Integrated Farming System

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Preface

All over the world, farmers work hard but do not make money, especially small farmers because there is very little left after they pay for all inputs. 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 textbook for undergraduate level students of Integrated Farming System. At the postgraduate level also 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 text book of immense value.

The text book covers Farming system – scope, importance and concept, Basic terms: System’s approach: Direct, residual and cumulative effects; Farming system’s enterprises/components including post harvest technological interventions and their maintenance; Site specific enterprise planning and implementation for developing farming system model. Resource(s) use efficiencies and optimization techniques: Integrated-farming systems for different agro-ecosystems– irrigated lowlands, irrigated uplands, rainfed and dryland areas, hill regions, islands: Resource recycling and flow of energy in different farming systems: Farming system and environment.

The book is written in a very simple form with up to date and statistics. It is a comprehensive basic text book on integrated farming system and will specifically meet out the requirement of the students of Agron 4711 being taught at the university. The authors would welcome suggestions from the readers to improve the text book.

Palampur

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Farming system – scope, importance and concept

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 (land, labour, capital, machinery etc). 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. Earlier subsistence was the important objective of farming. Farmers took many activities such as planting of fruit trees in their farms or on the common lands just for the welfare of mankind without the expectation of anything in return. The kind of farming where subsistence and welfare of mankind were the main objectives is designated as mixed farming. Farming today is also a mix of enterprises. However, higher profitability without altering ecological balance is important in farming. A set of agricultural activities organized while preserving land productivity, environmental quality and maintaining desirable level of biological diversity and ecological stability is designated as “Farming system”. Here the emphasis is mainly on a system rather than on gross output.

In other words “farming system” is a resource management strategy to achieve economic and sustain agricultural production to meet diverse requirement of the farm household while preserving the resource base and maintaining high environmental quality. The farming system in its real sense will help to lift the economy of agriculture and standard of living of the farmers.

Farming system specially refers to a group/combination of enterprises in which the products and or the byproducts of one enterprise serve as the inputs for production of other enterprise. The waste of dairying like dung, urine, refuse etc. is used for preparation of FYM, which is an input in cropping systems. The straw obtained from the crops is used as fodder for cattle’s are used for different field operations for growing crops. Thus different enterprises of farming systems are highly interrelated.

Farming system takes into account the combination needs of the family- the economic factors like relative profitability of the technically feasible enterprises, availability off farm resources, infrastructure and institutions such as irrigation, marketing facilities including storage and transportation and credit besides the agro biological consideration namely interdependence, if any among various technically feasible enterprises and the performance of individual farmers.

Farming is defined as the way in which the farm resources are allocated to the needs and priorities of the farmers in his local circumstances which include-

1. Agro climatic condition such as the quantity, distribution and reliability of rainfall, temperature, etc
2. Soil type and topography and
3. Economic and institutional circumstances like market opportunities, prices, institutional and infrastructure facilities and technology.
Definition:

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).
- Farming system is a decision making unit comprising the farm household, cropping and livestock system that transform land, capital and labour into useful products that can be consumed or sold (Fresco and Westphal 1988)

Key principles

- **Cyclic.** The farming system is essentially cyclic (organic resources – livestock – land – crops). Therefore, management decisions related to one component may affect the others.
- **Rational.** Using crop residues more rationally is an important route out of poverty. For resource-poor farmers, the correct management of crop residues, together with an optimal allocation of scarce resources, leads to sustainable production.
- **Ecologically sustainable.** Combining ecological sustainability and economic viability, the integrated livestock-farming system maintains and improves agricultural productivity while also reducing negative environmental impacts.

Scope of Farming System

Farming enterprises include crop, livestock, poultry, fish, 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, labor & Capital.
3. Present level of utilization of resources.
4. Economics of proposed integrated farming system.
5. Managerial skill of farmer.

**Benefits or Advantages of Integrated Farming System**

The advantages of IFS include pooling and sharing of resources/inputs, efficient use of family labour, conservation, preservation and utilization of farm biomass including non-conventional feed and fodder resources, effective use of manure/animal waste, regulation of soil fertility and health, income and employment generation for many people and increase economic resources. It improves space utilization and provides diversified products. The IFS is part of the strategy to ensure sustainable use of the natural resources for the benefit of present and future generations (Preston 1995).

1) **Productivity:** IFS provides an opportunity to increase economic yield per unit area per unit time by virtue of intensification of crop and allied enterprises.

2) **Profitability:** Use waste material of one component at the least cost. Thus reduction of cost of production and form the linkage of utilization of waste material and elimination of middleman interference in most inputs used. Working out net profit/ BC ratio is increased.

3) **Potentiality or Sustainability:** Organic supplementation through effective utilization of byproducts of linked component is done thus providing an opportunity to sustain the potentiality of production base for much longer periods.

4) **Balanced Food:** Components of varied nature are linked to produce different sources of nutrition.

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

6) **Recycling:** Effective recycling of waste material (crop residues and livestock wastes ) in IFS. Therefore, there is less reliance to outside inputs – fertilizers, agrochemicals, feeds, energy, etc.

7) **Income Rounds the year:** Due to interaction of enterprises with crops, eggs, milk, mushroom, honey, cocoons silkworm, it provides flow of money to the farmer round the year. There is higher net return to land and labour resources of the farming family.

8) **Adoption of New Technology:** Resources farmer (big farmer) fully utilize technology. IFS farmers, linkage of dairy / mushroom / sericulture / vegetable. Money flow round the year gives an inducement to the small/ original farmers to go for the adoption technologies.
9) **Saving Energy**: To identify an alternative source to reduce our dependence on fossil energy source within short time. Effective recycling technique the organic wastes available in the system can be utilized to generate biogas. Energy crisis can be postponed to the later period.

10) **Meeting Fodder Crisis**: Every piece of land area is effectively utilized. Plantation of perennial legume fodder trees on field borders and also fixing 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**: Linking agro- forestry appropriately the production level of fuel and industrial wood can be enhanced without determining effect on crop. This will also greatly reduce deforestation, preserving our natural ecosystem.

12) **Employment Generation**: Combing crop with livestock enterprises would increase the labour requirement significantly and would help in reducing the problems of under employment to a great extent. IFS provide enough scope to employ family labour round the year.

13) **Agro – industries**: When one of producte linked in IFS are increased to commercial level there is surplus value adoption leading to development of allied agro – industries.

14) **Increasing Input Efficiency**: IFS provide good scope to use inputs in different component greater efficiency and benefit cost ratio.

**Farming System Concept**

Farming system is a complex inter related matrix of soil, plants, animals, implements, power, labour, capital and other inputs controlled in parts by farming families and influenced to varying degree by political, economic, institutional and socials forces that operate at many levels. Thus farming system is the result of a complex interaction among a number of interdependent components. Farm activities interact with market forces (socio-economic) and ecosystem (biophysical) for purchasing inputs and disposing outputs by utilizing and degrading natural resources (land, water, air, sunshine etc.).

A farm is a system in that it has **INPUTS, PROCESSES and OUTPUTS**

**INPUTS** - these are things that go into the farm and may be split into *Physical Inputs* (e.g. amount of rain, soil) and *Human Inputs* (e.g. labour, money etc.)

**PROCESSES** - these are things which take place on the farm in order to convert the inputs to outputs (e.g. sowing, weeding, harvesting etc.)

**OUTPUTS** - these are the products from the farm (i.e. wheat, barley, cattle)

Depending on the type of farming e.g. arable/pastoral, commercial/subsistence, the type and amount of inputs, processes and outputs will vary. You need to make sure you are able to define and give examples of Inputs, Processes and Outputs in farming systems.

Income through arable farming alone is insufficient for bulk of the marginal farmers. The other activities such as dairying, poultry, sericulture, apiculture, fisheries etc. assume critical importance in supplementing their farm income.
The modern agriculture emphasize too more dimensions viz., time and space concept. Time concept relates to increasing crop intensification in situation where there is no constraint for inputs. In rainfed areas where there is no possibility of increasing the intensity of cropping, the other modern concept (space concept) can be applied. In space concept, crops are arranged in tier system combining two or more crops with varying field duration as intercrops by suitably modifying the planting method. Income through arable cropping alone is insufficient for bulk of the marginal farmers. Activities such as dairy, poultry, fish culture, sericulture, bio-gas production, edible mushroom cultivation, agro-forestry and agri-horticulture, etc., assumes critical importance in supplementing farm income. It should fit well with farm level infrastructure and ensures full utilization of bye-products. Integrated farming system is only the answer to the problem of increasing food production for increasing income and for improving the nutrition of small scale farmers with limited resources.

Livestock raising along with crop production is the traditional mixture of activities of the farmer all over the country, only the nature and extent varies from region to region. It fits well with farm level infrastructure, small land base and abundant labour of small man and ensures full utilization of by products.
Sustainability is the objective utilization of inputs without impairing the quality of environment with which it interacts. 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 income and employment 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 model 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
4. To maintain sustainable production system without damaging resources/environment.

**Goals of IFS** The Goals of Integrated Farming Systems (IFS) are to:

- provide a steady and stable income rejuvenation/amelioration of the system’s productivity and
- achieve agro-ecological equilibrium through the reduction in the build-up of pests and diseases, through natural cropping system management and the reduction in the use of chemicals (inorganic fertilizers and pesticides).
Basic terms

Agroecology:

Agroecology can be defined broadly or narrowly. "Loosely defined, agroecology often incorporates ideas about a more environmentally and socially sensitive approach to agriculture, one that focuses not only on production, but also on the ecological sustainability of the productive system. [This definition] implies a number of features about society and production that go well beyond the limits of the agricultural field. At its most narrow, agroecology refers to the study of purely ecological phenomena within the crop field, such as predator/prey relations, or crop/weed competition."

Agroecology is a scientific discipline that uses ecological theory to study, design, manage and evaluate agricultural systems that are productive and resource conserving. Agroecological research considers interactions of all important biophysical, technical and socioeconomic components of farming systems and regards these systems as the fundamental units of study, where mineral cycles, energy transformations, biological processes and sociological relationships are analyzed as a whole in an interdisciplinary fashion.

Alternative Farming/Alternative Agriculture:

These are essentially synonymous terms encompassing a vast array of practices and enterprises, all of which are considered different from prevailing or conventional agricultural activities. "They include:

- nontraditional crops, livestock, and other farm products;
- service, recreation, tourism, food processing, forest/woodlot, and other enterprises based on farm and natural resources (ancillary enterprises);
- unconventional production systems such as organic farming or aquaculture; or
- direct marketing and other entrepreneurial marketing strategies

Alternative has also come to imply the use of environmentally-friendly farming practices in general, and the benefits of farm diversification.

Best Management Practices (BMPs):

"... BMPs were developed and implemented as a requirement of the 1977 amendments to the Clean Water Act. BMPs are established soil conservation practices that also provide water quality benefits. They include such practices as cover crops, green manure crops, and stripcropping to control erosion; and soil testing and targeting and timing of chemical applications (similar to IPM) to prevent the loss of nutrients and pesticides.

Biodiversity:

"At its simplest level, biodiversity is the sum total of all the plants, animals, fungi and microorganisms in the world, or in a particular area; all of their individual variation; and all the interactions between them."
**Agrobiodiversity** is a fundamental feature of farming systems around the world. It encompasses many types of biological resources tied to agriculture, including:

- genetic resources - the essential living materials of plants and animals;
- edible plants and crops, including traditional varieties, cultivars, hybrids, and other genetic material developed by breeders; and
- livestock (small and large, lineal breeds or thoroughbreds) and freshwater fish;
- soil organisms vital to soil fertility, structure, quality, and soil health;
- naturally occurring insects, bacteria, and fungi that control insect pests and diseases of domesticated plants and animals;
- agroecosystem components and types (polycultural/monocultural, small/large scale, rainfed/irrigated, etc.) indispensable for nutrient cycling, stability, and productivity; and
- 'wild' resources (species and elements) of natural habitats and landscapes that can provide services (for example, pest control and ecosystem stability) to agriculture.

"Agrobiodiversity therefore includes not only a wide variety of species, but also the many ways in which farmers can exploit biological diversity to produce and manage crops, land, water, insects, and biota."

**Biodynamic Agriculture/Biodynamic Farming:**

Both a concept and a practice, biodynamics "owes its origin to the spiritual insights and perceptions of Dr. Rudolf Steiner, an Austrian philosopher and scientist who lived at the turn of the century." Dr. Steiner emphasized many of the forces within living nature, identifying many of these factors and describing specific practices and preparations that enable the farmer or gardener to work in concert with these parameters. "Central to the biodynamic method... are certain herbal preparations that guide the decomposition processes in manures and compost."

**Biointensive Gardening/Mini-farming:**

John Jeavons and Ecology Action have refined a production system that makes it possible for one person to grow all of his or her family's food using truly sustainable methods that maintain the fertility of the soil without relying on nonrenewable resources like petrochemicals or imported organic matter. The concepts and practices of biointensive gardening were synthesized and introduced to the U.S. by the English master horticulturalist, Alan Chadwick. Important components include double-dug, raised beds; intensive planting; composting; companion planting; and whole system synergy.

