as with plant age, and the period of maximum nutrient demand of one component crop may not necessarily coincide with that of the other. And also, within the same component crop, the uptake curves for nutrients may be different.
Sole crop data on nutrient requirements and accumulation patterns are probably directly applicable to the less intensive forms of intercropping, namely: sequential, strip and, in certain circumstances, relay intercropping. Such data may not apply in intensive intercropping systems because the total nutrient uptake in harvested products must be greater under intercropping if combined yields are to be significantly increased. Greater nutrient uptake by intercropping has been reported for N, P, K, Ca and Mg. Therefore, it seems inevitable that intercropping systems remove more nutrients than comparable sole crops. This leads to more rapid depletion of natural soil fertility or the need for higher fertilizer application rates (Mason et al. 1986).

Wahua (1983) suggested that in interpreting and discussing nutrient uptake by each component, attention should be focussed on both nutrient accumulation with time and mean rates of nutrient uptake at a given time. This is important because competition for a nutrient is indicated only when there is a significant difference between the uptake of that nutrient in intercropping and in sole crops. Conversely, the absence of competition is indicated only when none of the components of an intercrop shows a difference in uptake at any of the growth stages examined. The growth stage when such a difference is first noticed tends to indicate the onset of competition for that nutrient.

When maize is grown with an associated legume crop, fertilizer applications increase the yield of the maize grain and usually the legume does not respond or yield is significantly decreased. The reduction in yield of the legume is ascribed to greater competition for light from improved maize growth. Under this system the yield of the legume is said to be a bonus because only recommendations for the staple crop (maize) are followed. However, we believe nutrient uptake is greater in intercropping systems and so some of the nutrients supporting the system must be derived from the soil supply. As it turns out, one of the obscure features of this cropping system is the negative soil N balance after harvest. This may be due to the fact that the legume will also be dependent on the applied fertilizer or nitrogen released by the soil because its nitrogen fixation capacity is inhibited by N fertilizer application. This contention of reduced yield advantages from intercropping under fertilized conditions has been disputed by Willey (1979). In northeastern Brazil Faris et al. (1983), working with sorghum or maize with beans or cowpeas, found that the two legumes were responsive to fertilizer application. Work done on fertilizer application in intercrops in Costa Rica (North Carolina State University, 1973, 1974) also reported the responsive nature of beans. Odurukwe (1986) reported improvement in LER with fertilizer application to maize-yam intercrops. Thus,
improved management through fertilizer usage may be appropriate without the loss of the advantageous effects realized from intercropping.

Under low fertility systems, there seems to be competition from maize due to the fact that it is more aggressive and is better able to forage the soil for nutrient resources (Wahua, 1983). This may be due to it having a fibrous rooting system as opposed to the tap-root system of legumes. This competition by maize is short-lived because it is diminished by \(N_2\)-fixation of the legume later in the season. Under a low N regime LER was better than under a high N regime. Under low P the growth of maize is more limited than that of cowpea and its competitive ability is, therefore, reduced. This led to an improved LER with the low P regime. One of the most important aspects of intercropping under low fertility is the fact that it invariably results in a positive soil N balance.

The role of legumes in intercropped cereals is beneficial especially in low soil or applied N availability situations. Most farmers that practise intercropping live in marginal areas and so the system benefits them. In high N availability situations (e.g. estate farming in Malawi) the role of nitrogen fixation in balancing N economy is relatively unimportant. Under such circumstances N is balanced by chemical fertilizers because these farmers can afford them.

**Nutrient availability**

The level of availability of nutrients to plants, whether present in the soil or added to it as chemical fertilizers, is largely determined by the soils through their mineral reserves, pH, organic matter content, cation exchange capacity, base saturation, sesquioxide content, permeability, and moisture retention capacity. The amounts of nutrients released to the crop will depend on these soil features and their interaction. Limitations to plant growth on most tropical soils include poor exchange capacity, nutrient deficiencies, excessive acidity, low organic matter content, and inadequate release of nitrogen, poor porosity and high soil compaction impeding deep root development and water percolation. Other factors may provide a platform on which the above soil features interplay. Out of the world's total land area about 22.5% is characterized by mineral nutrient stress, 27.9% by drought stress, 12.2% by excess water, 24.2% by shallowness and only 10.1% are soils in which stress features are least pronounced (Dudal, 1976).

In designing fertilizer strategies for intercropping systems, encouragement and support should be given to the determination of the initial levels of all nutrient elements and the soil characteristics that determine the release of nutrients to crops as enumerated above. Particular emphasis needs to be placed on soils with specific stress features and these need to be
mapped accordingly so that fertilizer schemes can be developed for those areas that are prone to stress problems. Development of varieties that tolerate such stresses in these areas should be given some priority in breeding programs.

**Contribution of Nitrogen by Legumes in Intercropping**

Legumes have been known for decades to fix nitrogen and enrich the soil. In intercropping systems an earlier report (Agboola and Fayemi, 1972) indicated that legumes do not benefit the associated crop in terms of nitrogen from dinitrogen fixation processes unless they decay. However, with newer $^{15}$N isotope dilution methods, results to the contrary have been reported. Much of the work in this area has been in grass-legume mixed pastures. Recently, with ryegrass-clover mixtures in Wales, Goodman and Collison (1986) used the $^{15}$N isotope dilution method to detect N transfer from the legume (clover) to the grass (ryegrass). Nitrogen transfer may be shown in two ways: the total Kjeldhal N in grass plants mixed with white clover may exceed that in the monoculture grass, or the isotope ratio may differ between mixtures and monocultures. In the latter case, $\text{N}_2$-fixation causes the isotope ratio to be less in clover than in grass, so that if transfer occurs, N becomes more diluted in grass mixed with clover than monoculture grass. Either way, Goodman and Collison (1986) reported evidence of N transfer from white clover to ryegrass.

In grain crop species similar results have been reported. Bandyopadhyay and De (1986) used the $^{15}$N dilution technique on an intercrop of sorghum and legumes. They indicated greater N uptake in intercropped sorghum than in sole sorghum. In an intercrop of sorghum and mung, 18% of the total N removed by sorghum was derived from the fertilizer urea and 81.9% came from the soil pool; the latter included 21.9% N derived from current fixation by the legume. The yield of wheat after sole crops of legume was greater than after their mixture with sorghum. The latter was, however, greater than its yield after sole sorghum crops. This indicates that not only did the legume partially supply N to the cereal crop in intercropping but more N was left for the next crop in rotation. The former may have been through N excretion and the latter through N residues (Saito, 1982). Results (Ofori et al., 1987) to the contrary have been reported in a maize-cowpea intercropping system where a current intercropped maize crop did not benefit from the associated cowpea crop. This aspect of N contribution to crop production needs further research.

When the legume is associated with a cereal crop in intercropping system, legume supplement a portion of nitrogen required of cereal crop; the amount may be of 20 kg/ha by legumes. Application of higher dose of nitrogen to the cereal + legume intercropping system
not only reduces the nitrogen fixation capacity of legumes, but also growth of the legume is suppressed by aggressive fast growth of cereals. Cereal + legume intercropping, therefore is mainly advantageous under low fertilizer application. Considering all the factors, it is suggested that the nitrogen dose recommended for base crop as pure crop is sufficient for intercropping system with cereal + legume or legume + legume. With regards to phosphorus and potassium, one eighth to one fourth of the recommended dose of intercrop is also added in addition to recommended dose of base crops to meet the extra demand. Basal dose of nitrogen is applied to rows of both components in cereal + legume inter crop. Top dressing of nitrogen is done only in cereal rows. P & K are applied as basal dose to both crops.

**Contribution of Phosphorus by Mycorrhizae in Intercropping**

'Mycorrhizae' is a term that refers to a mutualistic, symbiotic relationship formed between fungi (Greek *mukes*) and living roots (Greek *rhiza*) of higher plants (Miller *et al.*, 1986). This type of association has been observed in most plant species except the Cruciferae and Chenopodiaceae. Mycorrhizae have been classified (Harley and Smith, 1983) through a description of seven types, namely vesicular-arbuscular, ecto-, ectendo-, arbutoid, ericoid, monotropoid, and archid mycorrhizae. The vesiculararbuscular mycorrhizae (VAM) comprise the major type observed in crop plants. They produce structures known as vesicles and arbuscules, as well as hyphae and spores. Arbuscules are intracellular, haustoria-like structures that develop by repeated, dichotomous branching of hyphae. Vesicles are sac-like, usually terminal swellings at the tip of hyphae. The hyphae can be formed both within the root and outside it. The transfer of mineral nutrients from the soil to the host plant is mediated by these hyphae.

Phosphorus is a notoriously immobile nutrient in the soil, and is absorbed only when growing roots come in contact with organic or inorganic materials containing available forms of the nutrient. VVahua (1983) contends that the reduction in P uptake by intercropped cowpea was a result of higher competition by maize roots which were more extensive and could forage for P more effectively. Cowpea-YAM associations have been reported (Kwapata and Hall, 1985). The increase in plant growth in such associations is through greater P uptake as a result of reduction in the distance that the nutrient must diffuse to plant roots (Abbott and Robson, 1984). The VAM increases the surface area of the roots several-fold and so a plant in association with VAM may compete more favorably for P under intercropping systems.
Future Approaches on Nutrition in Intercropping

Palaniappan (1985), Davis and Garcia (1983), Ahmed and Rao (1982), and Ofori and Stern (1987) have all identified research areas that need attention as regards nutrition in intercropping systems. These will be mentioned briefly but in order of importance. Firstly, soil maps incorporating the problem areas (like saline and alkaline patches; compact sub-soil zones, chronic micronutrient deficient areas, etc.) and fertility status of the soil need to be prepared. Secondly, soil fertility in intensive cropping systems should be monitored. So far recommendations have been for sole crops but available information suggests considerable scope for economies in fertilizer use. As alluded to elsewhere, the residual effect of nutrients applied to previous crops, contribution of legumes included in the system, addition of residues by component crops, temporal differences in nutrient requirement, spatial differences in foraging and differential response of crops to nutrients all add to the complexity of the problem. Thirdly, information on the interaction between the root systems of the component crops, the soil layers in which they forage, nutrient dynamics and depletion of soil moisture is lacking.

Research is also needed on the following: (1) the application of low rates of N fertilizer early in order to encourage N\textsubscript{2} fixation of the associated legume, as well as later application of N during the peak vegetative stage of the cereal in order to minimize competition for N; (2) the effects of applied N on N\textsubscript{2} fixation of the associated legume; (3) the effectiveness of slow-release N fertilizers to establish whether they minimize losses of applied N leading to minimization of competition; (4) the identification of crop combinations for use under various ecosystems and management levels, and (5) the contribution of rhizosphere N by cereals and mycorrhizal phosphorus uptake by legumes to the nutrient economy of intercropping systems.

In summary, intercropping is the predominant cropping system for the smallholder subsistence farmer and will probably remain so for many years to come. Due to the fast rate of population growth and limited farmland expansion, higher crop productivity per unit area has become necessary and so intercropping becomes even more important and could even be of relevance to large-scale agricultural producers also. Sustainable agriculture cannot be achieved if the demand for nutrients by crops is not matched with the supply by the soil. Therefore, clear objectives in this research area need to be formulated. Sole crop fertilizer recommendations are probably directly applicable in the less intensive forms of intercropping, e.g sequential, strip and relay intercropping. But for the intensive intercropping
systems, e.g. mixed and row, more nutrients than those needed by sole crops are required. In order to prevent rapid depletion of nutrients under intensive intercropping systems researchers are urged to identify ways and methods in which nutrients could be replenished each year.

The role of legumes in intercropping would be important for balancing the nitrogen economy in marginal areas for smallholder farmers. Under these conditions legume genotypes that are able to fix more and leave more N in the soil and those that are more compatible with prevalent mycorrhizal fungi (for P uptake) need to be identified for the more competitive intercropping systems. Under estate farming (large-scale production) the role of legumes for balancing the nitrogen economy may be relatively unimportant because under high N and P (from fertilizers) conditions symbiotic N\textsubscript{2} fixing systems and mycorrhizae are suppressed. Therefore, compatible associations between legume genotypes, rhizobia and VAM that tolerate high levels of N and P are preferable if they could be identified. Generally, crop components that respond to fertilizer application would be appropriate for intercropping in order to maximize productivity under improved fertility levels of estate farming. Alternatively, competition between crops could be minimized by selecting crops of different phenological development because these would reach peak demands for nutrients at different times. This would allow fertilizer applications to be split to enhance the productivity of one crop without either inhibiting that of other component crops or the nitrogen fixation of the legume component.
Preparation of different farming system models

Farming enterprises include crops/cropping systems (Field, horticultural, plantation), cattle rearing, poultry, fish, piggery, sericulture, mushroom, bee keeping, agroforestry, biogas, vermicompost etc. A combination of one or more enterprises with cropping when carefully chosen, planned and executed, give greater returns than single enterprise(s) specially for small and marginal farmers. Farm as a unit to be considered and planned for effective integration of the enterprises to be combined with crop production activities. In the IFS, it is always emphasized to combine cropping with other enterprises/activities.

Various components for integration are

- Parkland systems
- Trees on bunds
- Wind breaks
- Silvi-pasture system
- Agri-horticulture system
- Block plantations
- Economic shrubs
- Live fences
- Kitchen garden and polyhouses
- Composting, vermicomposting and biogass
- Crops + green leaf manure species (mixed/intercrops)
- Integrated animal based systems- Fisheries, Dairy, Piggery, Small ruminants, Poultry, Apiary
- Post-harvest value addition

For purposes of description and study, a farm can be divided by space and time factors into different enterprises, each having its own resource requirements and productivity pattern. This system includes all activities, either on or off the farm, that use farm resources. Most enterprises of the system are interrelated. The layout of the farm varies in response to many social factors (Grimble 1973, Ruthenberg 1971, National Research Council 1989 and Harwood 1974) and selection of models.

Criteria for enterprise selection

The basic points that are to be considered while choosing appropriate enterprise in IFS are,

1. Soil and climatic features of an area/locality.
2. Social status of the family and social customs prevailing in the locality.
3. Economical condition of the farmer (Return/income from the existing farming system).
4. Resource availability at farm and present level of utilization of resources.
5. Economics of proposed IFS and credit facilities.
6. Farmer’s managerial skill.
8. Institutional infrastructure and technological knowhow.

Priority should be given to improve the present status of different components of the existing farming system, should have better compatibility with prevalent farming system, nil to very less dependence of input from outside, high risk bearing and capable to generate more per day income and employment. In addition to this technological knowhow related to the enterprise(s) should locally be available and particularly no wastage of products and by products due to integration of enterprises.

**Interactions and linkages**

IFS deals with utilization of wastes and residues. It may be possible to reach the same level of yield with proportionately less input in the integrated farming and yield would be interestingly more sustainable because the waste of one enterprise becomes the input of another leaving almost nothing to pollute the environment or to degrade the resource base. To put this concept to practice efficiently it is necessary to study linkages and complementarities of different enterprises in various farming systems. The knowledge of linkages and complementarities will help to develop farming system (integrated farming) in which the waste of one enterprise is more efficiently used as inputs in another with the system (Fig 1).
Integration of enterprises

In agriculture, crop husbandry is the main activity. The income obtained from cropping is hardly sufficient to sustain the farm family throughout the year. Assured regular cash flow is possible when crop is combined with other enterprises. Judicious combination of enterprises, keeping in view of the environmental condition of locality will pay greater dividends. At the same time, it will also promote effective recycling of residues/wastes.

The Principle of Combining Enterprises:

A farm manager is often confronted with the problems as to what enterprises to select and the level at which each enterprises should be taken up. How far he can go far or should go in combine enterprises with another depends partly on the inter-relationships, between different enterprises and the prizes of products and inputs.

The principle of combining enterprises requires a prior study of the nature of relationship between enterprises. First consider the nature of relationship between enterprises. If the relationship is found to be complementary, efforts should be made to arrange resources for increasing the area of complementarity, as complementary relationship implies and increase in both the enterprises. But if the enterprises are competitive, their combination will depend upon consideration of the following factors:

1. Price ratio of the products
2. Substitution ratio of the products
3. Per unit cost of production
   a) When cost of production is equal, selling price is considered.
   b) When cost production is unequal net price is considered.
In the integrated system, selection of enterprises should be on the cardinal principle that there should be minimal competition and maximum complementary effect among the enterprises.

**Types of Enterprises**

**Independent Enterprises:**
Independent Enterprises are those which have no direct bearing on each other, an increase in the level of one neither help nor hinders the level of other. In such cases each product should be treated separately e.g. production of wheat and maize independently.