**Biological Farming/Ecological Farming:**

Biological and Ecological Farming are terms commonly used in Europe and developing countries. Although sometimes strictly defined, e.g., "Biological farming is a system of crop production in which the producer tries to minimize the use of 'chemicals' for control of crop pests,". Both biological farming and ecological farming are terms used in the broader sense, encompassing various and more specific practices and techniques of farming sustainability, e.g., organic, biodynamic, holistic, natural. Norman et al. point to some differentiation between the two terms: "In Europe (e.g., the Netherlands), the term biological often refers to organic farming, whereas the term ecological refers to organic plus
environmental considerations such as on-farm wildlife management (i.e., the relationships between parts of the agroecosystem."

**Biotechnology:**

Although farmers have been practicing biotechnology in the broadest sense (i.e. plant and animal breeding to achieve certain traits) for thousands of years, it is the recent breaking of the genetic code that has pushed this science into a new era altogether. **Genetic engineering** differs significantly from traditional biotechnological techniques in that DNA from different species can be combined to create completely new organisms (Genetically Modified Organisms - GMOs). Whether this technology is compatible with sustainable agriculture, and if so, in what ways, provokes much controversy among sustainable agriculture advocates. Products such as plants engineered for herbicide tolerance or insect resistance, and bacteria engineered to produce drugs for livestock may point to reduced chemical use and other sustainable applications. But what are the risks?

The Union of Concerned Scientists' list of potential risks related to GMOs include those to human health--new allergens in the food supply, antibiotic resistance, production of new toxins, concentration of toxic metals, enhancement of the environment for toxic fungi; and those to the environment--gene transfer to wild or weedy relatives and increased weediness, change in herbicide use patterns, squandering of valuable pest susceptibility genes, poisoned wildlife, creation of new or worse viruses, and other, so far, unknown harms.

In addition, "The issue of who will be served by this technology and who will set the research agenda of the experts becomes intensely important when so few people control the tools and language of the trade."

**Carrying Capacity:**

Carrying capacity is the theoretical equilibrium population size at which a particular population in a particular environment will stabilize when its supply of resources remains constant. It can also be considered to be the maximum sustainable population size; the maximum size that can be supported indefinitely into the future without degrading the environment for future generations. "The Earth's capacity to support people is determined both by natural constraints and by human choices concerning economics, environment, culture (including values and politics) and demography. Human carrying capacity is therefore dynamic and uncertain. Human choice is not captured by ecological notions of carrying capacity that are appropriate for nonhuman populations. Simple mathematical models of the relations between human population growth and human carrying capacity can account for faster-than-exponential population growth followed by a slowing population growth rate, as observed in recent human history."

**Conservation Buffer Strips:**

Conservation Buffer Strips are areas or strips of land maintained in permanent vegetation, designed to intercept pollutants and erosion. Placed around fields, they can enhance wildlife habitat, improve water quality, and enrich aesthetics on farmlands. Various types of buffers include **Contour Buffer Strips, Filter Strips, Riparian Forest Buffers, Field Borders, Windbreaks/Shelterbelts, Hedgerows, Grassed Waterways**, and **Alley Cropping**.
Conservation Tillage:

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

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

Environmental Indicators:

There are diverse interpretations as to what constitute environmental indicators and how they should be used. In any system, however, the "goal of environmental indicators is to communicate information about the environment--and about human activities that affect it--in ways that highlight emerging problems and draw attention to the effectiveness of current policies... an indicator must reflect changes over a period of time keyed to the problem, it must be reliable and reproducible, and, whenever possible, it should be calibrated to the same terms as the policy goals or targets linked to it."

An agri-environmental indicator measures change either in the state of environmental resources used or affected by agriculture, or in farming activities that affect the state of these resources. Examples of sustainable agriculture processes monitored by such indicators are soil quality, water quality, agroecosystem biodiversity, climatic change, farm resource management, and production efficiency.

Farmland Preservation/Protection:

"The irreplaceable land that produces our food and provides us with scenic open space, wildlife habitat and clean water is increasingly at risk from urban sprawl and rural subdivisions... According to a 1997 American Farmland Trust study, every state in the nation is sacrificing irreplaceable agricultural resources to urban sprawl. We are converting a total of 1 million acres a year, and while the quantity of top-quality agricultural land being lost varies from state to state, the process of conversion increases the pressures on agriculture even beyond the acres that are actually taken out of production."

Actions to reverse this trend are being taken on many levels. Tactics include focusing on policies related to property tax relief and protection from nuisance lawsuits for farmers, purchase of agricultural conservation easement (PACE) programs, special agricultural districts where commercial agriculture is encouraged and protected, comprehensive land use planning, and farm-friendly zoning ordinances.
Holistic Management (HM):

"Holistic Management is a decision-making process that enables people to make decisions that satisfy immediate needs without jeopardizing their future well-being, or the well-being of future generations. This decision-making process helps people identify their most deeply held values which helps to create clarity in vision and commitment in action. Using that vision to help them create a long-term picture toward which they will progress, people can then use a simple testing process to ensure that the decisions they make will be economically, environmentally, and socially sustainable."

Holistic Management originated in a personal quest by Zimbabwean biologist Allan Savory to solve the riddle of desertification. The decision-making process that is now at the heart of Holistic Management (originally called Holistic Resource Management - HRM) arose from discoveries made earlier by Savory and others on the relationships between land, animals, and humans.

Integrated Farming Systems (IFS)/Integrated Food and Farming Systems (IFFS):

Farming research and policy programs have begun to recognize that by viewing farms and the food production system as an integrated whole, more efficient use can be made of natural, economic, and social resources. Included in this concept are the goals of finding and adopting "integrated and resource-efficient crop and livestock systems that maintain productivity, that are profitable, and that protect the environment and the personal health of farmers and their families," as well as "overcoming the barriers to adoption of more sustainable agricultural systems so these systems can serve as a foundation upon which rural American communities will be revitalized."

Integrated Pest Management (IPM):

IPM is an ecologically based approach to pest (animal and weed) control that utilizes a multi-disciplinary knowledge of crop/pest relationships, establishment of acceptable economic thresholds for pest populations and constant field monitoring for potential problems. Management may include such practices as "the use of resistant varieties; crop rotation; cultural practices; optimal use of biological control organisms; certified seed; protective seed treatments; disease-free transplants or rootstock; timeliness of crop cultivation; improved timing of pesticide applications; and removal or 'plow down' of infested plant material."

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

Biological Control/Bio-control: "Biological control is, generally, man's use of a specially chosen living organism to control a particular pest. This chosen organism might be a predator, parasite, or disease which will attack the harmful insect. It is a form of manipulating nature to increase a desired effect. A complete Biological Control program may range from choosing a pesticide which will be least harmful to beneficial insects, to raising and releasing one insect to have it attack another, almost like a 'living insecticide.'"
Intensive/Controlled Grazing Systems:

"The term 'intensive grazing' is meant to describe livestock and grass management practices that focus on increased levels of manager’s involvement, leading to increased productivity and the sustainability of the land. Managers practicing intensive grazing closely follow the interactions between plant, animal, soil and water. They determine where, when and what livestock graze and control animal distribution and movement."

"Controlled grazing is a flexible management method that balances plant and animal requirements. Controlled grazing relies on management, not technology. It uses variable rest periods, short graze periods, high stock densities, and a minimal number of relatively large herds. It requires changing the stocking rate to match annual and seasonal changes in carrying capacity."

Other terms, related to both dairy and meat production, that fall under the category of Intensive/Controlled Grazing are: Rotational Grazing, Management Intensive Grazing (MIG), High-Intensity Low-Frequency Grazing (HILF), Time-Controlled Grazing (TCG), Holistic Range Management, Grassfarming, Pasture-Based Farming, and Voisin Management Grazing.

Local/Community Food System:

A community food system, also known as a local food system, "is a collaborative effort to integrate agricultural production with food distribution to enhance the economic, environmental, and social well-being of a particular place (i.e. a neighborhood, city, county or region)."

"One of the primary assumptions underlying the sustainable diet concept is that foods are produced, processed, and distributed as locally as possible. This approach supports a food system that preserves local farmland and fosters community economic viability, requires less energy for transportation, and offers consumers the freshest foods."

Related terms:

The Foodshed concept, most often attributed to Arthur Getz in his 1991 Urban Foodsheds article in Permaculture Activist [Vol. VII, no. 3], uses the analogy of a watershed to describe "the area that is defined by a structure of supply." Getz used the image of a foodshed to answer the question of "where our food and regional food supply system works." Inherent in this concept, he emphasized, was "the suggestion of a need to protect a source, as well as the need to know and understand its specific geographic and ecological dimensions, condition and stability in order for it to be safeguarded and enhanced."

The Food Circle is a "dynamic, community-based and regionally-integrated food systems concept/model/vision. In effect, it is a systems ecology. In contrast to current linear production-consumption systems, the food circle is a production-consumption-recycle model. A celebration of cycles, this model mirrors all natural systems and is based on the fact that all stable, biological and other systems function as closed cycles or circles, carefully preserving energy, nutrients, resources and the integrity of the whole." [Ibid]
Low Input Agriculture:

Low input farming systems "seek to optimize the management and use of internal production inputs (i.e. on-farm resources)... and to minimize the use of production inputs (i.e. off-farm resources), such as purchased fertilizers and pesticides, wherever and whenever feasible and practicable, to lower production costs, to avoid pollution of surface and groundwater, to reduce pesticide residues in food, to reduce a farmer's overall risk, and to increase both short- and long-term farm profitability."

The term is "somewhat misleading and indeed unfortunate. For some it implied that farmers should starve their crops, let the weeds choke them out, and let insects clean up what was left. In fact, the term low-input referred to purchasing few off-farm inputs (usually fertilizers and pesticides), while increasing on-farm inputs (i.e. manures, cover crops, and especially management). Thus, a more accurate term would be different input or low external input rather than low-input."

Natural Farming:

Natural Farming reflects the experiences and philosophy of Japanese farmer Masanobu Fukuoka. His books *The One-Straw Revolution: An Introduction to Natural Farming* describe what he calls "do-nothing farming" and a lifetime of nature study. "His farming method involves no tillage, no fertilizer, no pesticides, no weeding, no pruning, and remarkably little labour! He accomplishes all this (and high yields) by careful timing of his seeding and careful combinations of plants (polyculture). In short, he has brought the practical art of working with nature to a high level of refinement."

Nature Farming:

Nature farming grew out of the philosophy and methodology of Japanese philosophist, Mokicho Okada in the mid-1940s. "The theory of Nature Farming, as Okada expounded it, rests on a belief in the universal life-giving powers that the elements of fire, water, and earth confer on the soil. The planet's soil, created over a span of eons, has acquired life-sustaining properties, in accordance with the principle of the indivisibility of the spiritual and the physical realms, which in turn provide the life-force that enables plants to grow. To utilize the inherent power of the soil is the underlying principle of Nature Farming." Practices focus on analyzing and building soil through composting, green manuring, mulch, and various other soil management techniques. Similar in many ways to organic farming, nature farming is most commonly practiced in the Pacific Rim countries of Asia and North America.

Related term:

**Kyusei Nature Farming**: Developed by Teruo Higa in Japan during the 1980s, "Kyusei Nature Farming means saving the world through natural or organic farming methods... An added dimension of Kyusei Nature Farming is that it often employs technology involving beneficial microorganisms as inoculants to increase the microbial diversity of agricultural soils, which, in turn, can enhance the growth, health, and yield of crops."
Nutrient Management:

Nutrient management is "managing the amount, source, placement, form, and timing of the application of nutrients and soil amendments to ensure adequate soil fertility for plant production and to minimize the potential for environmental degradation, particularly water quality impairment."

Nutrient management has taken on new connotations in recent times. Soil fertility traditionally dealt with supplying and managing nutrients to meet crop production requirements, focusing on optimization of agronomic production and economic returns to crop production. Contemporary nutrient management deals with these same production concerns, but recognizes that ways of farming must now balance the limits of soil and crop nutrient use with the demands of intensive animal production. Current decision-making processes include crop and animal production factors, economic factors, and the integrity of local surface water and groundwater, as well as the fate of far-away environmental systems.

Organic Farming:

The term 'organic farming' was first used by Lord Northbourne in the book, Look to the Land (London: Dent, 1940. NAL Call # 30 N81). Lord Northbourne, who embraced the teachings of Rudolph Steiner and biodynamic farming, had a "vision of the farm as a sustainable, ecologically stable, self-contained unit, biologically complete and balanced--a dynamic living organic whole...The term thus did not refer solely to the use of living materials (organic manures, etc) in agriculture although obviously it included them, but with its emphasis on 'wholeness' is encompassed best by the definition 'of, pertaining to, or characterized by systematic connexion or coordination of parts of the one whole.'

Under NPOP (India) ORGANIC AGRICULTURE is defined as- a system of farm design and management to create an eco system, which can achieve sustainable productivity without the use of artificial external inputs such as chemical fertilizers and pesticides

Permaculture:

A contraction of "permanent agriculture," the word "permaculture" was coined by Australian Bill Mollison in the late 1970s. One of the many alternative agriculture systems described as sustainable, permaculture is "unique in its emphasis on design; that is, the location of each element in a landscape, and the evolution of landscape over time. The goal of permaculture is to produce an efficient, low-maintenance integration of plants, animals, people and structure... applied at the scale of a home garden, all the way through to a large farm."