**Joint Enterprises:**
Joint products are those which are produced together e.g. cotton and cottonseed, wheat and straw etc. the quantity of one product decides the quantity of the other products. In case of joint products there is no economic decision to make with respect to the combination of products and two products can be treated as one.

**Competitive Enterprises:**
Competitive enterprises are those which compete for use of the farmers’ limited resources; use of resources to produce more of the one necessitates a sacrifice in the quantity of other product. When enterprises are competitive three things determine the exact combination of the product, which would be most profitable.

a. The rate at which one enterprises substitute for the other.

b. Prices of the products and

c. The cost of producing the product.

The rate at which one product substitutes for another is known as the marginal rate of substitution.

**The products can:**
1. Constant rates of substitution.
2. Decreasing rate of substitution
3. Increasing rates of substitution

E.g. paddy- sorghum, paddy- groundnut

**Supplementary Enterprises:**
Two products are said to be supplementary when an increase in the level of one does not adversely affect the production of the other but adds to the income of the farm i.e enterprise which do not complete with each other but adds to the total income. For example, on many small farms dairy enterprise or a poultry enterprise may be supplementary to the main crop enterprises because they utilize surplus family labour and shelter available and perhaps even
some feeds, which would otherwise go to waste. Some time enterprises are supplementary for one resource but competitive for another. In such cases the relationship should be treated as one of competitive. Even though they are supplementary to one another in respect of other sources e.g. mixed crops.

**Complementary Enterprises:**

Complementary enterprises are those, which add to the production of each other e.g. Berseem and maize crops. Two products are complementary when the transfer of available input for the production of the one product to the production of the other results in increases in the production of both products. Then two crops are complementary enterprises, the use of resources for the two crops result in the increased production of both the crops.

Two enterprises do not remain complementary over all possible combinations. They become competitive at some stages. When both complementary and competitive relationship occurs, the complementary relationship occurs first and then is followed by competitive relationship.

**Enterprise integration**

Livestock is the best complementary enterprise with cropping, especially during the adverse years. Installation of bio-gas plant in crop-livestock system will make use of the wastes, at the same time provides the valuable manure and gas for cooking and lightning. In a wetland farm there are greater avenues for fishery, duck farming and buffalo rearing. Utilizing the rice straw, mushroom production can be started. Under irrigated conditions (garden lands), inclusion of sericulture, poultry and piggery along with arable crop production is an accepted practice. The poultry component in this system can make use of the grains produced in the farm as feed. Pigs are the unique components that can be reared with the wastes which are unfit for human consumption. In rainfed farming, sheep and goat rearing form an integral part of the landscape. Sericulture can be introduced in rainfed farming, provided the climatic conditions permit it. Agro-forestry (Silviculture and silvi-horticulture) are the other activities which can be included under dryland conditions.
Synthesis of IFS models (using primary, secondary & on-station experimental data) - An example of WPZ of UP (1.2 ha with family size of 7)

Integration of enterprises

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Existing farming system</th>
<th>Scientifically validated IFS model</th>
</tr>
</thead>
<tbody>
<tr>
<td>Holding size</td>
<td>1.20 ha</td>
<td>1.20 ha</td>
</tr>
<tr>
<td>Household size</td>
<td>7 no’s (Adult: 5, Child: 2)</td>
<td>7 no’s (Adult: 5, Child: 2)</td>
</tr>
<tr>
<td>Cropping systems</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. Sugarcane-ratoon-wheat (60 % area, 0.72ha)</td>
<td>1. Sugarcane (spring) + onion-ratoon (12 % area, 0.12 ha)</td>
<td></td>
</tr>
<tr>
<td>2. Rice-wheat-summer sorghum (fodder) (30 %, 0.36 ha)</td>
<td>2. Rice-potato-wheat (0.15 ha) /marigold (0.15 ha)-dhaincha (26 % area, 0.30 ha)</td>
<td></td>
</tr>
<tr>
<td>3. Others (fodder, veg, fruits (10 %, 0.12 ha)</td>
<td>3. Maize for cobs +arhar-wheat (11 % area, 0.13 ha)</td>
<td></td>
</tr>
<tr>
<td>4. Others</td>
<td></td>
<td>4. Sorghum-rice-mustard (0.21 ha)/oat (0.07 ha)/berseem (0.07 ha) (28 % area, 0.35 ha)</td>
</tr>
</tbody>
</table>

Supplementary and complimentary enterprises

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Existing farming system</th>
<th>Scientifically validated IFS model</th>
</tr>
</thead>
<tbody>
<tr>
<td>Livestock/ household</td>
<td>Buffalo (B:2 no’s)</td>
<td>Buffalo (B:2 no’s)</td>
</tr>
<tr>
<td></td>
<td>Cattle (C:1 no’s)</td>
<td>Cattle (C:1 no’s)</td>
</tr>
<tr>
<td>Complementary</td>
<td>Nil</td>
<td>Apiary, vermicompost (0.7 % area, 100 m²), Karonda, citrus, jackfruit bel, subabul as boundary plantation</td>
</tr>
<tr>
<td>Supplementary</td>
<td>Nil</td>
<td>Hort: Mango, Guava + brinjal, tomato (16 % area, 0.20 ha), Fishery (7.5 % area, 0.08 ha)</td>
</tr>
</tbody>
</table>

Production and profit

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Existing farming system</th>
<th>Scientifically validated IFS model</th>
</tr>
</thead>
<tbody>
<tr>
<td>Production Crop</td>
<td>SEY: 56 t/annum</td>
<td>SEY: 108 t/annum</td>
</tr>
<tr>
<td></td>
<td>5088 litres/annum</td>
<td>6121 litres/ annum</td>
</tr>
<tr>
<td>Livestock*</td>
<td>Nil</td>
<td>SEY: 11.3 t/annum</td>
</tr>
<tr>
<td>Complementary</td>
<td>Nil</td>
<td>SEY: 25.5 t/annum (178 % increase in total)</td>
</tr>
<tr>
<td>Supplementary</td>
<td>Nil</td>
<td></td>
</tr>
<tr>
<td>Cost</td>
<td>Rs 1,34,500</td>
<td>Rs 1,81,000 (35 % increase)</td>
</tr>
<tr>
<td>Net Profit</td>
<td>Rs 80,000</td>
<td>Rs 1,51,000 (88 % increase)</td>
</tr>
</tbody>
</table>

SEY, sugarcane equivalent yield; *2 buffaloes + 1 cow
### Balanced food for the family

<table>
<thead>
<tr>
<th>Commodity</th>
<th>Requirement</th>
<th>Existing FS</th>
<th>Diversified system</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cereals (kg)</td>
<td>1550</td>
<td>4870</td>
<td>5135</td>
</tr>
<tr>
<td>Pulses (kg)</td>
<td>200</td>
<td>0</td>
<td>203</td>
</tr>
<tr>
<td>Oilseeds (kg)</td>
<td>130</td>
<td>0</td>
<td>236</td>
</tr>
<tr>
<td>Vegetables (kg)</td>
<td>900</td>
<td>0</td>
<td>4100</td>
</tr>
<tr>
<td>Fruits (kg)</td>
<td>200</td>
<td>0</td>
<td>2418</td>
</tr>
<tr>
<td>Milk (litres)</td>
<td>1120</td>
<td>5088</td>
<td>6121</td>
</tr>
<tr>
<td>Fish (kg)</td>
<td>154</td>
<td>0</td>
<td>430</td>
</tr>
<tr>
<td>Green fodder (t)</td>
<td>27</td>
<td>21</td>
<td>36</td>
</tr>
<tr>
<td>Dry fodder (t)</td>
<td>5.5</td>
<td>6.2</td>
<td>6.4</td>
</tr>
</tbody>
</table>

### Gain in water and nutrients

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Existing farming system</th>
<th>Scientifically validated IFS model</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nutrient application</td>
<td>External purchase: 608 kg N + 129 kg P₂O₅ + 77 kg K₂O + 44 kg ZnSO₄, Internal supply: 100 kg N + 40 kg P₂O₅ + 100 kg K₂O</td>
<td>Requirement: 310 kg N + 160 kg P₂O₅ + 110 kg K₂O, Internal supply: 204 kg N + 136 kg P₂O₅ + 187 kg K₂O (65 % N, 85 % P₂O₅ &amp; 100 % K₂O can be met within the farm)</td>
</tr>
<tr>
<td>Water Utilization</td>
<td>12000 m³</td>
<td>10000 m³</td>
</tr>
<tr>
<td>Net Water Productivity</td>
<td>Rs 6.6/m³</td>
<td>Rs 15.1/m³ (128 % increase)</td>
</tr>
</tbody>
</table>

### Gain and marketable surplus and employment

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Existing system</th>
<th>Scientifically validated IFS model</th>
</tr>
</thead>
<tbody>
<tr>
<td>Marketable surplus</td>
<td>Rs 1,05,984</td>
<td>Rs 2,10,456 (98 % increase)</td>
</tr>
<tr>
<td>Saving after meeting household demand and cost of system</td>
<td>Rs. (-) 28500 (excluding sugarcane*)</td>
<td>Rs 29500 (excluding sugarcane)</td>
</tr>
<tr>
<td>Employment</td>
<td>360 man days</td>
<td>625 man days (73 % increase)</td>
</tr>
</tbody>
</table>

---

* Considering net profit obtained from sugarcane is utilized for purchase of household items of pulses, oilseeds, vegetables, fruits and fish at market price
IFS Model for small farm holder (1.20 ha), 7 no. family members (Karonda in boundary; subabul for fuel and fodder)
Evaluation of cropping systems and FSR/IFS

Evaluation of Cropping Systems: Various types of cropping systems are practiced in a farm/region. They are to be properly evaluated to find out their stability and relative advantage. Such a comparison may be made with reference to land use efficiency, biological potential, economic viability, etc. Some of the important indices to evaluate the cropping systems are discussed here.

(i) Land Use Efficiency

(a) Multiple Cropping Index or Multiple Cropping Intensity (MCI): It was proposed by Dalrymple (1971). It is the ratio of total area cropped in a year to the total land area available for cultivation and expressed in percentage.

\[ MCI = \frac{\sum_{i=1}^{n} a_i}{A} \times 100 \]

Where, \( i = 1,2,3,\ldots, n \), \( n = \) total number of crops, \( a_i = \) area occupied by ith crop and \( A = \) total land area available for cultivation. It is similar to cropping intensity.

(b) Cultivated Land Utilization Index (CLUI): Cultivated land utilization index (Chuang, 1973) is calculated by summing the products of land area planted to each crop, multiplied by the actual duration of that crop divided by the total cultivated land area, times 365 days.

\[ CLUI = \frac{\sum_{i=1}^{n} a_i d_i}{A \times 365} \]

Where, \( i = 1,2,3,\ldots,n \), \( n = \) total number of crops, \( a_1 = \) area occupied by the ith crop, \( d_i = \) days that the ith crop occupies; and \( A = \) total cultivated land area available for 365 days.

CLUI can be expressed as a fraction or percentage. This gives an idea about how the land area has been put into use. If the index is 1 (100%), it shows that the land has not been left fallow and more than 1, speaks about the specification of intercropping and relay cropping. Limitation of CLUI is its inability to consider the land temporarily available to the farmer for cultivation.

(c) Crop Intensity Index (CII): Crop intensity index assesses farmer’s actual land use in area and time relationship for each crop or group of crops compared to the total available land area and time, including land that is temporarily available for cultivation. It is cultivated by summing the product of area and duration of each crop divided by the product of farmer’s total available cultivated land area and time period plus the sum of the temporarily available land area with the time of these land areas actually put into use (Menegay et al., 1978). The
basic concept of CLUI and CII are similar. However, the latter offers more flexibility when combined with appropriate sampling procedures for determining and evaluating vegetable production and cropping pattern data.

Specific Crop Intensity Index

\[
SCII = \frac{\sum_{i=1}^{Nc} a_k t_k}{AoT \sum_{j=1}^{M} A_j T_j}
\]

Where, \( i = 1,2,3,\ldots, Nc \), \( Nc \) = total number of crops grown by a farmer during the time period, \( T \), \( a_i \) = area occupied by ith crop, \( t_i \) = duration of ith crop (months that the crop i occupied an area \( a_i \)), \( T \) = time period under study (usually one year), \( Ao \) = Total cultivated land area available with the farmer for use during the entire time period, \( T \), \( M \) = total number of fields temporarily available to the farmer for cropping during time period, \( T \), \( j = 1,2,3,\ldots, M \), \( A_j \) = land area of jth field and \( T_j \) = time period \( A_j \) is available. CII = 1 means that area or land resources have been fully utilized and less than 1 indicates under utilization of resources.

(ii) Biological potential

Production Efficiency (PE):

(a) Crop Equivalent Yield (CEY): Many types of crops/cultivars are included in a multiple cropping sequence. It is very difficult to compare the economic produce of one crop to another. To cite an example, yield of rice cannot be compared with potato yield. Similarly the yield of crops grown for fodder purposes cannot be compared with the yield of grain cereals or pulse crops and so on. In such situations, comparisons can be made based on economic returns (gross and net returns). The yields of protein and carbohydrate equivalents can also be calculated for valid comparison. Efforts have also been made to convert the yields of different crops into equivalent yield of any one crop such as wheat equivalent yield (Singh, 1997). The equation for calculating wheat equivalent yield (WEY) is as follows:

\[
WEY = \sum_{i=1}^{n} (Y_i e_i)
\]

Where, \( Y_i \) = the economic yield of ith crop, \( e_i \) = the wheat equivalent factor of ith crop, \( e_i = \frac{P_i}{P_w} \), \( P_i \) = the price of unit weight of ith crop, and \( P_w \) = the price of a unit weight of wheat.
This type of comparison is valid when considering the gross returns. However, it does not indicate the net gain obtained from a cropping system. This will not give any explanation about the land use pattern of the cropping system.

Some of the common indices have been developed to measure and compare farm land use and production potential in multiple cropping. Land Equivalent Ratio is the most important one.

(b) Land Equivalent Ratio (LER): This is the most frequently used efficiency indicator. LER can be defined as the relative area of sole crop that would be required to produce the equivalent yield achieved by intercropping.

\[ LER = \sum_{i=1}^{n} \frac{Y_{ab}}{Y_{aa}} + \frac{Y_{ba}}{Y_{bb}} \]

Where, \( Y_{ab} \) = yield of crop a in intercropping, \( Y_{ba} \) = yield of crop b in intercropping, \( Y_{aa} \) = yield of crop a in pure stand and \( Y_{bb} \) = yield of crop b in pure stand.

LER of more than 1 indicates yield advantage, equal to 1 indicates no gain or no loss and less than 1 indicates yield loss. It can be used both for replacement and additive series of intercropping.

(iii) Economic viability

(a) Gross returns or Gross profit: The total monetary returns of the economic produce such as grain, tuber, bulb fruit, etc. and bye-products viz., straw, fodder, fuel, etc. obtained from the crops included in the system are calculated based on the local market prices. The total return is expressed in terms of unit area, usually one hectare.

The main drawback in this calculation is that the market price of the produce is higher than that actually obtained by the farmer. Generally gross returns calculated is somewhat inflated compared to the actual receipt obtained by the farmer.

(b) Net returns or net profit: This is worked out by subtracting the total cost of cultivation from the gross returns. This value gives the actual profit obtained by the farmer. In this type of calculating only the variable costs are considered. Fixed costs such as rent for the land, land revenue, interest on capital, etc. are not included. For a realistic estimate, however, fixed costs should also be included.

(c) Rupees per rupee invested: This is also called profit-cost ratio or input-output ratio.

\[
\text{Return per rupee invested} = \frac{\text{Gross returns}}{\text{Cost of cultivation}}
\]
(d) **Per day return**: This is called as income per day and can be obtained by dividing the net returns by number of cropping period (days).

\[
\text{Per day return} = \frac{\text{Net returns}}{\text{Cropping period (days)}}
\]

This gives the efficiency of the cropping system in terms of monetary value. If the system is stretched over one year, the denominator can be replaced by 365 days and per day return for the whole year can be calculated.

**Farming system**

1. **Productivity (Productivity per unit area)**: To estimate the productivity of a component and compares with the crop component expressed in terms of equivalent crop yield. Further the production estimation itself varies among the interlinked animal component in IFS i.e. Rice based farming system

   Productivity in term of grain yield can be recorded and expressed as kg of grain equivalent yield (GEY),

   \[
   \text{GEY} = \frac{[\text{Productivity of component/intercrop (kg)} \times \text{Cost of component/intercrop (Rs/kg)}]}{\text{Cost of main crop (Rs/kg)}}
   \]

2. **Economic analysis**: Parameters like cost of cultivation/production, gross and net return and per day return can be worked out and expressed as Rs/ha.