Precision Farming/Agriculture:

Precision agriculture is a "management strategy that employs detailed, site-specific information to precisely manage production inputs. This concept is sometimes called Precision Agriculture, Prescription Farming, Site-specific Management. The idea is to know the soil and crop characteristics unique to each part of the field, and to optimize the production inputs within small portions of the field. The philosophy behind precision agriculture is that production inputs (seed,
fertilizer, chemicals, etc.) should be applied only as needed and where needed for the most economic production." This system requires the utilization of sophisticated technology including personal computers, telecommunications, global positioning systems (GPS), geographic information systems (GIS), variable rate controllers, and infield and remote sensing. Chemical inputs are reduced in precision agriculture, but several factors make it controversial in the sustainable agriculture community, including the requirements of large capital outlay and advanced technical expertise.

**Regenerative Agriculture:**

Robert Rodale coined this term, and it subsequently was expanded to "regenerative/sustainable agriculture" by the Rodale Institute and Rodale Research Center. Two reasons given for the emphasis on "regenerative" are (1) "enhanced regeneration of renewable resources is essential to the achievement of a sustainable form of agriculture," and (2) "the concept of regeneration would be relevant to many economic sectors and social concerns."

**Sustainable Development:**

During the past 20 years, considerable interest in sustainability as applied to all areas of human activity has emerged worldwide. Sustainable development must ... "meet the needs of the present without compromising the ability of future generations to meet their own needs."

"The vision is of a life-sustaining Earth. We are committed to the achievement of a dignified, peaceful and equitable existence. A sustainable Nation will have a growing economy that provides equitable opportunities for satisfying livelihoods and safe, healthy, high quality of life for current and future generations. Our nation will protect its environment, its natural resource base, and the functions and viability of natural systems on which all life depends."

**Whole Farm Planning:**

Whole farm planning strategies share a conservation, family-oriented approach to farm management, although specific components may vary from farm to farm, and from community to community. "Whole farm planning provides farmers with the management tools they need to manage biologically complex farming systems in a profitable manner. As a management system, it draws on cutting-edge management theory used by other businesses, industries and even cities. It encourages farmers to set explicit goals for their operation; carefully examine and assess all the resources -- cultural, financial, and natural -- available for meeting their goals; develop short- and long-term plans to meet their goals; make decisions on a daily basis that support their goals; and monitor their progress toward meeting goals."

**Cropping System:**

Cropping system is an important component of farming system: It represents cropping pattern used on a form and their interaction with resources, other farm enterprises and available technology, which determine their makeup.

**Cropping Pattern:**

Cropping pattern means the proportion of area under various at a point of time in a unit area. Or it indicates the yearly sequences and spatial arrangement of crops and fallow in an area.
Crop sequence and crop rotation are generally used synonymously.

**Crop Rotation:**
Crop rotation refers to recurrent succession of crops are so chosen that soil health is not impaired.

**Cropping Scheme:**
Cropping scheme is the plan according to which crops are grown on individual plots of a farm with an object of getting maximum return from each crop without impairing the fertility of soil is known as cropping scheme.

**Indigenous Farming Systems**

(i) **Shifting Cultivation:** It refers to farming system in north-eastern areas in which land under natural vegetation (usually forests) is cleared by slash and burn method, cropped with common arable crops for a few years, and then left unattended when natural vegetation regenerates. Traditionally the fallow period is 10-20 years but in recent times it is reduced to 2-5 years in many areas. Due to the increasing population pressure, the fallow period is drastically reduced and system has degenerated causing serious soil erosion depleting soil fertility resulting to low productivity. In north-eastern India many annual and perennial crops with diverse growth habits are being grown.

(ii) **Taungya Cultivation:** The Taungya system is like an organized and scientifically managed shifting cultivation. The word is reported to have originated in Myanmar (Burma) and tauang means hill, ya means cultivation i.e. hill cultivation. It involves cultivation of crops in forests or forest trees in crop-fields and was introduced to Chittagong and Bengal areas in colonial India in 1890. Later it had spread throughout Asia, Africa and Latin America. Essentially, the system consists of growing annual arable crops along with the forestry species during early years of establishment of the forest plantation. The land belongs to forest department or their large scale leases, who allow the subsistence farmers to raise their crops and in turn protect tree saplings. It is not merely temporary use of a piece of land and a poverty level wage, but is a chance to participate equitably in a diversified and sustainable agroforestry economy.

(iii)**Zabo Cultivation:** Zabo is an indigenous farming system practiced in north eastern hill regions particularly in Nagaland. This system refers to combination of forest, agriculture, livestock and fisheries with well-founded soil and water conservation base. The rain water is collected from the catchment of protected hill tops of above 100% slopes in a pond with seepage control. Silt retention tanks are constructed at several points before the runoff water enters in the pond. The cultivation fully depends on the amount of water stored in the pond. The land is primarily utilized for rice. This system is generally practiced in high altitude hill areas, where it is not possible to construct terraces and or irrigation channels across the slope. This is a unique farming system for food production to make livelihood. Zabo means impounding of water. The place of origin of zabofarming system is thought to be the Kikruma village in Phek district of Nagaland.
System’s approach

System

n.

1. A group of interacting, interrelated, or interdependent elements forming a complex whole.

2. A functionally related group of elements, especially:
   a. The human body regarded as a functional physiological unit.
   b. An organism as a whole, especially with regard to its vital processes or functions.
   c. A group of physiologically or anatomically complementary organs or parts: the nervous system; the skeletal system.
   d. A group of interacting mechanical or electrical components.
   e. A network of structures and channels, as for communication, travel, or distribution.
   f. A network of related computer software, hardware, and data transmission devices.

3. An organized set of interrelated ideas or principles.
4. A social, economic, or political organizational form.
5. A naturally occurring group of objects or phenomena: the solar system.
6. A set of objects or phenomena grouped together for classification or analysis.
7. A condition of harmonious, orderly interaction.
8. An organized and coordinated method; a procedure.
9. The prevailing social order; the establishment. Used with the: You can’t beat the system.

System could be defined as an organized unitary whole composed of two or more interdependent and interacting parts, components or subsystems delineated by identifiable boundary or its environmental super system (Singh, 2001). A system consists of several components or subsystems which depend on each other. A system is defined as a unified whole or set of elements/components that are interrelated and interacting among themselves. A system processes input into outputs. Therefore, each system consists of boundaries, components, interactions between components, inputs and outputs.

The term "systems" is derived from the Greek word "synistanai," which means "to bring together or combine." The term has been used for centuries. Components of the organizational concepts referred to as the "systems approach" have been used to manage armies and governments for millennia. However, it was not until the Industrial Revolution of the 19th and 20th centuries that formal recognition of the "systems" approach to management, philosophy, and science emerged (Whitehead 1925, von Bertalanffy 1968). As the level of precision and efficiency demanded of technology, science, and management increased the complexity of industrial processes, it became increasingly necessary to develop a conceptual basis to avoid being overwhelmed by complexity. The systems
approach emerged as scientists and philosophers identified common themes in the approach to manage and organize complex systems. Four major concepts underlie the systems approach:

- **Specialization**: A system is divided into smaller components allowing more specialized concentration on each component.
- **Grouping**: To avoid generating greater complexity with increasing specialization, it becomes necessary to group related disciplines or sub-disciplines.
- **Coordination**: As the components and subcomponents of a system are grouped, it is necessary to coordinate the interactions among groups.
- **Emergent properties**: Dividing a system into subsystems (groups of component parts within the system), requires recognizing and understanding the "emergent properties" of a system; that is, recognizing why the system as a whole is greater than the sum of its parts. For example, two forest stands may contain the same tree species, but the spatial arrangement and size structure of the individual trees will create different habitats for wildlife species. In this case, an emergent property of each stand is the wildlife habitat.

The systems approach considers two basic components: elements and processes. **ELEMENTS** are measurable things that can be linked together. They are also called objects, events, patterns, or structures. **PROCESSES** change elements from one form to another. They may also be called activities, relations, or functions. In a system the elements or processes are grouped in order to reduce the complexity of the system for conceptual or applied purposes. Depending on the system's design, groups and the interfaces between groups can be either elements or processes. Because elements or processes are grouped, there is variation within each group. Understanding the nature of this variation is central to the application of systems theory to problem-solving.

Farming system approach addresses itself to each of the farmer enterprises, inter relationship among enterprises and between the farm and environment. Thus farming system research has the objective of increasing productivity of various enterprises in the farm. Farming system approach introduces a change in farming technique for high production from a farm as a whole with the integration of all the enterprises. The farm produce other than the economic products for which the crop is grown can be better utilized for productive purposes in the farming system approach. A judicious mix of cropping system with associated enterprises like dairy, poultry, piggery, fishery, sericulture etc. suited to the given agro-climatic conditions and socio economic status of farmers would bring prosperity to the farmer.

In crop production, management practices are developed for individual crops and recommendation are made for individual crops. The residual effect of individual crops is not considered in crop based recommendation. In this resources are not utilized efficiently. To a farmer instead of crop, land is a
unit and management practices should be for all crops that are to be grown one after the other on a piece of land. Therefore system approach is applied to agriculture for efficient utilization of all resources maintains sustainability in production and obtaining higher net returns.

Farming is a dynamic biological and open system with human or social involvement. Being primarily biological with a high degree of dependence on weather variables and changing socio-political environments. Farming is inherently more risky than any other system. Farming system can also mean different things to different people. To avoid ambiguity and confusion both terms farming and system should be clearly understood. Farming is the process of harnessing solar energy in the form of economic plant and animal products and system implies a set of inter related practices/processes organized into a functional entity.

Farming systems research (FSR): Originates from recognizing the inter-dependence and inter relationships of natural environment within the farming system. In FSR the farmers by participating in the research process help in the identification of the research problems as well as take part in testing the possible solution.

Goals:

The growing concern on suitable development has led the FSR to compasses on sound management of farm resources to enhance farm productivity and reduce the degradation of environment quality or to develop sustainable land use, which will optimize farm resource, minimum degradation with consideration to regenerative capacity, increase income and employment for farm families and promote quality of life.

Principal Involved: The FSR approach includes:

- Viewing the farm as a whole,
- Identifying the farming system, the interacting component and delineating boundaries,
- Systematical investigation of the nature and extent of interdependence among the enterprises and identifying constraint,
- Applying the modern technical know-how to the system so as to make it yield optimum results,
- Studying the equity gender income, employment and resources use efficiency, and
- Dealing with the issue at integration level through analysis and solution of problems towards sustainable farming system development.

In the past decades, farming system research has emerged as a popular and major theme in international agricultural research. FSR evolved in post- green revolution era with the growing perception of the failure of main stream agricultural research and extension institution to generate and disseminate technologies widely adopted by small scale, resources poor farmers. Clearly technology, even when sound by scientific standards, is of limited value if is not adopted. The diagnosis of the problems was that agricultural researches and development planners, the generators and disseminators of new technology, had employed a fundamentally top-down approach to technology development, which is not valid one. In response to this situation, FSR argued that:
1. Development of relevant and viable technology for small farmers must be grounded in a full knowledge of existing of the farming system and
2. Technology should be evaluated not solely in terms of its technical performance, but in terms of its conformity to the goals, needs and socio-economic condition of small farm system as well.

Therefore, FSR concept was developed in 1970 in response to the observation that groups of small-scale farm families operation on harsh environment were not benefiting from conventional agricultural research and extension strategies. The term FSR in its broadest sense is any research that views the farm in a holistic manner and considers interactions (between component and of components with environment) in the system.

Farming system research is a ‘research method’ designated to understand farmer’s priorities, strategies and resources allocation decisions. It is most often used in conjunction with on-farm highly location specific research with multi and inter-disciplinary in nature and uses a whole farm approach for improved technologies to enhance and stabilize agriculture production.

The Characteristics of Farming System Research

1. It is holistic or system oriented,
2. It is problems solving: involvement of farmers in problem identification and solving process,
3. It is farmer participatory,
4. It envisages location specific technology solutions,
5. It is for specific client group – small/marginal farmer,
6. It adopts bottom up approach,
7. It compasses extensive on farm activities, collaboration between farmer and scientist,
8. It is gender sensitive,
9. It ultimate objective is sustainability,
10. It focuses on actual adoption,
11. It recognizes interdependence among multiple clients.
Direct, residual and cumulative effects

Direct effect

A chemical effect caused by the direct transfer of energy from ionizing radiation to an atom or molecule in a medium (physical chemistry).

Residual

Residual is used to describe what remains of something when most of it has gone.

1. [noun] something left after other parts have been taken away; "there was no remainder"; "he threw away the rest"; "he took what he wanted and I got the balance"
   Synonyms: remainder, balance, residue, residuum, rest

2. [noun] (often plural) a payment that is made to a performer or writer or director of a television show or commercial that is paid for every repeat showing; "he could retire on his residuals"

3. [adjective] relating to or indicating a remainder; "residual quantity"
   Synonyms: residuary

Cumulative effect

• n. The state at which repeated administration of a drug may produce effects that are more pronounced than those produced by the first dose. Also called cumulative action.

adjective

1. increasing or growing by accumulation or successive additions: the cumulative effect of one rejection after another.

2. formed by or resulting from accumulation or the addition of successive parts or elements.

3. of or pertaining to interest or dividends that, if not paid when due, become a prior claim for payment in the future: cumulative preferred stocks.