3. **Employment generation**: Labour required for various activities in crop production given as man days/ha/year (A man working for 8 hours in a day is considered as one man day; A woman working for the same period is treated as 2/3 man day and computed to man days).

4. **Productivity of Livestock Components**: Milk (per day or lactation), dung, urine etc

   Fisheries: Fish weight recorded at harvest and expressed as kg/unit area.
   Poultry: Egg production per day from birds and expressed as total number per month/year from the unit.
   Pigeon: Growth rate at monthly interval and weight at the time of disposal recorded and expressed as kg/unit.

5. **Mushroom**: yield per day and total yield per year from the unit.

6. **Water requirement**: Water requirement for varying component linkages in the IFS expressed in ha-cm.

7. **Residue addition**: the quantity of residue available from each component (kg). Potential residue addition in terms of N, P and K.

8. **Energy efficiency**: Energy input and output was worked out for individual components based on the input and output energies and energy efficiency.

9. **Nutritive value**: Nutritive value in terms of carbohydrates, proteins and fat (kg)
Economics as the framework for farm-system analysis

Economics or economic analysis is the science of making choices so as to best achieve desired objectives given that only limited (physical and other) resources and opportunities are available and that the future is uncertain. There are no choices to which the science of economics cannot be applied. It is just as pertinent, e.g., to the choice of a spouse as to the choice of which crops to grow or to the choice between using an insecticide or using environmentally friendly integrated pest management. In contrast to this wide applicability of economic analysis, financial analysis is restricted to matters that are naturally of a financial or monetary nature. Financial analysis is thus a subset of economic analysis and, in circumstances where everything is valued in money terms, may be the natural way in which to conduct economic analysis. In other cases, it may be feasible to facilitate economic analysis of possible choices by imputing money values to possible gains and losses. And in yet other cases, such as assessing the resource sustainability and environmental compatibility of alternative farm systems, it may often be infeasible to impute money values to the gains and losses of alternative choices. Decisions must then be made using economic analysis based on non-money values, intuition and judgement.

Farm management economics (i.e., economic analysis applied to the choices confronting farmers) provides the general disciplinary basis for farm-level systems analysis. Obviously other farm and family-related disciplines will be involved in systems' construction: agronomy, animal husbandry, soil and water conservation/management, human nutrition etc. However, except in the case of special-purpose technical systems (e.g., when the farm-household unit is analysed in terms of nutritional or energy flows among components), these other disciplines should play subordinate contributing roles coordinated by farm management economics as the lead discipline. That in fact this often does not happen and the lead is taken instead by workers in other disciplines is really not important. It might just reflect the fact that many agriculturists are aware of the necessity for a systems approach if application of their expertise is to be effective; or that many agricultural economists are content in the more modest role of economics.

Nevertheless, the disciplinary basis of farm management remains economics - but economics of a special wide-ranging kind, the core of which is production economics supported by other branches of economics of which marketing, resource economics, agricultural credit and data analysis (including operations research, econometrics and risk analysis) are probably the most
important. When working with the household component, especially of small traditional farms, the most important supporting disciplines are sociology and social anthropology.

**Alternative bases for farm-system analysis**

There are several reasons why farm economics provides a good conceptual framework for most farm-household systems analysis. The most important of these is the necessity to bring the many relationships of a system and between systems to some common unit or basis of comparison. Unless this is done, systems analysis and the comparison of alternatives will not be possible. The base usually most convenient - and in the case of commercial farm systems most relevant and which has the highest degree of universality - is money or financial value. But several other bases for systems analysis are possible and in certain circumstances they might well be more relevant than money value. The four most important bases of comparison are as follows:

(a) **Money value:** The convenience of using money or financial values as the basis of commercial farm systems analysis will be obvious: it permits the various system inputs (e.g., seed, fertilizer, power, labour etc.) to be standardized as money costs and the various system outputs to be standardized as money returns so that net revenue, i.e., money returns minus money costs, can be used as the basis of comparison between alternatives. In commercial farming, all or most of these inputs/costs and outputs/revenues can be stated in explicit quantitative terms. On the other hand, when dealing with less commercialized systems where there are no actual price-setting markets for farm inputs and/or outputs, one is often obliged to base the analysis on imputed values. However, this is possible only up to a point; beyond this point, as one moves further from a commercial environment towards a traditional one, the attempted use of money value as the basis for analysis becomes too abstract to be useful and one has to search for some other base.

(b) **Family labour effort:** Probably the best alternative to money value on small family farms of a subsistence or semi-subsistence nature is labour input, both as a measure of inputs and as a yardstick to judge the worth of outputs. At least this is so in the eyes of the majority of Asian (and African) small-farm families for two reasons. First, on these farms most production activities involve few if any commercial inputs and most outputs are also not disposed of through commercial channels. Money hardly enters into the matter at all. What such activities do have as their common factor is family labour - often very hard labour - from hand-preparation of fields, to carrying all inputs/outputs perhaps long distances, to hand-pounding the harvested grain. Not unnaturally then, these families plan, compare and
evaluate their several different farming activities and alternatives (i.e., analyse their systems) in terms of labour content. To conduct such analysis on any other basis such as money value would be an incomprehensible abstraction. However, 'labour' is not a simple quantity. It can have several dimensions: quantity when labour is measured in terms of standardized units (e.g., labour-days or task-days on estates); quality where the relevant factor is the actual effort required or the degree of skill or unpleasantness associated with separate tasks; and agency where the labour measurement reflects the social position or status of the person performing the task. Thus, in different societies, patriarchal or matriarchal, women's labour will be valued less or more highly than the labour of men regardless of the actual effort expended, while the labour performed by children might also be valued according to their (usually inferior) social status rather than to the actual work they perform. These dimensions of labour and the implied difficulties of measurement often limit the use of this factor as an alternative to money value. Nevertheless labour often provides a more relevant basis for systems analysis of a very large number of small traditional farms than does money.

(c) Bio-mechanical energy: A factor which all farm-household systems and their subsystems have in common is their explicit or implicit energy content (including labour, above). Farm-system models have sometimes been structured on the basis of such energy content and inter-component energy flows - see, e.g., Axinn and Axinn (1983). Use of energy-based farm systems analysis rests on the view that, in a world of declining energy resources and materials that can be represented by their energy content, the energy generation and consumption of farm-household systems is a more valid basis for systems analysis than is money profit, and usually also that energy flows which are directly or indirectly involved in all economic activities (including agriculture) are not properly represented - indeed they are often severely distorted - by commercial pricing mechanisms. However, these views involve issues and require solutions at much higher than farm level. Farm systems analysis based on energy flow is more appropriate for some aspects of macro/industry/sector strategic planning than for farm-level operational planning where the immediate interest of farm families is in income (in whatever form it takes) and the effort required to achieve it.

(d) Water consumption: A fourth possible basis for analysis of farm systems is offered by water with systems analysis conducted in terms of the relative water consumption of different crops and animal populations and the implicit water content of products and by-products. Water is obviously the critical common factor in all the farming systems of that great belt of lands stretching from North Africa to India, so much so that even the very wealthy Gulf
States, while they have been able to import or create all other agricultural resources, including soils, micro-environments and farmers, remain constrained by water. Moreover, in the 'wet' tropics, the critical nature of this input common to all parts of all farming systems is not yet widely recognized; e.g., even 'well-watered' Java will probably exhaust its water supplies before its soils. However, as important as water is, like bio-mechanical energy it is more appropriate as a basis for some aspects of macro-level systems analysis than for operational-oriented systems analysis at farm level.

In summary, except when used in connection with special-purpose systems, such bases of analysis as energy, water, ecological balance etc. lack the universality and the value orientation required of a general systems base. Money value and labour will probably continue to be used as such a base, either separately in the case of commercial and near-subsistence farms respectively, or jointly in the case of the bulk of small traditional partly commercialized farms.
New concepts and approaches of farming systems and cropping systems and organic farming

The Farming Systems

Prior to the mid-1960’s, active research collaboration between technical agricultural scientists (i.e., mainly working on experiment stations), agricultural economists (i.e., mostly in planning units) and anthropologists/rural sociologists (i.e., generally in academia), was limited. By the mid-1960s, the Green Revolution was beginning to have a major impact on crop production in parts of Asia and Latin America through the introduction of fertilizer-responsive, high-yielding varieties of rice, wheat, and maize in favourable and relatively homogeneous production environments where there was assured soil moisture, good soils, ready access to cheap fertilizer, and relatively efficient output markets. However such conditions did not exist in most of Sub-Saharan Africa and in certain parts of Latin America and Asia, and as a result, these areas were bypassed.

The reductionist approach failed in terms of developing technologies for resource-poor farmers in less favorable heterogeneous production environments or agricultural areas. This led to the incorporation of a systems perspective in the identification, development, and evaluation of relevant improved technologies. Hence in the mid to late 1970s, the farming systems research (FSR) approach evolved, a basic principle of which was the need to create new types of partnerships between farmers and technical and social scientists.

FSR thus became very popular with donor agencies, to the extent that, by the mid 1980s, about 250 medium- and long-term externally funded (i.e., in addition to those domestically funded) projects worldwide were implementing FSR-type activities. Between 1978 and 1988, USAID alone had funded 76 bilateral, regional, and centrally funded projects containing a farming systems orientation. Forty-five of these were in Africa. Most of these projects supported the establishment of separate FSR units, which often were poorly integrated into, or poorly linked to, mainstream technology development activities. Although it is probably true to conclude that few of these projects succeeded in producing new technologies that were widely adopted, the approach of looking at farmers’ constraints and needs for technical change from within was eventually mainstreamed into most national and international agricultural research programs by
the late 1980s. Therefore although donor support for supporting explicit FSR activities dwindled towards the end of the 1980s, most national agricultural research systems (NARS) had adopted major components of the FSR philosophy and approach, and the spirit of the FSR approach lived on.

Since then there has been considerable evolution in the methodologies employed (e.g., new farmer participatory research (FPR) techniques, gender analysis, environmental impact analysis, and statistical techniques adapted to on-farm research). Also participation has been broadened to include a wider set of agricultural stakeholders, including extension, development, and sometimes even planning/policy staff. Perhaps even more significant has been incorporating the underlying principles of the farming systems approach into the priorities of donors and nationally based agricultural programs. These include increasing emphasis on participatory approaches and empowerment of farmers and their families and a new focus on ecological sustainability and sustainable livelihoods. Although appropriate technologies still are viewed as important catalysts for improving farmers’ welfare, the criteria for relevancy have become more clearly defined and specific.

In this discussion it is summarised how the farming systems approach that has evolved over the last 40 years with a very brief indication of the factors that contributed to bringing about those changes. A key dimension of that evolution has been the way the scope or inclusiveness of a systems perspective has been expanded systematically over time. “The way in which the systems perspective is implemented, in particular the scope or inclusiveness of the systems analysis, depends on how, for any given problem, researchers define the ratio of variables to parameters; or put another way, which factors are considered endogenously determined and thus subject to analysis and modification, and which are taken as exogenously determined constants. Because of the analytical difficulties of simultaneously handling large numbers of variables, most of the early FSR programs took only incremental steps away from traditional reductionist approaches by limiting the number of variables they studied and by regarding the other factors that influence the farming system as parameters or constants. As analytical methods have grown more sophisticated, and particularly as farmers have become active partners in the analysis, the ratio of variables to parameters has increased, and the analytical domain has expanded considerably” [Norman and Matlon, 2000].
This evolutionary process is operationally summarized in four phases:

1960’s TO EARLY 1970’s – Farm Management

The farm management approach of the early 1900s was in many ways analogous to what the farming systems approach had become in the latter part of the same century. The farm management of the early 1990s was multidisciplinary and holistic whereas by the middle of the century it, at least in the US, it had become narrower and more reductionist in perspective and increasingly focused on production economics. Emphasis was on normative and prescriptive issues through application of techniques such as budgeting, linear programming, and other tools for applied decision analysis [Johnson, 1981]. Thus agricultural economists armed with these analytical tools and with a strictly neoclassical orientation dominated the farm management-type studies undertaken in the low-income countries during the 1960s. Although useful studies using a more positivist orientation were conducted by sociologists and anthropologists, many of whom predated the work of the agricultural economists, they did not have a major influence on the initial development of the farming systems approach, at least in anglophone countries. They appeared to have had somewhat more influence in francophone countries.

Many of agricultural economists, associated with development/government organizations, academic institutions, and/or occasionally agricultural research institutions working independently, and spent the 1960s using formal, structured, cost-route, farm-management-type sample survey techniques, to describe farm-level resource allocation patterns and productivity among resource-limited farmers in Asia, Latin America, and Africa.

These studies produced a great deal of quantitative information describing cropping systems (and to a lesser extent farming systems) and their major socio-economic production constraints. They also described how households allocated their resources, and provided estimates of factor returns. Such studies were particularly common in Africa and Asia, but less common in Latin America, where economists generally had greater preoccupation with institutional or policy-related issues. These studies showed overwhelmingly that limited-resource farmers have an intimate understanding of their spatially variable and temporally risky production environments within which complex (i.e., combining crop, livestock, and off-farm enterprises) but fundamentally sound and sustainable farming systems had evolved over time. Given these very positive findings about the rationality of limited-resource farmers and the farming systems they
practiced, the focus of questions soon shifted to why formally recommended technologies were adopted so rarely [Matlon, 1987].

Thus many agricultural economists, particularly those associated with research stations in Africa, Asia, and Latin America, began to evaluate recommended technologies (i.e., usually packages and typically crop-oriented). Prior the mid-1960s, very few station-based experiments were subjected to any economic analysis, and therefore it was not surprising that the conclusion that often emerged was that many existing recommendations were poorly designed or irrelevant, especially when criteria relevant to farmers were applied. In addition three other significant insights emerged:

• Contrary to expectations of many, farmers were found to be natural experimenters [Biggs and Clay, 1981], using informal methods and consequently it was wrong to conclude they were conservative and averse to change.

• Farmers’ production environments were found to be much more heterogeneous than had been thought, and consequently there was a need to develop technological components that could be adjusted easily and combined variously to better respond to location-specific needs, rather than relying on a few technological packages (i.e., the one size fits all syndrome!).

• And although the recommended technological packages were sometimes compatible with the biophysical environments within which farmers operated, farmers were often not able to adopt them because of their incompatibility with the socioeconomic environment within which they operated [Norman et al., 1982].

Questions started arising as to whether the current process for developing and evaluating technologies was relevant for resource-poor farmers operating in less favourable and highly variable environments. It also became apparent that standard conventional economic criteria didn’t ensure identification of a relevant technology (e.g., farmers and their households had goals other than profit maximisation, there were usually multiple market failures for capital, labour, land, and information, and risk and uncertainty were significant issues). As a result many of us came to the conclusion that:

• The neoclassical economic paradigm was ineffective in dealing effectively with all the issues relating to small-scale farmers.
• The approach was also too static and deterministic in its orientation rather than recognizing that farmers operate in a dynamic and often uncertain environment.
• The approach of extracting data from farmers (i.e., treating them as objects) and analyzing it independently was much inferior to an approach that recognized the benefits of synergism as a result of interaction and active participation on the part of farmers themselves.
• The approach was flawed in its *ex post* orientation of focusing on evaluating available technologies, rather than using one that encouraged an *ex ante* involvement of farmers in the technology design and development process itself.

As a result many argued for that the conventional research paradigm needed to be modified drastically and replaced by one that would involve farmers as stakeholders from the beginning of the technology design process and that would use an interdisciplinary approach. Thus momentum developed for the evolution of a new approach based on changing from a “top-down” (“supply-driven”) approach to farmers, to one characterized as being “bottom-up” (“demand-driven”) from farmers.

**LATE 1970s To EARLY 1980s – Early Farming Systems Approaches**

Given what was discussed in the preceding section it is not surprising that the newly christened FSR activities were focused primarily on technology development objectives [Gilbert et al., 1980]. In the anglophone countries, several of the international agricultural research institutes (IARCs) (i.e., especially IRRI and CIMMYT) associated with the Consultative Group on International Agricultural Research ( CGIAR) played important roles in the early methodological development and popularisation of FSR. At the same time FSR was introduced, with donor support, in many nationally sponsored agricultural research institutes in low-income countries.

The FSR approach that evolved was based on the notion that: one had to begin with understanding the problems of farmers from the perspectives of farmers; and that solutions had to be based on a proper understanding of their objectives and their environments, including both biophysical and socioeconomic components. Also a central tenet of the new approach was that not only did farmers have a right to be involved in the technology development and evaluation process, but that their inputs were essential. Other significant features were its holistic perspective, the fact that scientists involved in the process should represent both technical and social scientists, and that the process was by nature iterative. Consequently, some of the
characteristics of the early farm-management approach started to reappear, leading Johnson to observe, in commenting on the new FSR methods, “there has been much reinventing of the wheel in developmental thinking”.

Although there was a commitment in principle to include a broader set of farmer-based criteria, in its earliest days FSR continued to focus on how yields of particular crops could be increased. However, even though the new on-farm research approach did involve the inclusion of socioeconomic elements, and hence had a farming systems perspective, it was done generally with a predetermined focus that targeted the productivity of a particular commodity. Thus, this approach involved looking at one part of an enterprise or one specific enterprise and identifying improvements within that focus that were compatible with the whole farming system. For example, CIMMYT and IRRI worked on maize-, wheat-, and rice-based systems, which were compatible with their crop mandates. Undoubtedly they had a favorable impact in introducing more of a systems perspective to the influential commodity-based research programs that had a strong reductionist orientation. They believed that the predetermined focus approach was directly relevant to farming systems dominated by one crop, because improving the productivity of that enterprise would have the greatest impact on the productivity of the overall farming system. These two IARCs, in particular, played influential roles through networks and training programs in Africa and Asia, thereby exposing scientists to the principles of the farming systems approach.

Although the IARCs undoubtedly played an important role in introducing and nurturing the farming systems perspective within national agricultural research systems (NARS), simultaneous independent efforts occurred in developing and promoting the approach, usually supported by donor funds. Notable examples were ICTA (Guatemala), Changmai (Thailand), Unite Experimentales, ISRA (Senegal), and the Institute of Agricultural Research, Ahmadu Bello University, Northern Nigeria. Because of the multi-commodity mandates of most NARSs, the farming systems efforts evolved quickly towards a more holistic orientation (i.e., what is labelled farming systems with a whole farm focus). This approach enabled focusing on constraints in any enterprise depending on farmers’ articulated needs. This evolution was further stimulated by two other factors, specifically:
• A desire to encourage greater participation by farmers through addressing their specific needs rather than simply trying to “fit” technologies to specific enterprises that had been preselected by researchers/mandates.

• The trend towards establishing separate area-based farming system teams in contrast to an on-farm testing component associated with each station-based commodity team.

The dominant disciplines in the early days of the farming systems approach were cropping systems agronomy and agricultural economics and the methodologies reflected this discipline mix. The trend away from treating farmers as “objects” to treating them as “people”, with whom useful interactive dialogue could be established, was helped greatly by increasing reliance on informal surveys or rapid rural appraisal (RRA) techniques. The results of these were sometimes verified by limited-visit formal surveys. The results were helpful in designing on-farm trials that were either managed by researchers or farmers -- but usually executed by the latter -- and were validated by conventional statistical techniques. Trials superimposed as separate plots on farmers’ operational fields also became commonplace.

Three very positive results from these early experiences with the farming systems approach:

• Technical scientists were increasingly sensitised to the complexity and variability of farmers’ production environments (i.e., consisting of both physical and socioeconomic components) thereby helping reorient technology generation towards addressing needs of different types of farmers and emphasizing more flexible technological components rather than simply blanket-type package technologies.

• The approach provided an opportunity for technical and social scientists to cooperate in the diagnosis of farmers’ situations and in the design, testing, and evaluation of new technologies, thus helping those concerned to better understand better the disciplinary perspectives and tools of other specialties.

• Results also demonstrated the importance of complementary policy/support systems (e.g., input distribution systems and product markets) in determining the appropriateness of new technologies.

However, a number of limitations or weaknesses became increasingly apparent. Five particularly significant weaknesses were:
• Farmers’ participation was still limited largely to roles assigned by researchers and methodologies for obtaining and systematizing farmers’ knowledge and for analyzing the results of on-farm experiments were also poorly developed, often resulting in scepticism about how valid were researchers’ interpretation of information obtained from farmers.

• Although the complexities of linkages between farm and household in influencing decision making and flows of resources and benefits were increasingly recognized, methodologies for incorporating such considerations into technology design and evaluation were inadequate and too often purely subjective and ad hoc in nature.

• Although some linkages had been developed between the different disciplines (i.e., mainly agronomy and agricultural economics) there was still a lot of room for improvement. The application of the farming systems approach to livestock enterprises was generally particularly weak.

• The most commonly used methodologies for data collection and analysis generally were based on the assumption of a monolithic household that could be described by a single objective function and with the household head at the center of the information nexus, in spite of increasing evidence to the contrary (e.g., multiple decision makers, differentiation in terms of distribution of benefits).

• Factors relating to the policy/support system were treated as parameters within which the search for improved technologies took place. This was partly because the mandates of the technology-oriented institutions in which most farming-systems-related work was – and for that matter still is -- based did not include objectives of influencing the policy context and support systems. As a result this severely constrained the types of technologies that could be developed/evaluated.

Fortunately, there was increasing recognition of the above limitations as the decade of the 1980s progressed. The changes that occurred during the decade were supported by an increasing acceptance of a new developmental paradigm, which Korten [1980] characterizes as a “learning process” (i.e. people centered) approach to the earlier “blueprint” (i.e. technology) approach.
LATE 1980s AND EARLY 1990s – NEW DIRECTIONS IN THE farming systems

Approach

During the mid to late 1980s, some significant methodological and institutional innovations were introduced in the implementation of the farming systems approach with a whole farm focus.

Three of the methodological innovations were as follows:

• The development of participatory rural appraisal (PRA) techniques provided a way of responding to three concerns namely: how farmers interpreted their production situations; how this influenced the way they articulated their constraints and needs to researchers; and the desire for farmers to contribute more directly and creatively to the design and evaluation of new technologies. Basically, PRA techniques improved the potential usefulness of farmers’ participation not only from the farmers’ but also from the researchers’ perspective by improving systematization of farmers’ knowledge and opinions. Thus researchers could move from working relationships with farmers that were contractual or at best consultative to those that were more consultative and collaborative [Biggs, 1989].

• Techniques for examining intra-household relationships also evolved and as a result increased sensitivity to gender issues. This helped dispel the notion that the farming household was a single decision making unit in which all persons benefited equally from the fruits of technological change. Thanks to the commitment of Feldstein, Poats, Jiggins, Flora and many others methodologies for incorporating gender-related issues began to be mainstreamed into FSR-related activities starting in about the mid 1980s.

• Significant progress also was made in developing more appropriate methods to analyze the results of on-farm research and make recommendations based on them. Two approaches that deserve special mention are: adaptability (formerly, modified stability) analysis which has proved to be a particularly valuable statistical tool for analyzing results of on-farm trials, particularly those that involve farmer implementation, or both farmer management and implementation [Hildebrand and Russell, 1996]; and PRA techniques – especially matrix ranking and scoring -- which have enabled farmers’ evaluative criteria to be systematically taken into account not only in designing on-farm trials but also in evaluating their results.

As a result of these methodological innovations, the potential usefulness of farmer participation in all phases of the research process, from problem identification to technology design,
development, and evaluation, has been improved. However, there have also often been institutional changes to encourage more collaborative and collegial relationships between farmers and researchers. Four examples of how new institutional arrangements have been used to promote such relationships are the following:

- Farmer groups (both formal and informal) have increasingly been used to help empower farmers and improve the efficiency of the research/development process by providing a focal point (hence potentially improving the multiplier effect) for interaction with farmers [Heinrich, 1993] and by facilitating farmer-to-farmer interaction. Given the right conditions, such groups have been proven to be very useful in influencing the research agenda and in evaluating technologies (e.g., in Botswana, Tanzania, Mali, Zambia).

- Another less widely used, but potentially even more powerful, way of empowering farmers -- thereby facilitating the development of collaborative/collegial working relationships -- is to involve farmers groups in the decision to allocate research funds, thereby ensuring that the agricultural research agenda is focused more tightly on farmers’ real needs. Ashby of CIAT has been one of the pioneers of this approach through the formation of CIALS (Comités de Investigacion Agropecuaria Local) in Colombia [Ashby et al., 1995]. Somewhat analogous approaches are also being tried in some West African countries (e.g., Mali, Senegal).

- Until relatively recently, the conventional wisdom was that farmers’ participation in the technology development process should be confined to the adaptive end of the research spectrum but thanks to the pioneering efforts of Sperling and colleagues [Sperling, 1991] working with beans in Rwanda, farmers have been found to be able to make uniquely valuable contributions toward the development of improved varieties. As a result, participatory plant breeding activities have become increasingly popular in a growing number of IARCs (e.g., beans in CIAT, maize in CIMMYT, pearl millet in ICRISAT, barley in ICARDA, and cassava in CIMMYT) as well as in a few NARSs [Witcombe et al., 1996].

- The number of agricultural development actors has expanded in recent years from farmers and public sector agencies to include private sector profit-oriented entities as well as NGOs. The importance of interactive linkages between the developmental stakeholders if relevant technologies were to be designed, disseminated, and adopted, was recognized in the early days of FSR. Thus the establishment of committees at the regional/district level consisting of
representatives of the different stakeholders, often including farmer representation, for 
information exchange, enhanced coordination, and design of collaborative initiatives has 
become more commonplace. Decentralization policies in terms of governance and in some 
countries local approval of technological recommendations (i.e., thus helping ensure that new 
technologies are more likely to address the needs of specific farmers) have also helped this 
process.

Consequently, major improvements have occurred in the application of farming systems with a 
whole-farm focus from the mid-1980s until the present time. Also, the range of social (e.g., 
anthropological, sociological) and technical (e.g., pest-, disease-, livestock-related) disciplines 
associated with the application of the farming systems approach has broadened, and farmers and 
their households have increasingly played more influential roles in all aspects of the 
technological research process.

Other major changes have involved developing technological options rather than standardized 
packages for farmers and increased transparency in providing information on the conditions in 
which technologies are most likely to fit and perform best (i.e. targeting information) and 
suggested fallback strategies if they are not applied in the optimal manner (i.e. conditional 
information) [Byerlee, 1986].

Most current FSR efforts of NARS fall within the whole-farm focus phase of the farming 
systems evolutionary ladder, although the degree to which the methodological and institutional 
issues discussed in this section are applied varies greatly. However, another major limitation that 
became increasingly apparent towards the end of the 1980s related to concerns about ecological 
sustainability and environmental degradation. Farmers often appreciate that some of their 
agricultural practices may contribute to environmental degradation, but short-term survival 
considerations can lead them to pursue strategies that ensure short-run food supplies but degrade 
the environment and reduce longer run production potential (e.g., resource-poor households 
being forced to cultivate marginal soils to meet their subsistence needs or to intensify cropping 
systems without the means to purchase the inputs necessary for soil fertility maintenance). 
However, evidence is also increasing that higher income farmers practicing high-input cropping 
also cause significant environmental damage (e.g., decreasing productivity in the intensive rice-
wheat systems of South Asia).
Although researchers often perceive or foresee ecological degradation to be a problem, farmers for reasons just given, may not mention such concerns, unless they threaten immediate survival [Fujisaka, 1989]. Thus, such concerns may not be addressed adequately in FSR, as it was originally conceptualized. Because felt needs articulated by farmers are likely to be strongly biased towards short-run productivity, researchers and development practitioners are increasingly concerned about possible conflict between strategies designed to improve short-run productivity and those aimed at ensuring long-run ecological sustainability. As a response to this, the principles of the farming systems approach and RRA/PRA have increasingly addressed ecological sustainability -- hence the term farming systems with a natural resource systems focus.

Incorporating the farming systems approach into natural resource-related issues has taken two major directions:

- One has involved development and implementation of methodologies to work with farmers to assess bioresource (nutrient) trends and flows at the farm-household level. The idea is to determine biomass trends over time and to help identify, with the farmer, vulnerable parts of the farming system for which modified strategies are needed to promote ecological sustainability. Many of these techniques have their origin in RRA/PRA. Lightfoot and others at ICLARM developed the principles for the approach, which involved integrating aquaculture and agriculture [Lightfoot, Bottrall et al., 1991]. A somewhat analogous approach has been developed by Defoer and colleagues in Africa [Defoer et al., 2000], also involving extensive interaction with farmers to derive bioresource flows on their farms and to identify strategies for reversing any trends towards ecological degradation. These approaches help promote ecologies problems from a foreseen problem to a felt problem in the eyes of the farmers and depend heavily on farmer empowerment and on interactive collaborative/collegial relationships with researchers and development practitioners. The solutions often are farm-specific and involve changes in practices, and, as such, implementation is primarily the responsibility of farmers and their households. Hence, farmers need to buy into adjustments via the participatory identification and design stages.

- The other is ecoregional research, which has been undertaken by some IARC's in collaboration with national research and development institutions. The goal has been to mobilize and focus
CGIAR and national funding on natural resource management research with the twin objectives of improved productivity and environmental conservation. Teams of international and national scientists conduct collaborative research targeted at priority regional problems, the aim being to achieve critical mass and economies of scale in the conduct of strategic and applied research, closely linked to adaptive research to address location-specific conditions. The approach involves, in a collaborative operational mode, all the stakeholders involved in the agricultural development process.

There are at least three major challenges when implementing farming systems with a natural resource focus. These are: that large investments are required to address complex processes that are manifested differently across locations; a long time frame needed to improve ecological sustainability and assess progress; and finally, because of the precarious existence of many farmers and their households, ecological sustainability initiatives are likely to be attractive only if they simultaneously improve short-run welfare.

**Currently – A Sustainable livelihood focus**

During the 1970s and 1980s, the scope of FSR was broadened systematically to encompass a wider set of issues. That is, the number of variables included within the analytical and prescriptive domain was increased with each new development. The sustainable livelihoods (SL) can be viewed as the end product (i.e., final phase or phase four) of that process.

Although many SL components are similar to earlier farming systems approaches, there are several distinct features. For example:

- Livelihoods are not just jobs but rather comprise a situationally determined complex of activities, asset sets, entitlements, and social relationships that are managed by households to assure their minimum basic needs over time. Because these vary across households in different socio-economic strata within the community, the livelihood strategies of different households also vary. The SL approach usually places greatest emphasis on the most vulnerable households that are in or near poverty and experiencing either chronic or temporary food insecurity.

- The SL approach places equal emphasis on enhancing efficiency through improved productivity, achieving greater social equity through poverty alleviation, and protecting and enhancing resource base productivity. Thus the SL approach requires a combination of
analytical methods including conventional FSR, political economics, anthropology, and environmental science. Generally, these are applied through interdisciplinary teams working in close partnership with local communities.

- The SL approach explicitly links technical change at the household level with complementary changes at the meso- and macro-levels.

Time and space does not permit a detailed discussion of the SL methodology but the aim is to empower households and communities by strengthening their abilities to combine indigenous and modern knowledge, analyze situations, define problems, identify opportunities, conduct experiments, and formulate plans of action. A distinctive feature of the SL approach is the emphasis placed on designing interventions that simultaneously improve current and future productivity, reduce poverty, and protect the environment, without weakening and preferably strengthening the coping and adaptive strategies of the most vulnerable groups in the community. Successful implementation requires major changes in the roles traditionally played by researchers and farmers. Chambers [1991], for example, suggests that outside professionals can help catalyze farmers’ empowerment by acting as conveners of farmers’ meetings; facilitating exchange of experiences among farmers; and supplying farmers with new technical options and new methodologies to elicit, systematize, and utilize traditional knowledge to solve new problems.

Obviously new production technologies should improve short-term productivity, fit the objectives and resource constraints of poor households, and protect the long-term productivity of the resource base. However, these are not new ideas but what the SL approach does add is the notion that improved technologies should be consistent with and, if possible, reinforce the coping and adaptive mechanisms of resource-poor farmers. Using this idea at least three properties of new technologies that would satisfy this are:

- The notion of flexibility meaning that new technologies should, wherever possible, increase farmers’ flexibility to adapt their production and broader livelihood systems to stochastic shocks and to the constantly changing economic environment [Chambers, 1991].

- Emphasis needing to be placed on technologies that reduce risk (e.g., new more resistant/tolerant crop varieties and agronomic practices that reduce the impact of biotic and abiotic stresses, technologies that promote enterprise diversification).
• Finally, new technologies should complement, and not conflict with, the complex livelihood systems of poor households (e.g., if technologies require changes in the demand for labor, such changes may increase returns to labor for the poor in own-farm, wage labor, or off-farm activities, may be neutral, or may compete with labor requirements in their current set of enterprises).