Cumulative

—adj

1. growing in quantity, strength, or effect by successive additions or gradual steps: cumulative pollution

2. gained by or resulting from a gradual building up: cumulative benefits

3. finance

   a. (of preference shares) entitling the holder to receive any arrears of dividend before any dividend is distributed to ordinary shareholders
4. statistics

a. (of a frequency) including all values of a variable either below or above a specified value

b. (of error) tending to increase as the sample size is increased

In agriculture knowledge regarding direct, residual and cumulative effects of fertilizers and manures, other agrochemicals and any other input or practice is strategically essential to plan their application at optimum rates for the purpose of sustainable production and, economic, social, and environmental issues. This is one of the fundamental in system’s approach. An under dose will not harness the full benefits of costly inputs, while the over accumulation will result in serious upheavals in the environment. The successive increments of many fertilizer nutrients such as P, S, Ca, Mg, Zn, B, Fe etc result in their accumulation at toxic levels. More application of N leads to luxuriant growth inviting more of diseases and insect-pest while showing no residual activity. More K application leads to luxury consumption.

**Residual effect of B and Zn**

Rice-wheat is a nutrient exhaustive system and nutrient removal from the soil is much higher than fertilizer input. As a result, wide spread micronutrient deficiencies occurred in rice-wheat system. Zinc (Zn) and boron (B) are increasingly important micronutrient deficiencies particularly on calcareous soils of arid and semi-arid region. Many available reports present that Zn and B deficiencies are most wide spread micronutrients deficiencies all over the world, which cause decline in crop production and quality (Alloway, 2004; Rashid and Ryan 2004; Rafique et al., 2008). The soils of rice-wheat area in Pakistan are alkaline calcareous in nature, having low organic matter, nutrient mining with intensive cultivation and imbalanced fertilization which causes nutrient deficiencies including Zn and B (Rafique et al., 2006, 2008). High pH and low levels of organic matter reduce solubility and mobility of Zn in soil and stimulate adsorption of Zn in soil constituents such as clay minerals and metal oxides (Marschner, 1993; Rashid and Ryan, 2004). Zia et al. (1996) reported that residual effect of 10 kg Zn ha⁻¹ was effective to increase grain yield of rice as compared to 5 kg Zn ha⁻¹ in rice-wheat cropping system. Similarly, highest cumulative yield was obtained when 10 kg Zn ha⁻¹ was applied to both the crops. Hussain (2004) reported that residual application of 5 kg Zn ha⁻¹ increased the paddy yield by 6.1% while cumulative application of Zn increased the paddy yield by 17.0%. Rashid (2005) advocated that soil applied micronutrients leave a beneficial residual effect on succeeding crop (s) grown in the same field. This is because the first crop removes only a small fraction of the applied micronutrient dose. To avoid toxicity of micronutrients which results in reduced crop yields, information on the residual effect of micronutrient fertilization after period of application is also desirable.

Khan et al (2009) found that the application of Zn in either way increased the yields of both the crops significantly over control, which indicates response of wheat and rice to Zn. However, direct application of Zn was found significantly better than other fertilizer treatments in case of wheat. While for rice crop the cumulative effect of Zn application was found significantly better than the other treatments.

Boron (B) an important mineral nutrient stimulate a number of physiological processes in vascular
plants, it is important for carbohydrates metabolism, translocation and development of cell wall and RNA metabolism (Herrera-Rodriguez et al. 2010; Siddiky et al. 2007; Marschner, 1995). Boron has been found to play a key role in pollen germination and pollen tube growth, stimulate the plasma membrane, anther development, floret fertility and seed development (Wang et al. 2003; Oosterhuis, 2001). Deficiency of B causes reduction in leaf photosynthetic rate, total dry matter production, plant height and number of reproductive structures during squaring and fruiting stage (Zhao and Oosterhuis, 2003). Rashid et al. (2007) reported that an increase of 14 to 23% in rice yield occurred with B application in different areas of Punjab and Sindh, Pakistan. Boron fertilization increases 46.1% seed yield of rapeseed in light textured soils (Yang et al. 2009). Hussain (2006) reported significantly higher grain yield of rice and wheat with cumulative application as compared to direct and residual applied Zn and B in rice-wheat area of Lahore. Khan et al (2011) found that the application of boron in either way increased the yields of rice and wheat crop over control, which shows the response of wheat and rice to boron. However the direct soil application of 2 kg B ha$^{-1}$ to wheat crop after rice gave maximum yield as compared to cumulative or residual application, while in rice the cumulative effect of 1 kg B ha$^{-1}$ was found significantly better than other treatments in rice-wheat system.

Residual effect of P

Long-term application of fertilizers containing P, especially organic fertilizers, usually increases the water soluble and available P of soil and at the same time may result in P accumulation in soil. Organic fertilizers may also increase movement of P in the soil profile that could result in surface and ground water pollution. Mohammadi et al. (2009) used three applications (25, 50 and 100 Mg ha$^{-1}$) of solid dairy manure, sewage sludge, or urban solid waste compost, and one application of chemical fertilizers (250 kg ha$^{-1}$ urea plus 250 kg ha$^{-1}$ mono-ammonium phosphate) for 1, 2, 3, 4 or 5 consecutive years. Average organic matter content in the soil increased as a result of organic fertilizer applications. The increase was proportional to the rate of application and was highest for dairy manure and lowest for urban solid compost. Both the water extractable and bioavailable P contents of soil increased with the rate of application, the nature of organic fertilizer and the number (years) of applications, with the rate being the most effective and the nature of fertilizer the least effective. Dairy manure had the largest and solid waste compost the smallest positive impact on both the water soluble and available P content of soil. Effect of sewage sludge application on available P content of the soil was greater than its effect on the water extractable P. The phosphorus sorption index was independent of the source of P (organic or chemical), the nature and the rate of organic fertilizers and was only significantly dependent on the number (years) of fertilizer applications.

Sahrawat et al (1997) determined the response of four upland rice cultivars to fertilizer P applied at 0, 45, 90, 145 and 180 kg P ha$^{-1}$ only once in 1993, and to fertilizer P residues in 1994 and 1995. The soil in the humid forest zone of Ivory Coast (West Africa), was an Ultisol, low in available P. Grain yields of the rice cultivars were significantly increased by fertilizer P in 1993, and by the fertilizer P residues in 1994 and 1995 although the magnitude of response decreased with time since the fertilizer was applied. The cultivars differed in cumulative agronomic and physiological efficiencies, and the efficiencies were higher at the lower rates of P. The amounts of total P removed in three successive crops were similar for all the four rice cultivars although P harvest index was 10–12% higher in the P efficient than inefficient cultivars. The results suggest that the differences observed in the P efficiency of rice cultivars are due to differences in the internal efficiency of P.
Farming system’s enterprises/components and their maintenance

Cropping systems:
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 income for domestic and cultivation expenses.

Plant interactions

Interactions between component crops
In intensive cropping, crops are grown in association (intercropping) or in sequence (sequential cropping). In such situations there is possibility of interaction between the component crops. The interaction is mainly due to response of one species to the environment as modified by the presence of other species. Interaction may be competitive or non-competitive or complementary.

Interactions in intercropping
Factors such as light, water, nutrients, oxygen and CO2 are required for plant growth. In mixed or intercropping situations, the component species compete for the growth factors. The close proximity of the species causes sub-optimal utilization of the growth factors and hence there is inequitable distribution of resources among the plants. Generally competition will develop between two components or within the components.

Light: Intercropping can increase light inception by as much as 30-40%. When one component is taller than the other in an intercropping system, the taller component intercepts most of the solar radiation. In intercropping situation where the component crops have different growth durations, the peak demand for light would occur at different times. In such combinations, competition for light is less among the component crops and there is greater light use in intercropping than in pure stands. In general the component crops under intercropping situations are grown in such a way that competition for light is minimized. Proper choice of crops and varieties, adjustment of planting density and pattern are the techniques to reduce competition and increase the light use efficiency.

Moisture and nutrients: Competition for water and nutrients results in two main types of effects on the less successful or suppressed component. First, the roots of dominated crop may grow less on the sides of aggressive component. The suppressed components adapt to such conditions by increased capacity for uptake. Also, if one part of the root system is on the depleted side, the remaining part shows compensatory activity and vigour. Secondly, plants affected by competition for soil factors are likely to have increased root/shoot ratio.

Allelopathy. Allelopathy is any direct or indirect harmful effect that one plant has on another through the release of chemical substances or toxins into the root environment. Some crops may be unsuitable to be grown as intercrops because they may produce and excrete toxins into the soil which are harmful to other components.

Annidation. Annidation refers to complementary interaction which occurs both in space and time.

Annidation in Space. The canopies of component crops may occupy different vertical layers with
taller component tolerant to strong light and high evaporative demand and shorter component favouring shade and high relative humidity. Thus, one component crop helps the other. Multistoreyed cropping in coconut gardens and planting of shade trees in coffee, tea and cocoa plantations use this principle. Similarly, root systems of component crops exploit nutrients from different layers thus utilizing the resources efficiently. Generally, one component with shallow root system and another with deep root system are selected for intercropping as in Setaria (shallow) + red gram (deep) intercropping system.

**Annidation in Time.** When two crops of widely varying duration are planted, their peak demands for light and nutrients are likely to occur at different periods, thus reducing competition. When the early maturing crop is harvested, conditions become favourable for the late maturing crop. This has been observed to occur in sorghum + red gram, groundnut + red gram and maize + green gram intercropping systems.

**Other Complementary Effects.** In an intercropping system, involving a legume and a non-legume, part of the nitrogen fixed in the root nodule of the legume may become available to the non-legume component. The presence of rhizosphere microflora and mycorrhiza on one species may lead to mobilization and greater availability of nutrients not only to the species concerned, but also to the associated species. Another example is the provision of physical support by one species to the other in intercropping system. Erect crop plants may improve the yield of a climber as in the case of coconut + pepper, maize + beans. The taller component acts as wind barrier protecting the short crop as in maize + groundnut, onion + castor and turmeric + castor.

**Interactions in Sequence Cropping**

Competition for light, water and nutrients as in mixed crop communities does not occur when sole crops are grown in sequence. It occurs only in relay cropping where there is a short span of overlapping between two crops in a sequence and the relay crop experiences the shortage of light. The important purpose in sequential cropping is to increase the use of solar radiation. It is achieved by longer field duration and rapid ground coverage. Crops are raised one after another to keep the land occupied by the crop for longer period. If the crop development is slow, much of the solar radiation reaches the ground, favouring weed growth and increasing evaporation losses from the soil surface.

In sequential cropping, the proceeding crop has considerable influence on the succeeding crop mainly by changes in soil conditions, presence of allelopathic chemicals, shift in weeds and carry over effects of fertilizers, pests and diseases. Field preparation is difficult after rice crop since soil structure is destroyed due to puddling. Crops like sorghum and sunflower leave toxic chemicals in the soil which do not allow germination of subsequent crops. The previous leguminous crop leaves considerable amount of nitrogen for the succeeding crop. Phosphorous applied to the previous crop is available for the succeeding crop. Weed number and species differ in the succeeding crop due to the effect of the previous crop. Wheat crop that follows rice suffers from high density of weed Phalaris minor. The pests and diseases in crop stubbles and other residues of the previous crop may infect the subsequent crop.

**CROPPING SYSTEM MANAGEMENT**

The principles involved in management of intercropping and sequence cropping system are different. Intercropping is practiced with two objectives: to get additional yield through an intercrop as a bonus and to avoid risk.
Management of Intercropping Systems

The crops in intercropping system are grown simultaneously. Management practices that are followed should, therefore, aim to provide favourable environment to all the components, exploit favourable interactions among the component crops and minimize competition among the components.

**Seedbed Preparation.** Seedbed preparation for different crops varies depending on the crop. Deep rooted crops respond to deep ploughing while for most of the cereals shallow tillage is sufficient. The crops with small seed require fine seedbed. Certain crops like cotton and maize are planted on ridges, while most of the other crops are grown on flat seedbed. Since more than one crop is involved in intercropping, the seedbed preparation is generally done as per the needs of base crop. The seedbed for sugarcane, as usual, is made into ridges and furrows. Sugarcane is planted in furrows and intercrops are sown on ridges. In groundnut + red gram intercropping system, flat seedbed is preferred for sowing the crops. However, ICRISAT is recommending broad bed and furrows for black soils of semi-arid regions for pure crops as well as intercrops grown under rainfed conditions. Where the crop requirements are quite different as in rice + maize under rainfed conditions and also in agro-forestry, seedbed preparation is done separately for component crops. In rice + maize intercropping system, ridges and trenches are formed. Maize is planted on ridges and rice in trenches. In agro-forestry, pits are dug for tree species and a rough seedbed is prepared in interspace for the introduction of forage crops.

**Varieties.** The varieties of component crops selected for intercropping system should be less competing with the base crop and the peak nutrient demand period should be different from the base crop. The difference in duration between the components in intercropping should be a minimum period of 30 days. The short duration sorghum hybrids like CSH-6, CSH-9 are suitable for intercropping with long duration red gram varieties like C 11 and LRG 30 because of wider gap between maturity periods. Selection of compatible genotypes of component crops increases the complementarity of intercropping system. The varieties selected for intercrop should have thin leaves, tolerant to shading and less branching since these crops are generally shaded by the base crop. If the base crop is shorter than intercrop, the intercrop should be compact with erect branching, and its early growth should be slow. The characteristics of base crop should be as in sole crop.