Although it is obviously elegant and holistic, the application of SL to date is limited. There are a number of important challenges for wide application. A particular problem is the problem of up-scaling: because livelihood systems and their associated coping/adaptive strategies vary greatly across sites, and thus the results of SL field work usually are very location specific; and the full application of the SL concept requires well trained and experienced interdisciplinary teams that are skilled in participatory methods and that can work together over extended periods.

Cropping systems

At present mainly in the rice-wheat cropping system biological research is focusing on issues related to natural resource management (NRM). Its most notable success to-date has been the recent development of several resource conservation technologies (RCTs) due to the efforts championed by rice and wheat coordinating (RWC) units with its NARS (National Agricultural Research System) partners, including the private-sector machinery manufacturers.

Resource Conservation Equipment & Technology

<table>
<thead>
<tr>
<th>Technology</th>
<th>Savings/Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Laser land leveller</td>
<td>30-50% saving in water</td>
</tr>
<tr>
<td>Rotavator</td>
<td>50% fuel saving &amp; better quality seed bed</td>
</tr>
<tr>
<td>Zero till drill/minimum till drill/ multipurpose tool bar/ raised bed planter</td>
<td>5-10% increase in yield and saving of Rs. 2000-3000/ha.</td>
</tr>
<tr>
<td>Pressurized irrigation</td>
<td>20-30% saving in water</td>
</tr>
<tr>
<td>Rotary power weeder</td>
<td>20-30% saving in time and labour</td>
</tr>
<tr>
<td>Vertical conveyor reaper/ combine</td>
<td>Timely harvesting, more yield</td>
</tr>
<tr>
<td>Multi-crop thresher</td>
<td>50% saving in labour and time and 54% saving in cost of threshing</td>
</tr>
<tr>
<td>Straw combine</td>
<td>Recovers 50% straw and also 70-100 kg grain/ha resulting into an average saving of Rs. 1250/ha.</td>
</tr>
<tr>
<td>Straw baler</td>
<td>Makes bales and checks environmental pollution</td>
</tr>
<tr>
<td>Straw cutter-cum-spreader</td>
<td>Cuts and spreads the straw evenly and helps in sowing by zero till drill.</td>
</tr>
<tr>
<td>Improved manual harvester for mango &amp; kinnow</td>
<td>No damage to fruit and higher capacity</td>
</tr>
</tbody>
</table>
The focus on RCTs is important for reasons other than efficiency and sustainability per se. The new RCTs provide a novel ‘platform’ for land and water management approaches and to introduce new crops and varieties into the systems, which may also help to re-establish better ecological balance.

The biophysical and socio-economic heterogeneity in different IGP transects must be borne in mind in planning future programs. In the west, traditionally a wheat-based production system, introduction of intensive rice cultivation has raised concern about environmental sustainability due to antagonism between the current soil-water production requirements of the two crops. The challenge for RWC is to undertake research to determine what possibilities exist to grow rice in different ways to the benefit of the RWSs in terms of productivity, diversity and sustainability (particularly of water use) and determine under what circumstances (including national policies) such changes are appropriate. The RWC can make significant contributions both by improving water use efficiencies at farm-level through new RCTs, including laser land leveling and bed planting, and by joining with the CGIAR’s Challenge Program on Water and Food. In the east, where the production systems are traditionally rice-based, intensification and diversification in the winter (non-monsoon) season will need to be focused on enhancing economic viability, learning from farm-level experiences with diversification in Bangladesh.

The needs for expansion of successful RCTs, for system diversification and for water management research present an attractive window of opportunity for adoption of such a strategy and for exploring different options for securing medium-term funding. At the same time, the RWC members should also examine a move towards a more equitable cost sharing arrangement in line with their size, degree of involvement and capacity to bridge the gap in sustainable funding for the CU.

Conservation agricultural (CA) practices are widely adopted for rainfed and irrigated systems in tropics/subtropics and temperate regions of the world. Acreage of CA is increasing steadily world-wide to cover about 108 m ha (Derpsch and Friedrich 2009) globally (7% of the world arable land area). Recent estimates revealed that CS based RCTs are being practiced over nearly 3.9 m ha of South Asia (Gupta 2010).
Site specific crop management practices including SSNM, BMP besides IPNS results in better crop yield and efficiency. Building crop management programmes by integrating available BMPs for the site with due consideration of interactions and their careful management result in huge cumulative benefits – additive, and/or multiplicative from the biological system of crop production. This would greatly reduce external input supply and achieve highest fertilizer use efficiency and sustainability. With increased productivity, acreage under arable cropping can be reduced, fertilizer requirement rate can be reduced, residual accumulation and further wastage of nutrients can be reduced, more C can be fixed due to the higher biomass and higher oxygen to atmosphere can be released – a true sustainable meaning.

In recent years, the adoption of various precision agriculture technologies by U.S. maize and soybean growers has been increasing dramatically. Among the more commonly adopted precision farming technologies are those associated with autonavigation of equipment, auto-control of individual rows or nozzles of application equipment, and variable rate control of application equipment. Interest in data management technologies is also growing as these capabilities become more available and affordable. The increasing availability and affordability of sub-inch (cm) accuracy in GPS receiver technologies has contributed to growers’ interest in auto-navigation and auto-control technology in recent years in the USA. In particular, adoption of accurate RTK-based GPS receiver technologies is increasing rapidly partly due to the ever increasing availability of RTK networks throughout the countryside. These networks may be subscription-based (e.g., Trimble) or free access via state government department of transportation RTK networks known as continuously operating reference stations (CORS).

The advantages of auto-navigation and individual row control systems lie mainly with their potential for decreasing costs of crop production by virtue of their ability to reduce time and wastage associated with over- and under-laps of field operations (tillage, fertilizer spreading, herbicide applications, headlands or endrows). Some potential for yield increases exists due to fewer skips in weed control and less over-population of headlands (end rows), but these yield improvements will be relatively minor. However, it is believed that none of today’s precision agriculture auto-nav or autocontrol technologies represents a “quantum leap” in productivity.
Rather they offer the potential to reduce production costs through more accurate placement of crop inputs.

An intangible, yet meaningful, benefit of auto-nav technologies is the reduction in operator fatigue accompanied with the freedom to monitor equipment more closely. The opportunity for variable rate (VR) control for application of certain crop inputs, primarily fertilizers and seeds, has been available for some time to U.S. agricultural retailers and increasingly so at the farmer level in recent years. Fertilizer retailers in the U.S. adopted VR application technologies for application of phosphorus and potassium fertilizers plus lime as long ago as the 1990’s.

**Variable rate application of phosphorus and potassium fertilizers plus lime** has proven effective in reducing whole field input costs and improving yields in areas of fields with serious deficiencies for P, K, or soil pH. One of the reasons this VR technology has been effective is that the agronomic data to support the VR decisions can easily be generated from spatially intensive soil sampling data that are then used to develop spatial application maps. In other words, the VR decisions for these inputs are based on a sound understanding of the agronomic relationships between a single variable (spatial soil sample data) and crop response.

While effective, these particular VR technologies do not result in “quantum leap” shifts in the annual rate of maize productivity. At best, VR application of P, K, and lime improve the lower yielding areas of fields identified as deficient for these important nutritional factors.

**Variable rate control technology is also available for nitrogen fertilizer applications or seeding rates.** Both technologies are becoming increasingly available to farmers and becoming common standard accessories on applicators and planters. Active optical reflectance sensors are very sensitive to changes in plant biomass and overall health of a maize crop. Various reflectance indices (e.g., NDVI, chlorophyll index) have been shown to closely correlate with N content of plants or overall N uptake by crops and also correlate closely with eventual grain yield.

The **System of Rice Intensification**, or SRI for short, is a fascinating case of rural innovation that has been developed outside the formal rice research establishment both in India and the rest of the world. The System of Rice Intensification (SRI) is new technique of rice cultivation which changes the management of soil, water and nutrients that support optimal growing environment for rice. The SRI showed that keeping paddy soils moist gives better results, both agronomically and economically, than flooding the soil throughout its crop cycle. This benefit is enhanced by complementary agronomic practices that greatly increase the growth of roots and of soil biota.
which make it possible to grow more productive phenotypes from any rice genotype. The SRI, thus is currently attracting the greatest attention to address the issue of ‘more yield with less water’. The SRI can also reduce GHG emission and improves soil health. A study at IARI, New Delhi showed that the global warming potential (GWP) in the SRI was only 28.9% over the conventional method. It increased the water productivity by 44% compared to conventional planting method. The seed rate in SRI was much lower which reduced the input cost. The SRI, therefore, seems to be a ‘win-win’ technology.

One of the most promising developments in the controversial field of genetic engineering is the success obtained in breeding a nutritionally enriched rice variety now popularly being referred to as ‘golden rice’. This golden rice is genetically modified rice which contains genes that produce high levels of beta carotene and related compounds. Beta carotene is contained in yellow fruits like carrots (from which it gets its name) and mangoes and in vegetables like spinach. Beta carotene and other related compounds are converted in the human body to the crucially needed vitamin A. Unfortunately, many in the developing world that do not have access to fruits and vegetables, suffer from chronic vitamin A deficiency which results in night blindness. Night blindness plagues millions of undernourished people in Asia, including India, crippling their lives. According to the WHO, vitamin A deficiency hits the poor in 96 countries of the world, resulting in over five lakh blind children every year. This blindness is irreversible, these children will never see.

Maize is a major cereal crop for both human and livestock nutrition, worldwide. Protein from cereals including normal maize, have poor nutritional value because of reduced content of essential amino-acids such as lysine and tryptophan leading to harmful consequences such as growth retardation, protein energy mal-nutrition, anemia, pellagra, free radical damage etc. As a consequence, the use of maize as food is decreasing day by day among health conscious people. The complex nature of these problems posed a formidable challenge. This challenge was gladly accepted by two distinguished scientists of CIMMYT, Mexico, Dr. S. K. Vasal and Dr. Evangelina Villegas whose painstaking efforts for a period of 3 decades led to development of Quality Protein Maize (QPM) with hard kernel, good taste and other consumer favouring characteristics. This work is globally recognized as a step towards nutritional security for the poor. QPM research and development efforts appropriately spread from Mexico to Central and
South America, Africa, Europe and Asia. India also benefited with such germplasm and developed its first QPM composite variety ‘Shakti–1’ released in 1997 for commercial cultivation across the country. In 1998, the Rajendra Agricultural University (RAU) stepped ahead with further R & D towards the development of QPM variety and popularization of QPM as food. As of today, RAU has marched ahead and has its own success story upon QPM. It is an improved variety of maize which contains higher amount of lysine and tryptophan with lower amount of leucine and isoleucine in the endosperm than those contained in normal maize. Such balanced combination of amino acids in the endosperm results into its higher biological value ensuring more availability of protein to human and animal than normal maize or even all cereals and pulses.

**Vertical farming** is a concept that argues that it is economically and environmentally viable to cultivate plant or animal life within skyscrapers, or on vertically inclined surfaces. The idea of a vertical farm has existed at least since the early 1950s. Vertical farming discounts the value of natural landscape in exchange for the idea of "skyscraper as spaceship". Plant and animal life are mass produced within hermetically sealed, artificial environments that have little to do with the outside world. In this sense, they could be built anywhere regardless of the context. This is not advantageous to energy consumption as the internal environment must be maintained to sustain life within the skyscraper. The concept of "The Vertical Farm" emerged in 1999 at Columbia University. It promotes the mass cultivation of plant and animal life for commercial purposes in skyscrapers. Using advanced greenhouse technology such as hydroponics and aeroponics, the skyscrapers could theoretically produce fish, poultry, fruit and vegetables.

In the recent past greenhouse/polyhouse technology has been successfully popularized and the high value cash crops are being grown by the farmers. Research was undergoing on design and development of polyhouses and development of agro-techniques including post harvest and value addition.

The research efforts over last two decades (1989-90 to 2010) under the aegis of AICRP–Cropping System (now AICRP in integrated farming system) have lead to several significant findings. The summary of major achievements is listed hereunder.
• Resource efficient alternative cropping systems to rice-wheat system were developed for 11 states viz. Haryana, Punjab, U.P., Bihar, Uttarakhand, parts of Orissa, M.P., W.B., Jammu Kashmir, H.P. and Gujarat, involving potato, maize, onion, sunflower, green gram, brinjal, berseem (F), cabbage, okra, radish, potato etc, which gave average productivity of 20 t/ha as rice equivalent yield as compared to 11-13 t/ha, which led to induce the scope of increasing per unit productivity substantially.

• Likewise, efficient alternatives to pearl millet-wheat system in five states, viz.; Haryana, Gujarat, U.P., Rajasthan and Maharashtra, involving potato, green gram, cowpea, mustard, cluster bean, chickpea etc. were identified, which gave the productivity up to 12 tonnes per ha as compared to existing 8 t/ha.

• Efficient alternatives to soybean-wheat system in three states, viz.; M.P., Rajasthan and Maharashtra, were developed. Diversification options involving high value crops like isabgol, groundnut, soybean, potato, turmeric etc resulted in average productivity of 15 tonnes/ha as compared to existing 12 t/ha (rice equivalent) yield.

• Integrated plant nutrient supply systems have been established to be beneficial and standardized. Substitution of 25-50% N with FYM or green manure in rice-wheat system was found to increase the productivity by 4%, which may save chemical fertilizers worth Rs. 7.0 crores. It also helped in increase of soil organic carbon by 55.9%. In rice-rice system, green manuring increased the yield by 3.6%.

• Site Specific Nutrient Management Technology has been proven to be a potential tool in breaking the yield barrier through efficient and balanced nutrient management leading to significant productivity increase. Results clearly show that by adoption of SSNM, across the locations, grain yields of more than 13 t/ha in rice - wheat system (with a contribution of 58% rice and 42% wheat) and 12-15 t/ha in rice-rice system (with a contribution of 48% kharif rice and 52% rabi rice), are achievable. It also helped in increase of organic carbon by 55.9%.

• The use of different resource conservation technologies in rice-wheat system has been established to help in significant improvement of crop productivity and resource saving. Adoption of RCTs lead to an improvement in productivity of rice by 1 to 7% in mechanical transplanting, 3 to 8% in drum seeding, 1 to 2% in zero till drilling and 10 to 13% in system of rice intensification (SRI) compared to traditional hand transplanting at
different locations. Similarly, in wheat, productivity increased by 5 to 29% in zero-till drilling, 4 to 11% in strip-till drilling and 3 to 23% in bed planting compared to conventional sowing.

- With the application of recommended technologies and balanced fertilization to at least 10% of the area under different cropping systems, spread over various agroclimatic regions as indicated by on-farm research on cultivator’s fields, India can easily add about 5 million tonnes of food grain equivalent to rice to its food bowl.

- Through long-term studies in all the major cereal-cereal cropping systems, it has been proved that continuous use of chemical fertilizers (NPK) only and omitting P or K application leads to occurrence of deficiency of these nutrients and decline in yield of crops. However, the extent of yield reduction and occurrence of P or K deficiency is governed by the inherent soil supplying capacity and cropping system adopted.

- On-farm crop response to N, P and K application in different cropping systems has been determined. The average response of different cropping systems was 8-12 kg rice equivalent yield/kg of any of the major plant nutrients like N, P or K with mean economic responses of 7-10 Rs./Re invested on N, 4 Rs./Re spent on P and 6-8 Rs./Re spent on K.

- To improve the sustainability of rice-wheat system over the years, growing of legumes as break crop showed a marked influence on weed flora over the years and a reduction of 45 to 61% weed count was noted in succeeding rice-wheat crop cycle. To improve upon soil organic carbon and micro-nutrients application of organic manures has been proven very effective.

- In hybrid as well as inbred rice, N management through LCC proved superior to locally recommended N application in three splits and it was found possible to curtail 20-30 kg of fertilizer N/ha without sacrificing rice yield, when N is applied as per LCC values. N application at LCC<3 in Basmati 370 and at LCC<4 in coarse and hybrid rice was found optimum. Moreover, in LCC-based N management, basal application of N can be skipped without any disadvantage in terms of grain yield, and agronomic, physiological or recovery efficiency of fertilizer N.

- Similarly, nitrogen application as per soil supplying capacity and crop demand based on SPAD reading (35) produced highest yield of rice (4.92 t/ha) and wheat (4.55 t/ha).
Skipping basal N application in both rice and wheat led to higher use efficiency of N (partial factor productivity, uptake efficiency and internal efficiency) and better crop productivity.

- Crop residue recycling in rice-wheat was found to increase rice as well as wheat yields by 13 and 8%, decrease cost effectiveness by 5 and 3% and energy efficiency by 13 and 6%, respectively, compared to residue retrieval, whereas yield advantage was to the tune of 9 and 3% compared to residue burning. Recycling improved SOC by 31 and 2% and MWD by 11 and 10%, compared to residue retrieval and burning after seven crop cycles. It also improved soil moisture content (15%), bulk density (3%), cone index (14%), total N (17%), available P$_2$O$_5$ (12%) and K$_2$O (8%) compared to residue retrieval.

- A comparison of yield, economics and energy of mechanical and manual transplanting revealed that the transplanting by rice transplanters provided 85 and 72% savings in labour and cost of transplanting including nursery raising, respectively; provided higher rice yield (10%), net returns (26%), benefit: cost ratio (29%) and energy efficiency (7%); compared to manual transplanting of rice.

- During 3-4 years of conversion period, crop yields under organic farming were recorded to be comparable with conventional (chemical) farming in many regions. Some of these crops and their percent improvement in yield are coarse rice (+2%), garlic (+20.4%), maize (+22.8%), turmeric (+51.5%), fodder crops (+14.4 to 89.9%) and basmati rice (-6%) at Ludhiana; *kharif* French bean (+19.0%), veg. pea (+62.1%), cabbage (+9.5%), garlic (+7.0%) and *kharif* cauliflower (-4.6%) at Bajaura; fodder berseem (+6.5%), chickpea (+1.5%), soybean (-2.3%) and mustard (-6.6%) at Raipur; Rice (+12.9%), Wheat (+24.4%), Potato (+7.3%), mustard (+9.6%) and lentil (+2.5%) at Ranchi, groundnut (+6.9%), *rabi* sorghum (+15.8%), soybean (+9.5%), durum wheat (+32.4%), chilli (+18.8%), cotton (+35.5%), potato (+3.3%), chickpea (+3.2%) and maize (-1.1%) at Dharwad; soybean (+10.7%), isabgol (+11.2%), durum wheat (+1.1%), mustard (+3.1%) and chickpea (+4.2%) at Bhopal; okra (+1.0%), berseem (-0.2%) and veg. pea (+1.8%) at Jabalpur; *Dolichos* bean (+16.6%) at Karjat; maize (+18.2%), cotton (+38.7%), chilli (+8.2%), brinjal (+14.9%) and sunflower (+29.1%) at Coimbatore; rice (+1.9%) at Pantnagar; fodder sorghum (+32.5%), okra (+11.3%), baby corn (+11.8%) and veg. pea
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(+2.2%) at Modipuram; and carrot (+5.8%), tomato (+30.6%), rice on raised beds (+7.3%), french bean (+17.7%) and potato (+3.0%) at Umiam.

- Improvement of different magnitudes was recorded in respect of soil organic carbon (negligible at Pantnagar to 45.9% at Ludhiana), available-P (negligible at Pantnagar to 45.9% at Ludhiana), and available-K (up to 28.8% at Modipuram). However, available-N content was, in general, lower under organic systems.

- An improvement in some of the quality parameters of ginger (oleoresin by 11.5% and starch content by 10.6%), turmeric (oil by 10.8%, oleoresin by 12.4%, starch by 20.0% and curcumin by 21.7%), chillies (ascorbic acid content by 2.1%), cotton (ginning percentage), and vegetables (iron, manganese, zinc and copper content in tomato, French bean, cabbage, cauliflower, pea and garlic) was recorded.

Organic farming

Increasing consciousness about sustainable production, conservation of environment as well as health hazards associated with agrochemicals and consumers’ preference to safe and hazard-free food are the major factors that led to the growing interest in alternative forms of agriculture across the world. Organic agriculture is one among the broad spectrum of production methods that are supportive of the environment where “inorganic chemical free” methods of production and post-harvest of crops is practiced. It has been gaining gradual momentum across the world both in terms of production and consumption. The awareness of the harmful effects of using inorganic fertilizers and chemical pesticides has increased the demand for organically produced food products. Scientific surveys and studies indicate that the residue of pesticides when transferred to humans and other living beings, cause a number of diseases, ailments and harmful effects. On the other hand, organically produced food contains more vitamins, minerals and even cancer-preventing antioxidants. This growing awareness of health and environmental benefits of organic agriculture has resulted in steadily increasing demand for such products both in the developed and developing countries with an annual average growth rate of 20–25%. However, economics of production of organic production of crops is often a major bottleneck in attracting farmers to take up production of organic agriculture. A switch from conventional to organic production can cause substantial loss due to yield reduction, absence of separate markets for
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organic products that help fetch premium price, non-availability of appropriate inputs, and high certification costs. These difficulties can be addressed effectively through the concept of clustering. Considering the potential environmental benefits of organic farming and its compatibility with integrated agricultural and rural development, organizing clusters of organic farming and other SMEs may be considered as a development vehicle for developing countries like India, in particular. Naik and Babu suggested such an approach for development of bivoltine mulberry silk in India.

Many states in India have been formulating specific policies to promote organic farming. The marketability of organically produced products in distant markets depends largely on the certification and such certification requires spatial isolation of organic farms. While there is scale neutrality in production, market transactions for both inputs and products and certification have significant economies of scale. Therefore, it is essential to have a cluster approach for the organic farming to be successful.

The concept of organic farming in India was well documented. In the early twentieth century, Albert and Gabrielle Howard felt that it was a fundamental mistake to try the European practices of wheat cultivation in India. They argued that the present agricultural practices of India were worthy of respect, however strange and primitive they might first appear to Westerners. They felt that what was needed was the application of Western scientific methods to the local conditions to improve Indian agriculture on its own lines. The Howards developed a holistic approach to the cultivation of wheat that took into account the life and welfare of the plant in relation to its environment including such factors as manuring, soil conditions, irrigation, effect of mixed planting and crop rotation, diseases and pests.

In 1950, Rodel popularized the method of organic farming and also the term sustainable agriculture”. The organic farming received worldwide recognition with the formation of the International Federation of Organic Agricultural Movement in the year 1972 (IFOAM). Fukoka’s experiments in organic farming showed the way forward for increasing the yields significantly without the application of either inorganic fertilizers or chemical fertilizers.

As the demand for organically produced farm products increased across the world, the need for setting standards and define guidelines has become essential. Codex issued the guidelines for organic farming in 1999. The UN-Organizations Food and Agriculture Organization (FAO), the World Health Organization (WHO) as well as the United Nations Conference on Trade and
Development (UNCTAD) started negotiations on standards on organic agriculture in the 1990s and adopted the first edition in 1999. The ‘Codex Alimentarius Guidelines for the Production, Processing, Labelling and Marketing of Organically Produced Foods’ were developed in view of the growing production and international trade in organically produced foods to facilitate trade and prevent misleading claims. The guidelines are intended to facilitate the harmonization of requirements for organic products at the international level, and they provide assistance to governments wishing to establish national regulations in this area. As a result, the certification of organically produced food and food products has become an essential ingredient of organic farming.

The concept of close contact between the consumer and the producer is a long established practice. Greater market demand, the increasing economic interests in production, and the increasing distance between producer and consumer has stimulated the introduction of external control and certification procedures. An integral component of certification is the inspection of the organic management system. Procedures for operator certification are based primarily on a yearly description of the agricultural enterprise as prepared by the operator in cooperation with the inspection body. Likewise, at the processing level, standards are also developed against which the processing operations and plant conditions can be inspected and verified. Where the inspection process is undertaken by the certification body or authority, there must be clear separation of the inspection and certification function. In order to maintain their integrity, certification bodies or authorities that certify the procedures of the operator should be independent of economic interests with regard to the certification of operators.

Except for a small portion of organic agricultural commodities marketed directly from the farm to consumers, most products find their way to consumers via established trade channels. To minimize deceptive practices in the market place, specific measures are necessary to ensure that trade and processing enterprises can be audited effectively. The regulation of a process, rather than a final product, demands responsible action by all involved parties.

Import requirements should be based on the principles of equivalency and transparency as set out in the Principles for Food Import and Export Inspection and Certification. In accepting imports of organic products, countries would usually assess the inspection and certification procedures and the standards applied in the exporting country. Recognizing that organic production systems continue to evolve and that organic principles and standards will continue to
be developed under these guidelines, the Codex Committee on Food Labeling (CCFL) reviews these guidelines on a regular basis. The CCFL initiates the review process by inviting member governments and international organizations to make proposals to the CCFL regarding amendments to these guidelines prior to each CCFL meeting.

In the Planning Commission of India constituted in 2000, a steering group on agriculture identified organic farming as National challenge, and suggested it should be taken in the form of a project as major thrust area for Tenth Plan. The group recommended organic farming in North East Region, rain-fed areas and in the areas where the consumption of agro chemicals is low or negligible. The National Agricultural Policy (2000) recommended promotion of traditional knowledge of agriculture relating to organic farming and its scientific upgradation. The Ministry of Commerce launched the National Organic Programme in April 2000 and Agricultural and Processed Food Products Export Development Authority (APEDA) is implementing the National Programme for Organic Production (NPOP). Under the NPOP, documents like National standards, accreditation criteria for accrediting inspection and certification agencies, Accreditation procedure, inspection and certification procedures have been prepared and approved by National Steering Committee (NSC). Under NPOP programme, the Government of India has developed National Standard for organic export. The Ministry of Agriculture, in principle, has accepted this standard for domestic purpose also. The scope of these standards is to lay down policies for development and certification of organic products; facilitate certification of organic products confirming the standards for organic production; institute a logo and prescribe its award by accrediting bodies on products qualifying for bearing “India organic label”.

There are 12 accredited certifying agencies in the country. This tariff structure is very expensive for an individual farmer particularly those having small holding. On the other hand, the tariff would become manageable when a number of farmers get together to form a group and get the certification done for the entire group.

An Expert committee on organic farming mission was set up in 2000. The committee submitted its report in April 2001. National guidelines on organic farming by Central government issued in July 2003 and the Broad framework was circulated. In March 2004, the Cabinet has announced a policy which indicated how to promote organic farming by providing backward and forward linkages, and what needs to be done.
One of the strategies for implementing this policy is to follow an Area/Commodity approach. The strategy is to start with small areas initially and use the experience to scale up. The emphasis in the initial stages is to concentrate on rain-fed areas of agriculture. It was also decided to involve many non-government organizations (NGOs) operating in the area as key players. Government is expected to act as a facilitator. It is to follow an integrated approach by pooling efforts of various departments such as agriculture, horticulture, watershed development, animal husbandry, sericulture, agricultural universities, etc.

One of the important requirements for the success of organic farming is that it cannot be practiced in isolation. It is necessary to bring in large tracts of contiguous agricultural land under organic farming. Otherwise, non-organic farming practices such as use of inorganic fertilizers and chemical pesticides will not only affect the organic produce but also the chemical residues will make their way into the organically produced output, and subsequently, results in the loss of certification. In other words, it is essential to develop a cluster approach for the success of the organic farming.
Case studies on different farming systems

FARM DIVERSIFICATION IN THE STATE OF HIMACHAL PRADESH

The study was conducted in five districts viz. Una and Bilaspur representing zone I, Kangra and Mandi representing zone II and Kullu representing the Zones III and IV of Himachal Pradesh. There was a total sample of 360 respondents (72 in each district). Enterprise-wise gross income as realized by the farmers during 2012-13 formed the basis of present investigation. In all 103 sub-farming systems were identified. The maximum number of sub-farming systems was under Livestock based system (46) followed by cereals based (28), fruit based (15), vegetable based (10), other enterprises based (2) and oilseed based (1). Based on the adoption of sub-farming systems by larger number of households, the most preferred farming systems were (first two from the first four categories): Livestock + cereals (26 households), Livestock + cereals + fodder + vegetables (22 households), Cereals + livestock (28 households), Cereals + livestock + fodder + vegetables (14 households), Fruits (15 households), Fruits + livestock (14 households), Vegetables + livestock (6 households), and Vegetables + livestock + cereals (2 households). Livestock based farming systems followed by cereals based farming systems were the dominating farming systems in Zone I and II of Himachal Pradesh. In these zones 63.9 and 59.7% of the farmers were dependent on Livestock based farming systems and 33.3 and 36.8% farmers, respectively, were dependent on cereals based farming systems. In Zone III fruit growing was main activity and 72.2% of the households were dependent on fruit based farming systems. This was followed by vegetable based farming systems from which 23.6% of the households earn their livelihood. Overall fruits (36.4%) had highest share in the gross income which was followed by livestock production (28.77%), cereals (23.28%) and vegetables (8.11%).

Low hills (Zone I, upto 650 m altitude comprising of Una, Bilaspur and Hamirpur districts and parts of Sirmour, Kangra, Solan and Chamba districts adjoining to Punjab and Haryana)

<table>
<thead>
<tr>
<th></th>
<th>Marginal</th>
<th>Small</th>
<th>Medium</th>
<th>Large</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vegetable crops based</td>
<td>0.00</td>
<td>2.17</td>
<td>0.00</td>
<td>0.00</td>
<td>0.69</td>
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<tr>
<td>Livestock based</td>
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<td>28.57</td>
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<td>49.31</td>
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<tr>
<td>Field crops based</td>
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<td>71.43</td>
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<tr>
<td>Sample size</td>
<td>71</td>
<td>46</td>
<td>21</td>
<td>6</td>
<td>144</td>
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</table>
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<table>
<thead>
<tr>
<th>Source of income (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Field crops</td>
</tr>
<tr>
<td>Vegetable crops based</td>
</tr>
<tr>
<td>Live stock based</td>
</tr>
<tr>
<td>Field crop based</td>
</tr>
</tbody>
</table>

Mid hills (Zone II, 651 – 1800 m altitude comprising of Palampur and Kangra Tehsils of Kangra district, Rampur Tehsil of Shimla district and parts of Mandi, Solan, Kullu, Chamba and Sirmour districts)

<table>
<thead>
<tr>
<th>Source of income (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fruit crop based</td>
</tr>
<tr>
<td>2.15</td>
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<tr>
<td>Live stock based</td>
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<tr>
<td>Field crop based</td>
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<tr>
<td>Farm machinery based</td>
</tr>
<tr>
<td>Total</td>
</tr>
<tr>
<td>Sample size</td>
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</table>

<table>
<thead>
<tr>
<th>Farming system</th>
<th>Source of income (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fruit crop based</td>
<td>Field crops</td>
</tr>
<tr>
<td>30.64</td>
<td>0.27</td>
</tr>
<tr>
<td>Live stock based</td>
<td>26.89</td>
</tr>
<tr>
<td>Field crop based</td>
<td>66.32</td>
</tr>
<tr>
<td>Farm machinery based</td>
<td>12.66</td>
</tr>
</tbody>
</table>

High hills and cold desert (Zone III & IV, above 1800 m altitude comprising of Parts of Shimla, Kullu, Solan, Chamba, Mandi, Kangra, Sirmour, Kinnaur and Lahaul and Spiti)

<table>
<thead>
<tr>
<th>Farming system</th>
<th>Marginal</th>
<th>Small</th>
<th>Medium</th>
<th>Large</th>
<th>Total</th>
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<tbody>
<tr>
<td>Fruit crop based</td>
<td>59.5</td>
<td>81.8</td>
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<td>100.0</td>
<td>70.8</td>
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<tr>
<td>Vegetable crops based</td>
<td>28.6</td>
<td>18.2</td>
<td>0.0</td>
<td>0.0</td>
<td>22.2</td>
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<tr>
<td>Live stock based</td>
<td>9.5</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>5.6</td>
</tr>
<tr>
<td>Field crop based</td>
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<td>0.0</td>
<td>1.4</td>
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<tr>
<td>Total</td>
<td>100.0</td>
<td>100.0</td>
<td>100.0</td>
<td>100.0</td>
<td>100.0</td>
</tr>
<tr>
<td>Sample size</td>
<td>42</td>
<td>22</td>
<td>7</td>
<td>1</td>
<td>72</td>
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<table>
<thead>
<tr>
<th>Farming System</th>
<th>Source of income (%)</th>
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<tr>
<td>Fruit crop based</td>
<td>Field crops</td>
</tr>
<tr>
<td>1.02</td>
<td>5.99</td>
</tr>
<tr>
<td>Vegetables based</td>
<td>4.37</td>
</tr>
<tr>
<td>Live stock based</td>
<td>1.43</td>
</tr>
<tr>
<td>Field crop based</td>
<td>100.00</td>
</tr>
</tbody>
</table>

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On station IFS Model (crop + dairy)

The IFS model at Phadiarkhar Farm was initiated during rabi 2010-11. Since dairy unit was established from May 2011, the results are presented from 2011-12 only. In the initial establish year, the one ha IFS model generated farm products worth total gross revenue of `244275. The negative returns in Horticulture component were because of costs involved in Fruit plantation. All costs were included during the 2011-12. In case of fodder crops the fodder component was fed to dairy animals. The model gave net returns of `67537. During 2012-13, the on station IFS model at Bhadhiarkhar farm resulted in gross returns of Rs. 219629/- and net returns of Rs. 84588/-. The highest net returns of Rs. 56100/- were obtained from Dairy unit followed by cropping system unit with net returns of Rs. 24460/-. Horticulture cum vegetable unit could result in net returns of Rs. 4951/- only. The fodder block had negative returns since the fodder output which was fed to dairy animals was not counted while working out the gross returns.