**Sowing.** Sowing practices are slightly altered to accommodate intercrop in such a way that it causes less competition to the base crop. Sowing of base crop is done either as paired tow, paired wider row or skip-row planting. The sowing of base crop and intercrop is also done in fixed ratios. In paired-row planting, two rows of base crop are brought close by reducing inter-row spacing. The spacing between the two pairs of rows are increased to accommodate the intercrop. For example, the normal row spacing of rainfed groundnut is 30 cm. The row spacing is reduced to 20 cm between the paired rows and 50 cm spacing is given between two pairs of rows. The spacing in paired row planting designated as 20/50 cm indicates that the spacing between two rows in a pair is 20 cm and among the pairs 50 cm. Similarly, pearl millet is planted with row spacing of 30/60 cm in paired row planting. These changes in crop geometry do not alter base crop yield, but intercrops are benefited to some extent. The seed drill used for normal planting contains tynes with uniform spacing. The spacing of the tynes on the beam of seed drill is to be changed to 20/40 or 30/60 as per requirement for sowing in paired rows.

Planting in fixed ratio of intercrops is most common. The intercropping system of groundnut + redgram is either in 5 : 1 or 7 : 1 ratio and sorghum + redgram in 2: 1 ratio. In these cases, the normal three tyned or four tyned seed drill can be used without any modification. The hole pertaining to
intercrop row in the hopper is closed with a piece of cloth. In that row, intercrop is sown with akkadi or kera.

In traditional cropping systems, the component crops are grown with sub-optimum population. Yields of intercrops can be increased with higher plant population. For higher yields, base crop population is maintained at its sole crop population and intercrop population is kept at 80% of its sole crop population. Even 100% population of both the crops is maintained with advantage in some intercropping systems. For example, sorghum red gram intercropping with 100% population of both crop ($180 \times 10^3$ and $50 \times 10^3$) gives higher yield than lower population of these crops. When the difference in duration of component crops is less than 30 days, staggered planting is done to increase the difference in duration. The aggressive or dominant crop is sown 10 to 15 days after sowing the dominated crop.

**Fertilizer Application.** The amount of nutrients present in the component crops indicates the requirement of fertilizers for the intercropping system. The nutrient uptake is generally more in intercropping system compared to pure crops. When legumes are associated with cereal crop in intercropping system, a portion of nitrogen requirement of cereal is supplemented by the legume. The amount may be as small as a few kilograms to 20 kg/ha. Application of higher dose of nitrogen to the cereal + legume intercropping system not only reduces the nitrogen fixation capacity of legume, but also growth of legume is suppressed by aggressive cereals owing to fast growth of cereals with increased availability of nitrogen. Cereal + legume intercropping, is therefore; 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 cereals + legume of legume + legume. With regard 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 crop to meet the extra demand.

Basal dose of nitrogen is applied to rows of both components in cereals + legume intercrop system. Top dressing of nitrogen is done only to cereal rows. Phosphorus and potassium are applied as basal dose to both crops.

**Water Requirement.** Intercropping systems are generally recommended for rainfed crops to get stable yields. The total water used in intercropping system is almost the same as for sole crops, but yields are increased. Thus water-use efficiency of intercropping is higher than sole crops. The component crops differ on their capacity to withstand excess or difficult moisture conditions. However the irrigation schedule followed for sole crops is suitable even for intercropping system. Scheduling irrigation at IW/CPE ratio of 0.6 to 0.8 or irrigation at one bar soil moisture tension is suitable for most of the systems. However, information on this aspect is meager.

**Weed Management.** Weed problem is less in intercropping system compared to their sole crops. The higher plant population used and also complete covering of the soil earlier in intercropping system reduces weed infestation. In late maturing crops that are planted on wide rows, presence of early maturing crops helps to cover the vacant interrow space and keep weeds under check. In certain situations, intercrops are used as biological agents to control weeds. Black gram, green gram, cowpea in sorghum and cowpea in banana reduce weed population and one hand weeding can be avoided by this method. However, in some intercropping systems like maize + groundnut, rice + tapioca, maize + tapioca, weed problem is similar to their sole crops. The growth habit of genotype used in intercropping has a great influence on weed growth. Early crop canopy to cover the soil is more important than rapid increase in plant height.
It is very well known that different species of weeds are associated with different crops. This is due to differences in weed management practices like tillage, herbicides etc., and also due to crop-weed interference. For these reasons, weeds present in sole crops are different than those present in intercropping systems. At Hyderabad, mixed weed flora appeared in sole crop of pearl millet and dominant weeds such as *Celosia, Digitaria* and *Cyperus* in sole crop of groundnut. In pearl millet and groundnut intercropping system, the type of weeds change with the proportion of component crops. As more rows of groundnut are introduced in place of pearl millet rows, there is a striking increase in both numbers and biomass of the tail and competitive *Celosia*, especially in groundnut rows.

Though weed problem is less, weed control measures are necessary in intercropping system. But the labour required for weeding is less. Second weeding is not necessary because of crop coverage. Chemical weed control is difficult in intercropping system because the herbicide may be selective to one crop, but non-selective to another. Atrazine gives good weed control in sole crop of sorghum, but it is not suitable for sorghum + redgram intercropping system as it is toxic to red gram. However, some herbicides are identified to suit both components (Table 1).

**Pests and Diseases.** Pests and diseases are believed to be less in intercropping system due to crop diversity than in sole crops. Some plant combinations may enhance soil fungistasis and antibiosis through indirect effects on soil organic matter content. The spread of the disease is altered by the presence of different crops. Little leaf of brinjal is less when brinjal is sheltered by maize or sorghum. As the insect carrying virus first attacks maize or sorghum, virus infection is less on brinjal. Non-host plants in mixtures may emit chemicals or odours that affect the pests, thereby protecting host plants.

<table>
<thead>
<tr>
<th>Herbicide</th>
<th>Time of application</th>
<th>Intercropping system</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pendimethalin or alachlor</td>
<td>Pre-emergence</td>
<td>Maize + greengram; Maize + cowpea</td>
</tr>
<tr>
<td>Trifluralin</td>
<td>Pre-plant incorporation</td>
<td>Maize + groundnut</td>
</tr>
<tr>
<td>Fluchloralin</td>
<td>- do -</td>
<td>Sorghum + pulse</td>
</tr>
<tr>
<td>Alachlar</td>
<td>Pre-emergence</td>
<td>Maize + soybean; Maize + cowpea; Sorghum + pulse</td>
</tr>
<tr>
<td>Dinitramine /Ametryne</td>
<td>Pre-emergence</td>
<td>Sorghum + lablab</td>
</tr>
<tr>
<td>Prometryne /Terbutryne</td>
<td>Pre-emergence</td>
<td>Sorghum + redgram</td>
</tr>
<tr>
<td>Nitrofen</td>
<td>Pre-emergence</td>
<td>Sugarcane + groundnut; Sorghum + pulse</td>
</tr>
</tbody>
</table>

The concept of crop diversification for the management of nematode population has been applied mainly in the form of decoy and trap crops. Decoy crops are non-host crops which are planted to make nematodes waste their infection potential. This is effected by activating larvae of nematodes in the absence of hosts by the decoy crops (Table 2).

<table>
<thead>
<tr>
<th>Crop</th>
<th>Nematode</th>
<th>Decoy crops</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brinjal</td>
<td><em>Meloidogyne incognita, M. Javanica</em></td>
<td><em>Sesamum orientale</em></td>
</tr>
<tr>
<td>Tomato</td>
<td><em>M. incognit., Pratylenchus allien</em></td>
<td>Castor, chrysanthemum, groundnut</td>
</tr>
<tr>
<td>Soybean</td>
<td><em>Pratylenchus sp</em></td>
<td><em>Crotalaria spectabilis</em></td>
</tr>
</tbody>
</table>
Trap crops are host crops sown to attract nematodes but destined to be harvested or destroyed before the nematodes manage to hatch. This is advocated for cyst nematodes. The technique involves sowing of crucifers and ploughing in before the nematodes of beets can develop fully. Similarly, in pineapple plantations, tomatoes are planted and ploughed in to reduce root-knot nematodes. There is also evidence that some plants adversely affect nematode population through toxic action. Marigold reduces the population of *Pratylenchus* eel worms.

**Management of Sequential Cropping Systems**

Unlike intercropping, crops are grown one after another in sequential cropping and hence, management practices are different.

*Seedbed Preparation.* The suitable type of seedbed for a particular crop can be prepared in sequence cropping systems like puddling for rice, ridges and furrows for vegetables, maize and cotton and flat seedbed for several other crops. However, two problems are encountered in seedbed preparation in sequential cropping system.

1. The time available for seedbed preparation is less in high intensity cropping system. Rains very frequently interfere with land preparation.
2. Due to the effect of the previous crop, the field may not be in proper condition to carry out field operations.

For example, field preparation after rice is difficult. It is mainly because soil structure is destroyed during puddling. The turn-around time, the time between harvesting of crop to sowing of next crop, is more if rice is the preceding crop. To avoid this problem, minimum tillage or zero tillage is adopted. It is a common practice to sow pulse crop just before or immediately after harvesting rice crop. In rice-wheat system, the rice stubbles are killed by spraying paraquat and wheat is sown in plough furrows between stubbles of rice. In Indonesia, Sorjan system has been developed to overcome this problem. In this system, upland and lowland crops are grown in alternate strips; rice is grown in the flooded strips, while maize, beans, mung bean, sorghum, cassava, cowpea or sweet potato are grown in the upland or elevated strips. During the dry season, cassava or sorghum is grown in the upland areas on residual moisture, while a catch crop of a legume or maize is grown where the rice has been harvested. A major constraint in the Sorjan system is the labour required to build and maintain permanent raised planting areas.

It is not possible to practice zero or minimum tillage in all sequence cropping systems. If sunflower is the preceding crop, ploughing is essential to oxidize the allelochemicals of sunflower. The stubbles of pearl millet and sorghum which contain high C : N ratio immobilize nitrogen. It is, therefore, necessary to remove them. They also interfere with running of sowing equipment. Generally tillage operations are done at the beginning of the season (for the first crop) and subsequently, zero tillage is practiced for other crops in the system. In rice-rice-green gram system, summer ploughing is done and later when water is available in the rainy season, puddling is done and first crop is sown. For the second crop, minimum tillage is done just to incorporate crop residues and rice is planted. Green gram is sown as a relay crop in the second rice crop. In cotton-sorghum-finger millet cropping system in garden lands, thorough field preparation is done and the field is laid out into check basins to transplant finger millet. In the next season, cotton is planted among the stubbles of finger millet without any land preparation. Weeds are controlled by inter-cultivation in cotton at subsequent stages. In Nigeria, 'no till' planting of sorghum into residues of the previous crop maintains the seed at 10°C lower temperature at 5 cm depth than conventional clean-tilled planting. In the latter tillage system,
temperature in the seeding zone reaches 4 °C.

**Varieties.** Short duration varieties of crops are selected to fit well in multiple cropping system. Photo insensitive varieties are essential for successful sequence cropping system. Most of the high yielding varieties are photo insensitive and intensive cropping is possible with the introduction of these varieties.

**Sowing.** Unlike in intercropping system, sowing is not a problem, provided there is sufficient time for seedbed preparation. If the proper seedbed is not prepared, establishment of crops is difficult. Special seeding technique and equipment are necessary under these conditions. For example, cotton establishment is difficult in heavy black soils after rice. Due to hard pans in the shallow layer, root penetration is hindered. Sufficient time is not available for field preparation. If the fields are allowed to dry sufficiently for field preparation, nearly a month time is lost. Hence seedlings are raised either on twisted paddy straw or leaf cups before harvesting of rice crop. After harvesting, a crow bar hole is made up to 30 cm. It is partly filled with sand and soil mixture and cotton seedlings are planted.

The establishment of a pulse crop after rice is also difficult. Broadcasting of seeds in standing rice crop or rice stubbles results in uneven germination and high seed rate is necessary. Crops planted in stubbles are subjected to competition from regenerated stubbles. It can be overcome by spraying paraquat or diquat on stubbles.

Delay in sowing or planting is the most common problem in intensive cropping systems. Situation necessitates transplantation with over aged seedlings. To reduce yield loss due to transplantation of over aged seedlings, higher level of nitrogen is applied to induce tillering. In rice-wheat system, wheat yields are reduced considerably when the sowings of wheat are delayed beyond November. In such situations, transplantation of 40 to 50 days old seedlings of wheat is done. Farmyard manure is broadcasted over the field to maintain higher soil temperature during December.

**Fertilizer Application.** Determining the fertilizer schedule is complex in sequential cropping system as several factors have to be considered. The important factors are: soil supplying power, total uptake by crops, residual effect of fertilizers, nutrients added by legume crop, crop residues left on the soil and efficiency of crops in utilizing the soil and applied nutrients.