SUMMARY OF THE COMPONENT WISE COSTS, GROSS RETURNS AND NET RETURNS IN ON STATION IFS MODEL (2011-12):

<table>
<thead>
<tr>
<th>Component</th>
<th>Net Area (ha)</th>
<th>Total Cost (Rs./ha)</th>
<th>Gross Revenue (Rs./ha)</th>
<th>Net returns (Rs./ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cropping systems</td>
<td>0.6500</td>
<td>52428.6</td>
<td>99975</td>
<td>47546.4</td>
</tr>
<tr>
<td>Horticulture</td>
<td>0.1750</td>
<td>44791.2</td>
<td>43000</td>
<td>(-)1791.2*</td>
</tr>
<tr>
<td>Fruit crops</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Floriculture</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Agro-forestry (Leucenia)</td>
<td>940</td>
<td></td>
<td>(-)940*</td>
<td></td>
</tr>
<tr>
<td>Livestock</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dairy animals</td>
<td>78606.12</td>
<td>97635</td>
<td>26209</td>
<td></td>
</tr>
<tr>
<td>Goats/ Sheep</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Poultry/ Ducks</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Others (Fodder Block)</td>
<td>0.1000</td>
<td>7152.644</td>
<td>3665</td>
<td>(-)3487.64*</td>
</tr>
<tr>
<td>Fisheries</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Apiary</td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Others (specify)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>All Component</td>
<td>0.925</td>
<td>183918.6</td>
<td>244275</td>
<td>67536.56</td>
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</table>
SUMMARY OF THE COMPONENT WISE COSTS, GROSS RETURNS AND NET RETURNS IN ON STATION IFS MODEL (2012-13):

<table>
<thead>
<tr>
<th>Component wise summary:</th>
<th>Year of start</th>
<th>Net Area</th>
<th>Total Cost (Rs./ha)</th>
<th>Gross Revenue (Rs./ha)</th>
<th>Net returns (Rs./ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cropping systems</td>
<td>2010</td>
<td>0.6500</td>
<td>24965</td>
<td>49425</td>
<td>24460</td>
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<tr>
<td>Horticulture</td>
<td>2010</td>
<td>0.1750</td>
<td>21890</td>
<td>26841</td>
<td>4951</td>
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<tr>
<td>Fruit crops</td>
<td>2010</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Floriculture</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Agro-forestry (Leucenia Plants)</td>
<td>2012</td>
<td>Border plantation</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Livestock</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Dairy animals</td>
<td>2010</td>
<td>0.1000</td>
<td>4813.1</td>
<td>3890</td>
<td>(-)923</td>
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<tr>
<td>Poultry/ Ducks</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Others (Fodder Block)</td>
<td>2010</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Fisheries</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Apiary</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Others/ (specify)</td>
<td></td>
<td></td>
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<td></td>
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</tr>
<tr>
<td>All components</td>
<td>0.925</td>
<td>135041</td>
<td>219629</td>
<td>84588</td>
<td></td>
</tr>
</tbody>
</table>

Crop- Livestock- Fish Farming (Wetland)

Asia has been the cradle of integrated crop-livestock-fish farming systems, which have evolved since the inception of human civilization particularly when human settlements started moving inland leaving the river banks. Though there are several successful practices of integrated fish farming in Asian countries including India, the system of farming using synergizing scientific integration of agriculture, aquaculture and livestock farming are not yet wide-spread in the region. Further, large-scale integration of carp culture with irrigation and sewage utilization are to be viewed seriously both for economic and ecological reasons (Sinha, 1979).

The wet land of paddy-field is congenial to many fish both for spawning and for pasture. Those breeding in paddy fields have adhesive eggs and are normally laid on green plants to facilitate more oxygen for developing embryo whereas shallow water spawners and the nest builders get favourable conditions of breeding in paddy fields. The flooded field has considerable quantities of putrifying plants giving rise to enormous amount of plankton and in fact serves as a richly laid table for fry and fingerlings. The fish while controlling the excessive growth of plankton, which
compete with the paddy, also control zootecton, insects, molluscs, the submerged and floating weeds harbouring the above and adversely affecting paddy. Fish fertilize through its fecal matter and also overturns the submerged soil normally under reduced stage thus making available more nutrient and oxygen to the root of paddy, acting like a biological plough (Sinha, 1985).

Evolved on the principles of productive recycling of farm wastes, fish-livestock farming systems are recognized as highly assured technologies for fish cultivation. In these technologies, predetermined quantum of livestock waste obtained by rearing the livestock in the pond area is applied in pond to raise the fish crop without any other additional supply of nutrients. Similarly, with the integrated poultry-fish farming system, the fish crop is integrated using only poultry droppings or dip litter by rearing the poultry either directly over the pond or on the pond embankment.

**Cropping + poultry/pigeon/goat + fishery (Tamilnadu)**

During 1998-2001, the study involved cropping, poultry, pigeon, goat and fishery in all possible combinations, with a view to recycle the residue and byproducts of one component over the other. In one hectare farm an area of 0.75 was assigned for crop activity, 0.10 ha for growing fodder grass to feed the goat unit (20+1), 0.03 ha allotted to goat shed and the remaining 0.12 ha was allotted to three fish ponds. Three integrated farming systems viz., crop + fish + poultry (20 Bapkok layer birds), crop + fish + pigeon (40 pairs) and crop + fish + goat (Tellichery breed of 20 female and 1 male maintained in 0.03 ha deep litter system) were tried for three years. Polyculture fingerlings of 400 numbers (calta, rohu, mrigal/common carp and grass carp) in the ratio of 40:20:30:10, respectively, reared in 3 ponds of size 0.04 ha (depth 1.5 m) each.

Fishes were fed with poultry, pigeon (700 kg poultry/pigeon droppings obtained from 20 Bapkok layers/40 productive pairs of pigeon) sheltered over two fish ponds and goat droppings (3 animals – 800 kg droppings) to assess the feasibility of rearing fish by using different manures as feed. Under integrated farming system, cropping sequences includes (i) sugarcane (planted) – sugarcane (ratoon)- banana (3 years) (ii) banana-turmaric-rice-banana (3 years) and (iii) maize-rice-sesame-sunhemp (annual) each in 0.25 ha and bajra–napier grass + desmanthus (perennial) in 0.10 ha.
Conventional cropping system comprising (i) rice-rice-blackgram (ii) maize-rice-blackgram (iii) maize-rice-sunhemp and rice-rice-sunhemp each in 0.25 ha as practiced by the farmers was taken up for comparison. To sustain the productivity of soil through integrated nutrient supply, recycled poultry, pigeon and goat manures and composted crop residue (banana waste and sugarcane trash) as vermicompost each 6.25 t ha were tested along with 100, 80 and 60% of the recommended fertilizer for the sequences of cropping.

Integrated farming system provides an opportunity to increase economic yield per unit area per unit time by virtue of intensification of crop and allied enterprises. Research results on integrated farming system for three years revealed that integration of crop with fish, poultry, pigeon and goat resulted in higher productivity than cropping alone under lowland. Crop + fish + goat integration recorded higher grain equivalent yield of 39610 kg/ha than other systems (Table 1). Similarly as individual animal component, the goat unit (20+1) gave the highest productivity of 8818 kg (mean over three years). This could also provide 11.0 t of valuable manure apart from supplementing the feed requirement of 400 number of fish. While assessing the feasibility of fish by using poultry, pigeon and goat droppings as feed, the fish fed with poultry droppings resulted in higher fish yield (825 kg/0.04 ha ponded water) than the two other sources of feed.

Table 1. Productivity of integrated farming system and its linked components

<table>
<thead>
<tr>
<th>Farming system</th>
<th>*Component productivity (kg)</th>
<th>System productivity (kg/ha)</th>
<th>% increase over cropping</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crop alone</td>
<td>12995</td>
<td>12995</td>
<td>-</td>
</tr>
<tr>
<td>Crop + fish + poultry</td>
<td>26352</td>
<td>26352</td>
<td>(89.0)</td>
</tr>
<tr>
<td></td>
<td>(1205 (4.1))</td>
<td>2052</td>
<td>(6.9)</td>
</tr>
<tr>
<td></td>
<td>29609</td>
<td>128</td>
<td></td>
</tr>
<tr>
<td>Crop + fish + pigeon</td>
<td>24854</td>
<td>24854</td>
<td>(85.2)</td>
</tr>
<tr>
<td></td>
<td>(2545 (8.7))</td>
<td>1774</td>
<td>(6.1)</td>
</tr>
<tr>
<td></td>
<td>29173</td>
<td>124</td>
<td></td>
</tr>
<tr>
<td>Crop + fish + goat</td>
<td>25725</td>
<td>1975</td>
<td>(68.3)</td>
</tr>
<tr>
<td></td>
<td>(1975 (5.2))</td>
<td>9979</td>
<td>(26.5)</td>
</tr>
<tr>
<td></td>
<td>37679</td>
<td>190</td>
<td></td>
</tr>
</tbody>
</table>

Productivity is expressed in rice grain equivalent yields. Figures in parenthesis indicate % contribution of each component. (Jayanthi et al. 2002).

The highest net return of Rs 131118 and per day return of Rs 511/ha were obtained by integrating goat + fish + cropping applied with recycled fish pond silt enriched with goat droppings (Table 2). Higher net return of Rs 3.36 for every rupee invested was obtained by integration of pigeon + fish + cropping applied with recycled fish pond silt with pigeon droppings.
Table 2. Economics of integrated farming systems

<table>
<thead>
<tr>
<th>Farming systems</th>
<th>Production cost (Rs/ha)</th>
<th>Gross return (Rs/ha)</th>
<th>Net return (Rs/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>I year</td>
<td>II year</td>
<td>III year</td>
</tr>
<tr>
<td>Cropping alone</td>
<td>16905</td>
<td>32939</td>
<td>33623</td>
</tr>
<tr>
<td>Crop + fish + poultry</td>
<td>60027</td>
<td>42628</td>
<td>42255</td>
</tr>
<tr>
<td>Crop + fish + pigeon</td>
<td>58842</td>
<td>41177</td>
<td>41250</td>
</tr>
<tr>
<td>Crop + fish + goat</td>
<td>63677</td>
<td>52689</td>
<td>50282</td>
</tr>
</tbody>
</table>

The employment opportunity was also increased to 576 man days/ha/year by integrating fish + goat in the cropping as against cropping alone (369 man days/ha/year) (Table 3). Combining cropping with other allied enterprises would increase labour requirement and thus provide scope to employ family labour round the year.

Table 3. Employment generation (man days) in Integrated farming systems (mean over three years)

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Cropping alone</td>
<td>369</td>
<td>369</td>
<td>309</td>
<td>369</td>
</tr>
<tr>
<td>Crop + fish + poultry</td>
<td>510</td>
<td>519</td>
<td>515</td>
<td>515</td>
</tr>
<tr>
<td>Crop + fish + pigeon</td>
<td>510</td>
<td>519</td>
<td>515</td>
<td>515</td>
</tr>
<tr>
<td>Crop + fish + goat</td>
<td>571</td>
<td>580</td>
<td>576</td>
<td>576</td>
</tr>
</tbody>
</table>

Integration of crop with fish and poultry resulted in higher fish productivity under lowlands. The poultry pigeon and goat droppings were utilized as feed initially and at the end of a year after the fish harvest, about 4500 kg of settled silt from each pond were collected. The pond silt was utilized as organic sources to supply sufficient quantity of nutrients to the crops. The nutrient contents of raw animal manures and settled silt collected from different fish ponds are furnished in Table 4.
Table 4. Nutrient value of recycled poultry/pigeon/goat manure

<table>
<thead>
<tr>
<th>Particulars</th>
<th>Poultry</th>
<th>Pigeon</th>
<th>Goat</th>
</tr>
</thead>
<tbody>
<tr>
<td>Birds/animals used to satisfy the feed requirement of 400 fingerlings</td>
<td>20 layers</td>
<td>40 pairs</td>
<td>3 animals</td>
</tr>
<tr>
<td>Quantum of dropping received in an year (kg)</td>
<td>700</td>
<td>700</td>
<td>810</td>
</tr>
<tr>
<td>Silt cleared after one year from 0.04 ha pond (t)</td>
<td>4.5</td>
<td>4.5</td>
<td>4.5</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Nutrient</th>
<th>Raw poultry dropping</th>
<th>Pond manure</th>
<th>Additional nutrient gained (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>% kg/700 kg</td>
<td>% kg/4500 kg</td>
<td></td>
</tr>
<tr>
<td>N</td>
<td>3.22</td>
<td>1.96</td>
<td>88.2</td>
</tr>
<tr>
<td>P_2O_5</td>
<td>2.5</td>
<td>1.02</td>
<td>45.9</td>
</tr>
<tr>
<td>K_2O</td>
<td>1.05</td>
<td>0.72</td>
<td>32.4</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Nutrient</th>
<th>Raw pigeon dropping</th>
<th>Pond manure</th>
<th>Additional nutrient gained (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>% kg/700 kg</td>
<td>% kg/4500 kg</td>
<td></td>
</tr>
<tr>
<td>N</td>
<td>1.82</td>
<td>0.84</td>
<td>37.8</td>
</tr>
<tr>
<td>P_2O_5</td>
<td>0.56</td>
<td>0.30</td>
<td>13.5</td>
</tr>
<tr>
<td>K_2O</td>
<td>0.98</td>
<td>0.56</td>
<td>25.2</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Nutrient</th>
<th>Raw goat dropping</th>
<th>Pond manure</th>
<th>Additional nutrient gained (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>% kg/810 kg</td>
<td>% kg/4500 kg</td>
<td></td>
</tr>
<tr>
<td>N</td>
<td>1.4</td>
<td>0.70</td>
<td>31.5</td>
</tr>
<tr>
<td>P_2O_5</td>
<td>0.85</td>
<td>0.62</td>
<td>27.9</td>
</tr>
<tr>
<td>K_2O</td>
<td>0.70</td>
<td>0.48</td>
<td>21.6</td>
</tr>
</tbody>
</table>

Jayanthi 2001

Twenty fowls in the poultry unit and 40 productive pairs in the pigeon unit voided 700 kg of droppings with the nutrient potential of 22.5, 17.5 and 7.4 kg and 12.7, 3.9 and 6.9 kg of N, P_2O_5 and K_2O, respectively, but when recycled through fish pond, nutrient contents were enhanced by three folds. Similarly three goats produced 810 kg of voiding contributing 11.3, 6.9 and 5.7 kg of N, P_2O_5 and K_2O nutrients, which were further enhanced by three folds through recycling. The additional nutrients gained by recycling were the highest with poultry manure with 65.7, 28.4 and 25 kg N, P_2O_5 and K_2O, respectively than with goat/pigeon manure.

The system as a whole provided an opportunity to make use of produce/waste materials of one component as input on another at the least cost/no cost at farm level. To enhance the
productivity, sustain the income and employment generation for family labour, integration of crop with fish +goat/pigeon/poultry could be adopted than cultivating the crop alone under lowland farms.

**Another Integrated Farming System (IFS) For Wetland System (Coimbatore (T: N)).**

Components are
1. Cropping (Rice- fish – poultry- mushroom)
2. Fish culture.
3. Poultry.
4. Mushroom production.
5. Cropping 0.36 ha.
6. Fish pond 0.04 ha.

This farming system was compared with conventional cropping normally followed in the region.

Rice – Rice – green gram and rice – rice – green manure (0.20 ha).