1. **Soil Supplying power.** Soil contribution to the crops should be known before deciding on the quantum of fertilizer application. The results of long term fertility trials revealed that there is no appreciable change in the soil physical properties and soil deficiency for micronutrients as a consequence of multiple cropping. However, zinc in light alluvial soils (sandy soils) of Ludhiana and iron in medium black soils of Coimbatore have been found to be critical. The soil nutrient status, estimated by soil analysis at the beginning of the season is altered by growing different crops during different seasons. The soil supplying power increases with legume in rotation, fertilizer application and addition of crop residues (Table 3). The available nitrogen and potassium in soil- after groundnut crop are higher compared to initial status of the soil. But after pearl millet, only potassium status in the soil is improved and there is no change in phosphorus status.

2. **Nutrient Uptake by Crops.** The total amount of nutrients taken by the crops in one sequence gives an indication of the fertilizer requirement of the system. Balance sheet approach is followed to know whether the amount of fertilizers applied is equal, more or less to the total uptake of nutrients by different crops in the system. The balance is obtained by subtracting the fertilizer applied to crops in the system from the nutrients taken up by the crop.
TABLE 3 Effect of groundnut and pearl millet on soil fertility

<table>
<thead>
<tr>
<th>Details</th>
<th>Available nutrients (kg/ha) in 30 cm depth of soil</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N</td>
</tr>
<tr>
<td>Initial status of soil</td>
<td>313</td>
</tr>
<tr>
<td>Fertilizer added to groundnut</td>
<td>50</td>
</tr>
<tr>
<td>Nutrient status after groundnut</td>
<td>424</td>
</tr>
<tr>
<td>Fertilizer added to pearl millet</td>
<td>120</td>
</tr>
<tr>
<td>Nutrient status after pearl millet</td>
<td>346</td>
</tr>
</tbody>
</table>

3. Residual Effect of fertilizers. The extent of residues left over in the soil depends on the type of fertilizer used. Because of their mobility and solubility, nitrogenous fertilizers leave no residues after the crop is harvested. ¹⁵N studies have shown that only 1 to 2 % of nitrogen applied to maize was taken up the following wheat crop. However, residues of nitrogen occur only when previous crop yields are poor. Phosphatic fertilizers and farmyard manure leave considerable residue in the soil which is useful for subsequent crops. Farmyard manure applied to the previous crops: used only 50 % of its nutrients and rest was available for subsequent crops. The residues left by potassium fertilizers are marginal.

4. Legume Effect. Legumes add nitrogen to the soil in the range of 15 to 120 kg N/ha. The amount of nitrogen added depends on the crop and also on the purpose for which it is grown. Green gram grown for grain contributes 15 to 20 kg N/ha to the succeeding crop. Cowpea grown for grain and fodder contributes 24 and 30 kg N/ha, respectively to the succeeding crop. Inclusion of leguminous green manures in the system adds 40 to 120 kg N/ha. The availability of phosphorus is also increased by incorporation of green manure crops. Potassium availability to subsequent crop is also increased by groundnut.

5. Crop Residues. Crop residues add considerable quantity of nutrients to the soil. Cotton planted in finger millet stubbles benefits by 20 to 30 kg N/ha due to decomposition of finger millet stubbles. Deep rooted crops like cotton and red gram absorb phosphorus and other nutrients from deeper layers. Leaf fall and its subsequent decomposition add phosphorus to the top layers. Crop residues containing high C: N ratio like stubble of sorghum and pearl millet temporarily immobilize nitrogen. Residues of leguminous crops contain low C: N ratio and, they decompose quickly and release nutrients.

6. Efficiency of crops. Crops differ in their ability to extract and forage nutrients from different layers of soils and their capacity to utilize them for the production of economic products. Jute is more efficient crop for utilization of nitrogen followed by summer rice, rainy-season rice, maize, potato and groundnut in that order. The order of phosphorus efficient crops are jute > summer rice > kharif rice > potato > groundnut > maize. Groundnut is more efficient in potassium utilization and the other crops their order of efficiency are maize, jute, summer rice, rainy-season rice and potato.

Fertilizer recommendation should be made to the cropping system considering all the above factors. For example, in wheat based cropping systems, an extra dose of 25 % nitrogen is recommended for wheat when it is grown after sorghum or pearl millet. Wheat after pulse crops like red gram, green gram or black gram needs 20 to 30 kg less nitrogen per hectare. When phosphatic fertilizers are added
to green manure crop, there is no necessity to apply phosphorus to succeeding wheat crop. In rice-wheat cropping system, recommended dose of nitrogen of crops has to be applied. However, it is sufficient to apply phosphorus to wheat and potassium to rice but not for both crops of the system. In rice-rice-pulse cropping system, nitrogen has to be applied to both the rice crops, phosphorus to dry season rice and potassium, sulphur and zinc, if necessary to the second crop. In rice based cropping system consisting of rice-rice in kharif and rabi and sorghum, maize, finger millet, soybean in summer, it is sufficient to apply phosphorus and potassium to summer crops only while nitrogen is applied to all the crops. Thus, lot of fertilizer can be saved by following system approach in fertilizer recommendation.

Water Management. Water management for sequential cropping is same as for individual crops. There are no carry over effects of irrigation as in the case of fertilizer. Depending on the availability of water, suitable cropping system has to be selected. Rice-rice is efficient cropping system for total yield, but it consumes large amount of water especially during summer. As availability of water in summer is less, instead of rice, groundnut is used in the cropping system. Rice-Rice-groundnut cropping system has high water use efficiency and high net returns. In wheat based cropping systems, depending on availability of water, cropping system is changed. When water is available for 10 irrigations, the efficient cropping system is maize-wheat, for 4 to 6 irrigations, black gram-wheat and for 2 irrigations fallow-wheat.

With regard to the method of irrigation, the layout should be planned in such a way that it is suitable for most of the crops in the system. In rice-rice-groundnut system, rice is irrigated by flood method of irrigation, while for groundnut border strip method is suitable. In cotton-sorghum-finger millet system, cotton and sorghum is irrigated by furrow method, while for finger millet check-basin method is adopted. For this system, the field is laid out into check basins and finger millet is transplanted. After harvest of finger millet, cotton is planted in the check basins in finger millet stubbles. After a period of 30 days ridges and furrows are made for irrigating cotton. Furrows could be used for subsequent crop of sorghum.

Weed Management. Weed management practices are followed for the entire system as a unit instead of considering weed problem of individual crops. This is necessary because weed shift occurs due to crops grown in the system and the carry over effects of weed control methods on succeeding crop.

Weeds are dynamic in nature and occasional shifts in weed species occur due to change in environment brought about either by cultural practices or by weed control methods. Generally, broad leaved weeds occur in wheat at later stages and 2, 4-D is applied as post-emergence herbicide to control them. If weed shift occurs, this practice is not suitable. For example, in rice-wheat system, canary grass (*Phalaris minor*) is a menace for wheat crop. The weed seeds of several species are decomposed and lose viability as soil is submerged for rice but *Phalaris minor* seeds do not lose viability. Wheat sown in rice stubbles is heavily infested with *Phalaris minor*. Weed seeds germinate even before the germination of crop seeds and there is severe competition from these weeds. Similarly, in cotton-sorghum-finger millet sequence cropping with zero tillage, weeds are controlled by herbicides in two rotations. Weed flora shifts form annual weeds to perennial weeds and *Cynodon dactylon* is a problematic and dominant weed in this system.

Herbicides applied to the previous crop may be toxic to the succeeding crop. Higher dose of atrazine applied to sorghum crop affects germination of succeeding pulse crop. Recommendation of herbicides and its dose should, therefore, take into consideration the succeeding crop. When herbicides are applied at recommended doses, their residual effects on controlling weeds of the succeeding crop has
not been observed.

Ploughing the field well ahead of the planting season, either at the end of the rainy season or after summer rains, helps to kill most of the weeds and reduces weed problem. For subsequent crops, thorough field preparation may not be possible. Judicious use of physical, mechanical and chemical weed control methods have to be adopted.

**Pests and Diseases.** The infestation of pests and diseases are more in sequence cropping system due to continuous cropping. Carry over effects of insecticides are not observed so far.

**Harvesting.** In sequence cropping, the crop can be harvested at physiological maturity instead of at harvest maturity. The field can then be vacated one week earlier for planting another crop. Because of continuous cropping, the harvesting time may coincide with heavy rains and special postharvest operations like artificial drying, treating the crop with common salt etc. are practiced to save the produce.

**Cattle maintenance**

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

**Draft breeds:** The bullocks of these breeds are good draft animals, but the cows are poor milkers. e.g. Nagore, Hallikar, Kangeyan, Mali.

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

**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 yielders. e.g. Jersey, Holstein Friesian, Aryshire, Brown Swiss and Guernsey.

**Buffaloes:** Important dairy breeds of buffalo are Murrah, Nili Ravi (which has its home tract in Pakistan), Mehsana, Suti, Zafrabadi, Godavari and Bhadawari. Of these Godavari has been evolved through crossing local buffaloes in coastal regions of AP with Murrah.

**Housing:** Each cow requires 12-18 sq m space and the buffaloes need 12-15 sq m. 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.

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, a second insemination may be given within 6-8 hours after the first insemination. The gestation period varies with individual cows and normally it is about 280 days.

In the case of buffaloes, the lactation period last for 7-9 months. She buffaloes come 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.

**Feeding**: Cattle feed generally contains fibrous, coarse, low nutrient straw material called roughage and concentrates.

**Roughages**: Dairy cattle are efficient use of roughages and convert large quantities of relatively inexpensive roughage into milk. Roughages are basic for cattle ration 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 of 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. minerals mixtures containing salt, Ca and P should also be provided in the ration.

The ration per animal per day normally includes concentrates at 1 kg for 2 litres of milk yield, green fodder at 20-30 kg, straw 5-7 kg and water 32 litres.

**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 India. 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 kittens 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 sq m.

**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 kittens per time. Number of ewings are three per 2 year. The kittens cane be weaned after 30-45 days. Mother can be allowed for mating 45-60 days after ewing. 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 per head requirement of nutrients in respect of goats is relatively low. Hence, they are suitable for resource poor farmers with marginal grazing lands. They are essentially browsers and eat 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 protein and calorie should be given to goats. They eat more of tree fodder and the rest with other grass species. Goats should be fed with concentrates of of maize, wheat, horse gram, 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 the 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.

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 2 m.

Breeds of Indian Sheep

There are three types of sheep in India based on the geographical division of the country.

1. The dry temperate Himalayan region: Gurez, Karanah, Bhakarwal, Gaddi, Rampur-Bushiar.
2. Dry western region: Lohi, Bikaneri, Marwahi, Kutchi, Kathiawari.

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 heat period will range from 1-3 days and 75% of 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 condition, 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.

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.

Breeds: Specific poultry stocks for egg and broilers 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 Australorp are used. Heavy breeds such as white Plymoth Rock, White Cornish and New Hampshire are used for cross-bred 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 m² per adult bird is adequate for light breeds such as white Leghorn. About 0.3-0.4 m² 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 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 contain more energy and 18-20% protein. Feed may be given 2-3 times. In addition to the stuffs, 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 F1 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 around six weeks, they can be marketed for broiler. Hens may be retained for one year for production i.e. upto the age of 1 ½ years. After that they are disposed off for table purpose. It may not be economical to keep the hens beyond ½ years since egg production would get reduced. One hen is capable of laying 180-230 eggs in a year starting from the sixth month. In addition, a laying hen produced about 230 g of fresh droppings (75% moisture) daily.

Piggery

Pigs are maintained for production of pork. They are fed with inedible feeds, forages, certain grain byproducts obtained from mills, meat byproducts, damage feed 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 pigs at a time. It is capable of producing two liters 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 I the most extensively used exotic bred in India. It is a prolific breed in India. It is a prolific breed having carcass quality, growth rate and feed conversion ability. For a small breeding farm of a unit, the selection of the herd boar is extremely important. A good boar weighs 90kg in about 5-6 months and is strong on feet and legs. The mother of pig is to be selected should have large litter 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 overheating. Locally available materials can be used for housing. One pig requires 2.7 sq. with a wall of 1.2m height. Eight boars can be kept in 2.7-4.5sq. m area with2.4-6.0sq m open space.

Feeding: feed plays an important role in successful pig production. Pigs are the moist rapidly growing livestock and suffer more than nutritional deficiencies than the ruminants. Proteins, fats, carbohydrates, minerals, vitamins and ample good water form a complete diet for pig. Pigs have a simple stomach; therefore they must fed with maximum of concentrates and minimum of roughage. The main ingredients of swine ration are cereals and millets and their byproducts. The fiber contents
in swine ration should be very low (around 5-6%) for better feed utilization efficiency. Mixed ration should be also containing 0.5% of added salt. Swine requires comparatively higher %age of Ca and P than do cattle or sheep. When pigs are maintained with agricultural/kitchen wastes or fish and slaughter house 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 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 moiré important than age at breeding. Sow with low body weight show higher rate of fetal and pre-weaning mortality and have been proved with 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 bred. 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 are 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 new born 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.

Rabbit rearing

Rabbit (Orcytologus cuniculles) is reared all over the world in various climatic conditions. Rabbit rearing in India is of recent origin, though hunting of wild rabbits for meat is not uncommon. Rabbit can easily be reared with relatively less concentrate feed and with very high reproduction rates. Rabbit meat is pure white and is low in fat and cholesterol content. Further rabbit meat does not have any religious taboo, unlike pork and meat from cow.

Breeds: Rabbit can be classified into two categories as meat and wool producing ones. Important meat breeds are New Zealand White, Soviet Chinchilla and Kandinrex. Breeds for wool are Angora, Polish Bolamina, Dan and Flirorida.

Housing: Rabbits can be kept in hutches outside or in cages inside. Cages should have door (30 x 30 cm) with welded wire mesh at floor and on sides. The area required by a rabbit depends on the body weight. For one kg weight, 1.8 sq m area is needed. Angora rabbits cannot be kept at high temperature and should be restricted to hills. Breeding bucks and adult does are housed single. Castrated male can be kept in group. Young rabbits also live in group till the age of 4 months and thereafter they are separated. Rabbit keeping require calm and quite areas. Sudden noise can cause death of rabbits. Disturbance by dogs, cats and humans should be kept to the minimum.

Feeding: Rabbit is a non-ruminant herbivorous animal having a simple stomach. Like any other animal, rabbit requires protein, carbohydrates, fats, minerals, and vitamins in its feed. Rabbits digest the fibre fraction very poorly and diet having 5-7% crude fibre is adequate. Alfalfa and other forages are well utilized by rabbits. The feed ingredients may constitute maize (20%), alfalfa (25%), wheat bran (40%), groundnut cake (12%), mineral mixture (2%) and salt (1%). The feed mixture should be
given twice a day, in the morning and evening. Other grasses and vegetables can be given intermittently in small quantities. Water should always be provided.

Maintenance: Rabbits of 5-6 months age are ready for breeding and the body weight should not be less than 2.0 kg. The female rabbit is taken to the cage of male for mating. At the time of mating, the male produces a particular noise. After that the female rabbit is taken out of the cage of the male. Early morning is the best time for mating. Rabbits mostly breed from March to July.

Gestation period is 28-32 days. The eyes of the young ones (pups) open around two weeks and at 3 weeks, they feed themselves. During this period, the pups should not be often handled. Around four weeks, the young ones are separated from the mother. After two weeks of weaning, the female can be allowed for mating.

In a year, it gives birth five times, each time producing about six numbers. Mortality in the kindlings is the most important component that determines the economics of rabbit rearing. In general, mortality in adult rabbit is very low ranging from 3-5%. However, it ranges from 10-15% in kindlings up to the age of 30-42 days. Mating during extreme hot and cold season causes high mortality of kindlings.

Bee keeping

Bee keeping is one of the most important agro-based industries which does not require raw material from the artisan like other industries. Nectar and pollen from flowers are the raw materials which are available in plenty in nature. Bee keeping can even be started with a single colony.

Species: there are two species, *Apis cerana* and *A. mellifera* are complementary to each other but have different adaptations. *A cerana* is better acclimatized to higher altitudes of the Himalayan region. *A. mellifera* is more profitable in the plains.

Management: The bee keeper should be familiar with the source of nectar and pollen within his locality. The most important source of nectar and pollen are maize, great millet, bulrush, sunflower and palm. The beginner should start with 2 and not more than 5 colonies. A minimum of two 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 floor board, brood chamber, top cover, frames 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 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.
Aquaculture

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, poly-fish culture with the stocking density of 7500 fingerlings and supplementary feeding will boost the total biomass production.

Pond: the depth of pond should be 1.5 to 2.0 m. this depth will help for effective photosynthesis and temperature maintenance for the growth of zoo and phytoplanktons. Clay soils have high 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). 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 an interval of 2-3 days. Higher pH (>8.5) can be reduced with 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 phosphate fertilizers 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:

1. 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.
2. Rohu (Labeo rohita) is a column feeder and feeds on growing plants, decomposing vegetation, large colonial algae, zooplanktons and detritus to a small extent.
3. Calbasu (Labio calbasu) is a common feeder on detritus.
4. Mrigal (Cirrhinus mrigale) is a bottom feeder, taking detritus to a large content, diatoms, filamentous and other algae and higher plants.
5. Common carp (Cyprinus cario) is a bottom feeder and omnivorous.
6. Silver carp (Hypophthalmichlthys molitrix) is mainly a surface and phytoplankton-feeder and also feeds on microplants.
7. Grass carp (Cyernus carpia) is a specialized feeder on aquatic plants, cut grass and vegetable matter. It is also a fast growing exotic fish.

Poly fish culture: The phytofagous fish (Catla, rohu and mrigal) can be combined with omnivorous (Common Carp), plankton- feeder (silver Carp) and mud eaters (Mrigal and Calbasu) in a composite fish culture system.

Management: The fish are to be nourished with supplementary feeding with rice brands and oilseed cakes. This will enable faster growth and better yield. Each variety of carps could be stocked to 500 fingerlings with the total of 5000-8000 per ha. This stocking density will enable to get a maximum yield of 2000-5000 kg/ha of fish annually.

Sericulture

Sericulture is defined as the practice of combining mulberry cultivation, silk worm rearing and silk reeling. Sericulture is recognized practice in India. It plays an important role in socio-economic development of rural poor in some areas.
The climatic conditions in India are favourable for luxuriant growth of mulberry and rearing of silkworms throughout the year. The temperature in Karnataka state, major silk producing site in India, ranges from 21.2 to 30°C. Climatic conditions in Kashmir are favourable to rear silkworm from May to October.

Moriculture: Cultivation of mulberry plants is called 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:
1. Mulberry silk worm (*Bombax mori*)
2. Eri silk worm (*Philosamia ricini*)
3. Tassar silk worm (*Antheraea mylitta*)
4. 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 an uniform hatch. In a bamboo tray rice husk is spread. Tender chopped mulberry leaves are added to the tray. The hatched out larvae are transformed to the leaves. It is important to change the leaves 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 the moth and processed. The cocoons required for further rearing are kept separately and moths are allowed to emerge from them.

A family of three can manage 0.75 acre without engaging extra labour. Under irrigated conditions one hectare of mulberry garden gives employment to 13 people throughout the year. It requires 607 man days and 827 woman days.

Mushroom cultivation

Mushroom is an Edible fungi with great diversity in shape, size and color. Essentially mushroom is a vegetable that is cultivated in protected farms in a high sanitized atmosphere. Just like other vegetables, mushroom contains 90% moisture with high in quality protein. Mushrooms are fairly good sources 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, Cu. They contain less of fat (0.3%) and CHO and are considered good for diabetic and blood pressure patients. Fibre content in mushrooms is very high which helps in excretion of waste and prevention of constipation.

Types of mushroom
1. Oyster mushroom- *Pleurotus spp.* (var CO1, APK 1, MDU 1,2, Ooty 1)
2. Milky mushroom- *Calsybe indica* (APK 2)

Oyster mushroom basically occurs in dead woods in nature and resembles the shape of oyster shell. It can be grown on a wide range of agricultural wastes. It can be grown on a wide range on a wide range
of temperature and with low investment. The production of this mushroom is being done on a small scale in different parts of the country and is most popular one.

Milky mushroom is new of its kind and was introduced for commercial cultivation in the year 1998 from TNAU with the variety, APK 2. The mushrooms are umbrella shaped, robust, attractive and milky white in nature. This variety is tropical in nature and can be grown when button and oyster mushroom cannot be grown due to high temperature.

Button mushroom is particularly suitable for winter season, in the northern states. Cultivation of this mushroom requires more investment. This mushroom cannot be cultivated in paddy or wheat straw.

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 * 30 cm of size and make two holes of one cm diameter in 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 alternately. The last layer ends up in the straw of 10 cm height. Keep this in a spawn running room maintained at a temperature of about 20-25 °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. Yield: 0.5- 1.0 kg/bed.

Biogas plant

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 materials are broken down to methane and carbon dioxide by different groups of microorganisms. It can be used for cooking purpose, burning lamps, running pumps etc.

Types of biogas plant:

1. Float dome type: Different models are available in this category, e.g. KVIC vertical and horizontal, PRagati model, Ganesh model.
   2. Fixed dome type: the gas plant is dome shaped underground construction. The masonry gas holder is an integral part of the digester called dome. The gas produced in digester collected in dome at vertical pressure by displacement of slurry in inlet or outlet. The entire construction is made of bricks and cement. The models available in this category are janata and deen-bandhu.

The selection of particular type depends on technical, climatologically, geographical and economic factors.

Size: the size of bio gas plant is decided by the number of family members and the availability of cattle. One cubic meter capacity plant will need 2-3 animals and 25 kg of dung. The ga produced will meet the requirement of the family of 4-6 members. It would suffice to have a 2 cubic meter plant to cater to the needs of a family of 6-10 members.

Site selection and management: the site should be closed to the kitchen or the place of the use. It will reduce the cost of gas distribution system. It should also be nearer to the cattle shed to reduce the cost of traspotaion of cattle dung. Land should be leveled and slightly above the ground leavel to avoid inflow or run off of water. Plant should get clear sunshine during most part of the day.
Generation of dung has directed 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.

Bio gas slurry: slurry is obtained after the production of bio-gas. It is an enriched manure. Another positive aspect of this manure is that even after weeks of exposure to the atmosphere, the slurry does not attract flies and worms.

**Duck rearing**

Ducks account for about 7% of the poultry population in India. They are popular in coastal and water logged states like West Bengal, Orrisa, 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 river side, wetland and barren moors where chicken or any other type of stock do not flourish, duck farming can be a 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 150 eggs/bird/year. Improved breeds for eggs and meat production are available. Khaki Campwell and Indian Runner are the most popular breeds for egg laying. Khaki Campwell has a production potential 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 free fence of atleast 1.2 m high enclosing the yard is enough to stop any predator. One nest of size 0.3 * 0.3 * 0.45 m to every 3 ducks is sufficient. In case of laying birds, a mating ration of 1 drake: 6-7 ducks and in meat type 1: 4-5 is allowed. The duck house should be well ventilated, dry, leak and rat proof. The roof may be thatched or asbestos sheeted. A water channel of 0.5 m wide and 0.2 m deep is constructed at the far end of 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. Latter on they may 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.

**Turkey rearing**

Turkey is a robust bird and can be reared in humid tropics. It actively feeds on a variety of crop residues and insects in the farm and hence can be raised with much ease.

Physical features: there are a few peculiar features in the physical appearance of a turkey. Male has black beard attached to the upper breast regions. This beard is small in females of white turkeys and absent in those of coloured varieties. A fleshy protuberance called snood is present near the base of the beak in both males and females. The head bears caruncles and a large flap of skin below the chin is known as dewlap. Broad Breasted Bronze breed are ordinarily seen in India. Norfolks and the Cambridge are the other important breeds.

Housing: housing for turkeys may be of range system, confinement or a combination of both. There is a growing trend towards confinement housing. Breeds require a floor space of 0.4 m²/bird in confinement and 32.5 m²/bird in the range rearing.

Feeding: Turkeys have much higher growth rate compared to chickens. Hence they have relatively higher feed and nutrient requirement. Turkey can be fed with all types of dry feed comprising pellets, wet mesh, grain and green feed in well balanced combination. They also need plenty of clean water.

Maintenance: Mating ratio in natural flock is 14 hens: 1 tom for small and 12:1 for medium sized turkeys. The birds should be carefully segregated when they reach the mating stage. Mating take place during summer. Particular attention should be bestowed in regulating mating. The males should be kept away from their mates in the morning and selectively mated with other birds by turn. Mating in the evening increases the number of fertile eggs.

Generally turkey lays eggs on alternate days from six onwards. In a year, they lay about 150 eggs. The bird attains a weight of 5-8 kg in a year. The birds should not be allowed to fatten too much as it would make them vulnerable for diseases. Changing the breeding stock periodically would be gainful for the farmer.

**Pigeons for meat**

Domestic pigeon (*Columba livia*) belonging to the sub-family Columbia can be reared for its meat. Females are smaller than the males and finer in the head. They hold their tails higher than males and their pelvic pones are spaced wide apart. The males are large, aggressive and make a loud cooling noise. They strut around females during the breeding season. There is difference in the growth rate among the males and females. The former grows faster than the latter. Thus, even at an early stage, the gender difference can be easily made based on their body weight.

Feeding: adults feed the young ones (squabs) with pigeon milk, a fluid, a fluid that is secreted in their crop. The pigeon milk looks like thick custard and has high protein content. Pigeons require water for drinking and for bating to remove external parasites. A pair of breeds drinks about 500 ml of water per day.

Pigeons are not fussy eaters, but do best on diets having whole grains. Nutrient requirement of pigeons is crude protein (13.5%), carbohydrates (65%), crude fibre (3.5%) and fat (3.0%). The daily feed intake of an adult pair is about 120 g.
Maintenance: Each pair normally produces 14 squabs in a year. The incubation period of the eggs is 18 days. Both partners build their nest and take turns to sit on the eggs. The female starts laying eggs again when the squabs are two weeks old. The young ones become independent in 35 days. Squabs of 30-35 days are best suited for meat purpose since recovery is high with the body weight of 350 g. In addition to the meat, pigeon droppings (25 g per bird day) can be used as fish feed or enriched manure.

**Japanese quail**

Quail belongs to class Aves, family Phasianidae and genus Coturnix. Quails, introduced initially as experimental birds, have become popular for their eggs and meat. Efforts are being made by Central Avian Research Institute, Izatnagar, to develop the guinea fowl for meat production. Males are lighter than females and are identified by the cinnamon coloured feathers on the upper throat and lower breast region. Female is similar to male in colour except that the feathers on the throat and upper breast are pointed and much lighter cinnamon in colour.