Component Description:

1. Fish pond area of 0.04 ha with 1.5 m depth.
2. Diff. fingerlings of diff. fish species with total of 7500/ ha.
3. Harvesting of fish commenced from trench month. A poultry shed at corner of fish pond (shed 2.2 m²).
4. Free fall of poultry dropping into the fish pond (Twenty Bapcock chicks of 18 weeks old reared).
5. The feed components were purchase only in 1st year of cropping.
6. The birds started laying eggs around 22 nd weeks up to 72nd when they were culled out.
7. A mushroom shed of 5 * 3 m was constructed with local materials. Oyster mushroom was produced utilizing rice straw as the base material.

Economics- on an average net profit of Rs. 11, 755 was obtained in rice – poultry- mushroom system as compared to Rs. 6, 335 only from conventional system of cropping. Additional employment of 174 man – days was generated due to IFS.
IFS – Tamil Nadu – Cauvery delta Zone (Crop – poultry- fish system)

Farmers of this zone are practicing monocropping of rice for two season followed by a rice fallow pulse. Among the different allied activities, pisciculture plays an important role in this zone since water is available in the canal about 7 – 8 months. Poultry farming is another feasible enterprise. By combing the enterprises of poultry – cum fish culture with rice cropping system the economic status of the small and marginal farmers could be improved.

Components: - One ha area has been selected.
- 0.04 ha area for fishpond
- Improved cropping as rice- rice cotton (0.76 ha) and
- Rice- rice – maize (0.20 ha).

Maize being a major constituent of poultry feed was included in the system. This system compared with the existing practice of rice- rice – black gram

Poultry unit: - 50 Bapock’s, Bu 300 hybrid layer bird of 21 weeks age were maintained till 43 Weeks.
- 100 g/day/ bird through maize, rice bran, groundnut cake.

Fish culture: Ponds near to poultry shed. Different fingerlings of fish in ponds, with density of population maintained were 10000 fingerlings / ha. The fish were harvested after six and half months.

Economic: A net return of Rs. 17,200 was obtained by integrating different enterprises by introducing poultry – cum – fish culture with cropping a total employment of 385 man- days was generated.

Crop + dairy + biogas + silviculture (Irrigated upland, Tamilnadu)

IFS experiments were conducted at irrigated uplands of TNAU, Coimbatore. The major source of water was met from deep borewell. the major cropping system followed under irrigated uplands are sorghum – cotton – maize, ragi – cotton  – maize and ragi - cotton – sorghum.

IFS involving crop, dairy, biogas and silviculture was taken from 1987-92. The normal cropping pattern followed in Coimbatore is ragi – cotton – sorghum. In the integrated approach, the same cropping pattern, was slightly modified by inclusion of intercropping such as green gram in
cotton, cowpea in sorghum and sunflower as border crop in ragi (0.75 ha). The perennial grass fodder (0.15 ha) and legume fodder Lucerne (0.05 ha) were also raised in the holding. Three jersey cross bred milch cows with 2 calves were included under dairy component. For effective recycling of farm and animal waste, a biogas unit of 2 m$^3$ capacity was installed for the production of fuel, light and enriched manure. Sixty kg of cow dung expected out of 5 animals is sufficient enough to produce 2 m$^3$ of gas every day which is equivalent to 1.5 litres kerosene. Two hundred numbers of subabul trees were planted all along the boundary of the field for fodder and timber production.

The results of the study revealed that the entire system produced a net income of Rs 20702/ha/year. This system also facilitated effective recycling of farm and animal waste, improved farm employment opportunities and continuous flow of income to farm throughout the year. By this recycling some of the weed seeds present in the raw cow dung also get killed during digestion process, thus improving the quality of the slurry over its raw material used viz. cow dung. The quality improvement by way of recycling the cow dung through biogas chamber was studied by analyzing the NPK content of slurry and FYM prepared utilizing the cow dung from the system. The total quantity secured from the unit over the period of 365 days has been taken on equal weight basis and the analyzed data is furnished in table 1 and 2.

### Table 1. Nutrient(macron in %, micro in ppm) enhancement through biogas slurry and FYM

<table>
<thead>
<tr>
<th>Particulars</th>
<th>N</th>
<th>P</th>
<th>K</th>
<th>Fe</th>
<th>Mn</th>
<th>Zn</th>
<th>Cu</th>
</tr>
</thead>
<tbody>
<tr>
<td>Biogas slurry</td>
<td>1.43</td>
<td>1.21</td>
<td>1.01</td>
<td>4200</td>
<td>550</td>
<td>150</td>
<td>52</td>
</tr>
<tr>
<td>FYM</td>
<td>0.94</td>
<td>0.56</td>
<td>0.72</td>
<td>4000</td>
<td>490</td>
<td>100</td>
<td>45</td>
</tr>
</tbody>
</table>

### Table 2. Nutrient gain by recycling (kg)

<table>
<thead>
<tr>
<th>Particulars</th>
<th>N</th>
<th>P</th>
<th>K</th>
<th>Fe</th>
<th>Mn</th>
<th>Zn</th>
<th>Cu</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nutrient in biogas slurry (11.0 t on dry weight basis)</td>
<td>157.3</td>
<td>133.1</td>
<td>144.4</td>
<td>46.2</td>
<td>6.05</td>
<td>1.65</td>
<td>0.57</td>
</tr>
<tr>
<td>Nutrient in FYM (11.6 t in an year)</td>
<td>112.8</td>
<td>67.2</td>
<td>86.4</td>
<td>44.0</td>
<td>5.39</td>
<td>1.10</td>
<td>0.49</td>
</tr>
<tr>
<td>Nutrient gained by way of recycling</td>
<td>44.5</td>
<td>65.9</td>
<td>28.0</td>
<td>2.2</td>
<td>0.66</td>
<td>0.55</td>
<td>0.08</td>
</tr>
</tbody>
</table>

Recycling of cow dung lead to the production of 730 m$^3$ of biogas with the possibility of enhancing the nutrient value of NPK to the tune of 44.5 kg, 65.9 kg and 28 kg, respectively.
Trace elements like Fe, Mn, Zn and Cu are also present in an enhanced level over FYM (Rangasamy 2000).

**Integrated Farming System (IFS) for Irrigated Situations (Garden lands):**

A model integrated farming system to suit the small and marginal farmers of garden land condition was studied at TNAU, Coimbatore, during 1988-1993 (Rangaswami et al. 1995). An area of one ha was selected for IFS and compared with conventional cropping system (CCS).

**Components of IFS:**

<table>
<thead>
<tr>
<th>Cropping</th>
<th>Area (ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>I. Cotton = green gram maize + fodder cowpea- Bellary onion</td>
<td>0.56</td>
</tr>
<tr>
<td>II. Wheat = sunflower – maize + fodder cowpea- summer cotton + green gram</td>
<td>0.11</td>
</tr>
<tr>
<td>III. Grass Bajra Napier ((Co. I)</td>
<td>0.15</td>
</tr>
<tr>
<td>IV. Lucerne</td>
<td>0.05</td>
</tr>
<tr>
<td>V. 150 Trees of Leucaena (planted in the bunds)</td>
<td>0.05</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>1.00</strong></td>
</tr>
</tbody>
</table>

**Farm Stead:**

<table>
<thead>
<tr>
<th>Dairy Unit</th>
<th>Biogas Unit</th>
<th>Mushroom Production</th>
</tr>
</thead>
<tbody>
<tr>
<td>3 jersey cows + 2 calves</td>
<td>2 m³ capacity</td>
<td>1.5-2.0kg/ha</td>
</tr>
</tbody>
</table>

The above integrate system was compared with the conventional cropping system of cotton sorghum- finger millet in 0.20 ha area.

Economic returns from the system: Maize flour, cottonseed and wheat bran obtained from the crop components were recycled for preparing dairy feed from the second year. About 45.5 t of to the animals. Dung was recycled for the biogas plant. Mean revenue of Rs. 34600/ha was realized in IFS as compared to Rs. 13950 obtained in CCS. Employment opportunity was also enhanced to the tune of 770 man- days per year under IFS as against conventional cropping.

**Integrated farming system (model) for small and medium farmers of Tungabhadra project area of Karnataka** (CHANNABASAVANNA et al 2009)

Integrated Farming system at Siruguppa, Karnataka, under canal irrigation of Tungabhadra project
Recent Advances in Integrated Farming Systems

during 2003-04 to 2005-06, involved cropping (rice, maize, sunflower, vegetables), fishery, poultry and goat as the integrated system, and cropping (rice-rice) alone as the control. In one hectare area of integrated farming system, an area of 0.73 ha was allotted for crop component (rice-rice, maize - sunflower sequence, vegetables), 0.06 ha for fish pond and 0.21 for goats (including fodder area). Poly culture fingerlings @ 10,000/ha (rohu 20%, catla 30% and mrigal 40%) were released into the pond (600 m²). Thirty poultry birds (giriraj) were maintained in the poultry shed constructed on the fish pond. Goats (10 females + 2 males) were maintained in a shed constructed separately. This was compared with the conventional rice-rice system. To sustain the productivity the residues obtained in the system were recycled. The model depicting the recycling the resources is given in Fig.1. Poultry droppings was allowed to drop into the pond directly which served as the source of food for fish. Fishes were harvested after completing one year using drag net. The nutrient rich pond water was used as source of irrigation. Observations on the productivity and economics of individual components and the farming system as a whole and employment generation and water requirement were recorded as per the standard procedure.

The integration of crop with fish, poultry and goat resulted in higher productivity than adoption of conventional rice-rice alone. Integrated farming system showed 26.3% higher productivity over conventional rice-rice system. Among the cropping sequences under

![Fig.1. IFS model depicting the recycling the resource](image-url)
Recent Advances in Integrated Farming Systems

integrated farming systems, rice-rice system yielded the maximum (2175 kg/ha/year) closely followed by vegetables (2136 kg/ha/year). Among the animal components goat produced the higher rice equivalent yield of 1339 kg/ha/year followed by poultry (327 kg/ha/year) and fish (203 kg/ha/year). Integration of fish-livestock-crop was beneficial (Sharma and Das 1988).

Among the cropping sequences, rice-rice system yielded the maximum net returns of Rs. 7387. Higher gross returns due to high procurement price of rice resulted in higher returns. Cropping (0.73 ha) in IFS led to maximum net returns of Rs. 14600 followed by animal components (Rs. 8286). Contributions from cropping, goat, fish and poultry were 63.8, 30.9, 4.0 and 1.3%, respectively. Net return was ₹ 22,887 with an increase of 32.3% higher than conventional rice-rice system. Sonjoysha, et. al. (1998) indicated that for irrigated situation rice-fish-vegetables-fruit crops farming system was profitable.

Table 1. Productivity (rice equivalent yield) and profitability of different components under integrated farming system (pooled data of 3 years)

<table>
<thead>
<tr>
<th>Treatments</th>
<th>Area (ha)</th>
<th>Productivity (kg/ha/year)</th>
<th>Cost of Cultivation (Rs)</th>
<th>Net returns (Rs)</th>
<th>B:C Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Integrated farming system</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rice-rice system</td>
<td>0.33</td>
<td>2175</td>
<td>8683</td>
<td>7387</td>
<td>1.84</td>
</tr>
<tr>
<td>Hybrid maize-sunflower</td>
<td>0.20</td>
<td>908</td>
<td>3697</td>
<td>3540</td>
<td>1.96</td>
</tr>
<tr>
<td>Vegetables</td>
<td>0.20</td>
<td>2136</td>
<td>4712</td>
<td>3673</td>
<td>2.00</td>
</tr>
<tr>
<td>Fodder + goat</td>
<td>0.21</td>
<td>1339</td>
<td>6289</td>
<td>7060</td>
<td>2.75</td>
</tr>
<tr>
<td>Fish</td>
<td>0.06</td>
<td>203</td>
<td>515</td>
<td>926</td>
<td>2.23</td>
</tr>
<tr>
<td>Poultry (0.005)</td>
<td></td>
<td>327</td>
<td>2145</td>
<td>300</td>
<td>1.13</td>
</tr>
<tr>
<td>Total</td>
<td>1.00</td>
<td>7088</td>
<td>18225</td>
<td>22887</td>
<td>1.97</td>
</tr>
</tbody>
</table>

Conventional cropping system

| Rice-rice                    | 1.00      | 5611                      | 25503                    | 17293            | 1.64      |

* Productivity in kg/ha/day.

The benefit cost ratio was also higher (1.97) in IFS than conventional system (1.64). Goat resulted in the highest benefit cost ratio (2.75) followed by fish (2.23) and by vegetables (2.00). Poultry showed the lowest benefit cost ratio (1.13) as a result of high cost of maintenance.

The energy flow in the system studied by evaluating the energetics for each components (Table 2). The rice-rice system (0.33 ha) showed the highest energy ratio (10.06) due to higher energy output (95630 MJ) as against the energy input of 9500 MJ. This was followed by Hy. Maize- sunflower sequence (8.62). The total energy ratio in IFS was 6.40 as against the conventional rice-rice
system (8.54). The reduced energy ratio in IFS was attributed to low energy output and energy ratio of animal components. The poultry recorded the lowest energy ratio (0.08 ).

Specific energy was calculated for each component and for products from animal components. Specific energy was less in the IFS (3.09 MJ/kg) over conventional rice-rice system (5.09MJ/kg). This indicates that low input energy is required under IFS to produce a kg of produce. Among various components, fish required the least specific energy (0.44 M J/ka) followed by goat (1.38 MJ/kg). The specific energy was highest in poultry (7.49 MJ/kg).

Rice is the labour consuming crop with peak requirement during transplanting, weeding and harvesting. In the present study, the IFS reduced the labour requirement by 40% but distributed throughout the year. The data in table 2 showed that rice-rice system (0.33 ha) consumed 62.5% of labours. Integration of other components (0.67 ha) with rice shared the remaining 37.9%. The scope of employment distribution round the year without much lean and peak demand for labour was also reported by Chinnuswamy, (1994) and Rangaswamy et al. (1995).

Rice- rice is the highest water consuming sequence (2370 mm). The present study showed an alternate profitable model requiring lower water requirement. The projected model consumed 47.4% less water (1247 mm) as compared to conventional rice-rice system. Among crop components, rice- rice system in 0.33 ha consumed 848 mm of water followed by fish (105 mm). The water use efficiency (WUE) was 56.8 kg/ha.cm in IFS as against 23.7 kg/ha.cm in conventional rice -rice system.

Table 2. Energy flow, employment generation and water requirement in integrated farming system (pooled data of 3 years)

<table>
<thead>
<tr>
<th>Treatments</th>
<th>Area (ha)</th>
<th>Energy input (MJ)</th>
<th>Energy output (MJ)</th>
<th>Energy ratio</th>
<th>Specific energy (MJ/kg)</th>
<th>Employment generation (man days/ha/year)</th>
<th>Water requirement (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Integrated farming system</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rice-rice system</td>
<td>0.33</td>
<td>9500</td>
<td>95630</td>
<td>10.06</td>
<td>4.37</td>
<td>172</td>
<td>848</td>
</tr>
<tr>
<td>Hybrid maize-sunflower</td>
<td>0.20</td>
<td>3850</td>
<td>33200</td>
<td>8.62</td>
<td>4.24</td>
<td>45</td>
<td>82</td>
</tr>
<tr>
<td>Vegetables</td>
<td>0.20</td>
<td>4200</td>
<td>7200</td>
<td>1.71</td>
<td>1.97</td>
<td>31</td>
<td>95</td>
</tr>
<tr>
<td>Fodder + goat</td>
<td>0.21</td>
<td>1850</td>
<td>3955</td>
<td>2.14</td>
<td>1.38</td>
<td>9</td>
<td>82</td>
</tr>
<tr>
<td>Fish</td>
<td>0.06</td>
<td>92</td>
<td>341</td>
<td>3.71</td>
<td>0.44</td>
<td>5</td>
<td>105</td>
</tr>
<tr>
<td>Poultry (0.005)</td>
<td>0.06</td>
<td>2450</td>
<td>205</td>
<td>0.08</td>
<td>7.49</td>
<td>13</td>
<td>35</td>
</tr>
<tr>
<td>Total</td>
<td>1.00</td>
<td>21942</td>
<td>140531</td>
<td>6.40</td>
<td>3.09</td>
<td>275</td>
<td>1247 (56.8)*</td>
</tr>
<tr>
<td>Conventional cropping system</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rice-rice</td>
<td>1.00</td>
<td>28560</td>
<td>243870</td>
<td>8.54</td>
<td>5.09</td>
<td>459</td>
<td>2370 (23.7)*</td>
</tr>
</tbody>
</table>

* Water use efficiency in kg/ha.cm