Maintenance: Quails need small space and are highly suitable for cage rearing. Therefore, it is possible to rear them even in urban areas where space is a major constraint. They are socially and commercially more adaptable due to their small body size, shorter generation interval, highly prolific nature and simplicity in rearing and are more economical. Females lay eggs as early as at the age of 5 weeks. The average age of the first egg production is 40 days. They are in full production by 50 days. They have a capacity to lay 300 or more egg each per annum. The shell of atypical quail’s egg is a mixture of greenish black and brownish speckles or patches of varying sizes. An egg weighs about 10-12 g on an average and is comparatively thin and delicate in nature. Albumen content is 56 to 59%, yolk 28-32% and shell 12-14%. The yolk content in relation to albumen is more in quail’s egg than in chickens egg. Special care should be given for collecting and handling the egg.

The rapid growth rate of the Japanese quail renders it an ideal broiler. At six weeks, quails attain a body weight of 125-150 g with a feed efficiency of 3.0. Japanese quails are fairly resistant to most of the common diseases affecting chicken. However, they are sensitive to abrupt environmental changes during first and second week of their life.
Site specific enterprise planning and implementation for developing farming system model

Farming enterprises include crops/cropping systems (Field, horticultural, plantation), poultry, fish, piggery, sericulture, mushroom, agroforestry, biogas, vermicompost etc., A combination of one or more enterprises with cropping when carefully chosen, planned and executed, give greater dividends 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.

Determinants of Farming Systems
The key categories of determinants influencing farming system are as follows:

(i) Natural Resources and Climate: The interaction of natural resources, climate and population determines the physical basis for farming systems. The increased variability of climate, and thus agricultural productivity, substantially increases the risk faced by farmers, with the concomitant reduction in investment and input use. Certain soil and water regimes are suitable only for given type of crops. Similarly, some of the physical and geographical features e.g. drainage characteristics, elevations and slopes as well as climatic factors e.g. total rainfall and its distribution, minimum and maximum temperature, humidity and intensity of sun light etc. are other factors which have to be taken in to considerations while making decision with respect to selection of enterprise for a farming systems.

(ii) Science and Technology: Investment in agricultural science and technology has expanded rapidly during the last four decades. During this period, major technical and institutional reforms occurred, which shaped the pattern of technology development and dissemination.

The research driven growth in developing countries has been green revolution, where it achieved considerable achievement in the field of food grain production and for this the policy and other aspects supported the farming system for such achievement. Research has been focused principally upon intensifying crop and livestock production. There has been for less research on integrated technologies for diversifying the livelihoods of small farmers in developing countries and increasing the sustainability of land use.

Despite these weaknesses, the natural and global research agenda is gradually moving from a focus on individual crop performance to a growing acceptance of the importance of increased system productivity. There has been emphasis in recent agriculture of targeting technologies towards women farmers and poorer households.

(iii) Trade Liberalization and Market Development: Markets have a critical role to play in agricultural development as they form the linkages between farm, rural and urban economics upon which the development processes depend. As a result of the reduction of impediments to international trade and investment, the process of trade liberalization is already generating changes in the structure of production at all levels-including small holder-farming systems in many developing countries. Not only the market development is accelerating, but patterns of production and natural resources usage are also changing profoundly in response to market forces.

The availability of new production, post harvest and transport technologies will also change demand patterns due to delivery of new products or established products in new forms to markets, where they have been previously unattainable.
(iv) Policies, Institutions and Public goods: The development of dynamic farming systems requires a conducive policy environment. Moreover, the establishment of the farm-rural-urban linkages requires effective demand. Policy makers have increasingly shifted their attention to the potential to increase the efficiency of service delivery through the restructuring of institutions. The production incentives have dramatic effect on farming systems. Policies on land ownership, water management and taxation reform etc have a great bearing on types of farming system in a region or area.

(v) Information and Human Capital: The evolution of farming systems based upon increasing specialization (e.g. large scale broiler units) or integrated intensification (e.g. rice-fish-ducks) has required extra knowledge on the part of farm operators. The need for better information and enhanced human capital has also increased, as production systems have become more integrated with regional, national and international market systems.

Lack of education, information and training is frequently a key limiting factor to smallholder development. Many observers anticipated an information revolution i.e. bridge gap of knowledge between scientists and farmers will be very key factor for agricultural growth of these small farmers. Whilst in the past many development efforts failed women-because planners had a poor understanding of the role women play in farming and household food security-greater efforts are being made to take account of their actual situations. It is increasingly recognized and acknowledged by development workers that the empowerment of women is the key to raising levels of child and family nutrition, improving the production and distribution of food and agricultural products, and enhancing the living conditions of rural populations. It has been concluded that, if women in Africa received the same amount of education as men, farm yield would rise by between seven and 22 % (FAO, 1990).

Similarly, better access to credit, land and extension services would enable women to make an even greater contribution to eliminating rural hunger and poverty. As gender bias is progressively eliminated during coming years - often in the face of severe cultural and religious barriers productivity within many farming systems will be transformed.

(vi) Indigenous Technological Knowledge: Indigenous technical knowledge is the knowledge that people in a given community has developed over times, and continues to develop. It is based on experience, often tested over long period of use, adapted to local culture and environment, dynamic and changing, and lays emphasis on minimizing risks rather than maximizing profits. The ITK covers a wide spectrum – soil water and nutrient management; pasture and fodder management; crop cultivation; plant protection; farm equipment, farm power, post-harvest preservation and management; agro-forestry; bio-diversity conservation and also exploitation; animal rearing and health care; animal products preservation and management; fisheries and fish preservation; and ethnic foods and homestead management. Thus, the ITK of a farmer has a great influence in managing the farm and farming system.

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).

![Fig 1. Linkages of different enterprises in farming system](image)

**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 Combing 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.

**Types of Enterprises**

1. Independent enterprises,
2. Competitive enterprises,
3. Supplementary Enterprises,
4. Complementary Enterprises and
5. Competitive 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 the 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 farmer 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 substitute 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

3. 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 daily enterprise or a poultry enterprise may be supplementary to the 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. When two products should be product up to the end of supplementary stage. Some time enterprises are supplementary for one resource but competitive foe 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.

4. 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 increases production on 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 is 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. In the integrated system, selection of enterprise should be on the cardinal principle that there should be minimal competition and maximum complementary effect among the enterprises.
Evaluation of FSR/IFS

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),

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

2. Economic analysis: Parameters like cost of cultivation/production, gross and net return an 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.


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 were 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)
Resource(s) use efficiencies and optimization techniques

Yield gaps and resource use (in-) efficiencies (RUEs) are typically assessed at field level. For regional assessments these are generally directly up-scaled, whilst in the real world they are explained by a range of factors that intersect and are integrated at farming systems level.

Farmers take decisions as to field, crop and livestock management given their access to knowledge and information, personal circumstances, and in the context of the broader socioeconomic, institutional and political environment. Comparative analysis of best, average and worst performing farms using frontier analysis may be combined with theory and information on production ecology to explore options for sustainable intensification. The analysis may be enriched using case studies which are under different phases of agricultural development and, where possible, both the past and possible future dynamics will be analyzed.

The innovativeness of the research is that a mix of agronomic and economic methods may be used, which allows to make use of the richness of individual farm level data in addition to regional data. Production ecological concepts may be integrated into the economic methods, allowing assessment of yield gaps and resource use efficiencies from an agronomic perspective. We may assess the influence of regional conditions, farm and farmer characteristics as well as the resulting management. Case studies may include arable farming in Europe, irrigated rice-based farming in the Philippines and Vietnam, and mixed crop-livestock farming in West-Africa.

The overarching question that may be addressed is essentially methodological:

What combination of methods can best be deployed to unravel the relative contribution of biophysical constraints versus constraints at other levels to current yield gaps across contrasting farming systems?

We may develop a generic method and test this method in contrasting case studies, with the specific objectives to:

1. Establish yield gaps and RUEs of different farm types using crop simulation models and approaches of frontier analysis;
2. Estimate and explain current variability in yield and RUE of land, water, nutrients, labour and capital across different farm types;
3. Use a design and re-design cycle to explore options for sustainable intensification by alleviating constraints to improving production and resource use efficiency through comparative studies across farming systems at different stages of intensification.

Resource use efficiency in Indian agriculture

Resource use efficiency in agriculture is defined to include the concepts of technical efficiency, allocative efficiency and environmental efficiency (Haque 2006). Public investment, subsidies and credit for agriculture are used in an efficient manner. There are large scale inter regional as well as inter farm variations in factor productivity due to varying influence of different factors in different regions. A number of management factors such as timeliness and method of sowing, transplanting, irrigation and application of right doses of inputs and input mix play an important role in influencing
inter-farm variation in crop productivity. Growing marginalization and fragmentation of land holdings coupled with rising incidence of informal tenancies and poor rural infrastructure such as road, electricity, markets and education affect factor productivity. The availability of good quality irrigation water coupled with flexibility of irrigation and drainage system and appropriate methods of application as well as pricing of irrigation water is crucial for sustainable use of land and water resources.

UMOH (2006) employed the stochastic frontier production function to analyse the resource use efficiency of urban farmers in Uyo, Southeastern Nigeria. The result shows that 65% of urban farmers were 70% technology efficient; maximum efficiency is 0.91, while minimum efficiency in urban farm is 0.43.

Three types of efficiency identified in the literature viz. technical efficiency, allocative efficiency and overall or economic efficiency (Farrell, 1957; Olayide & Heady, 1982) are defined as; Technical efficiency is the ability of a firm to produce a given level of output with minimum quantity of inputs under a given technology. Allocative efficiency is a measure of the degree of success in achieving the best combination of different inputs in producing a specific level of output considering the relative prices of these inputs. Economic efficiency is a product of technical and allocative efficiency (Olayide & Heady, 1982). In one sense, the efficiency of a firm is its success in producing as large an amount of output as possible from given sets of inputs. Maximum efficiency of a firm is attained when it becomes impossible to reshuffle a given resource combination without decreasing the total output.

Since the seminal work of Farrell in 1957, several empirical studies have been conducted on farm efficiency. These studies have employed several measures of efficiency. These measures have been classified broadly into three namely: deterministic parametric estimation, non-parametric mathematical programming and the stochastic parametric estimation. There are two non-parametric measures of efficiency. The first, based on the work of Chava and Aliber (1983) and Chava and Cox (1988) evaluates efficiency based on the neoclassical theories of consistency, restriction of production form, recoverability and extrapolation without maintaining any hypothesis of functional form. The second, first used by Farrell (1955) decomposed efficiency into technical and allocative. Fare et al. (1985) extended Farrell’s method by relating the restrictive assumption of constant returns to scale and of strong disposability of inputs (Llewelyn & Williams, 1996; Udoh & Akintola, 2001).

Several approaches, which fall under the two broad groups of parametric and non-parametric methods, have been used in empirical studies of farm efficiency. These include the production functions, programming techniques and recently, the efficiency frontier. The frontier is concerned with the concept of maximality in which the function sets a limit to the range of possible observations (Forsund et al., 1980). Thus, it is possible to observe points below the production frontier for firms producing less than the maximum possible output but no point can lie above the production frontier, given the technology available. The frontier represents an efficient technology and deviation from the frontier is regarded as inefficient.

The literature emphasizes two broad approaches to production frontier estimation and technical efficiency measurement: (a) The non-parametric programming approach, and (b) the statistical approach. The programming approach requires the construction of a free disposal convex hull in the input-output space from a given sample of observations of inputs and outputs (Farrell, 1957). The convex hull (generated from a subset of the given sample) serves as an estimate of the production
frontier, depicting the maximum possible output. Production efficiency of an economic unit is thus measured as the ratio of the actual output to the maximum output possible on the convex hull corresponding to the given set of inputs.

The statistical approach of production frontier estimation can be sub-divided into two, namely, the neutral-shift frontiers and the non-neutral shift frontiers. The former approach measures the maximum possible output and then production efficiencies by specifying a composed error formulation to the conventional production function (Aigner et al., 1977; Meeusen & van den Broeck, 1977). The non-neutral approach uses a varying coefficients production function formulation (Kalirajan & Obwona, 1994). The main feature of the stochastic production frontier is that the disturbance term is composed of two parts—a symmetric and a one-sided component. The symmetric (normal) component, \( v_i \) captures the random effects due to the measurement error, statistical noise and other non-symmetric influences outside the control of the firm. It is assumed to have a normal distribution. The one-sided (non-positive) component, \( \mu_i \) with \( \mu_i \geq 0 \), captures technical inefficiency relative to the stochastic frontier. This is the randomness under the control of the firm. Its distribution is assumed to be half normal or exponential. The random errors, \( v_i \) are assumed to be independently and identically distributed as \( N(0, \delta v^2) \) random variables, independent of \( \mu_i \)s. The \( \mu_i \)s are also assumed to be independently and identically distributed as, for example, exponential (Meeusen & van den Broeck, 1977), half normal (Aigner et al., 1977), truncated normal and gamma (Greene, 1990). The stochastic frontier function is typically specified as:

\[
Y_i = f(X_i; \beta) + v_i - \mu_i (i = 1, 2, n) \tag{1}
\]

\( Y_i = \) Output of the \( i \)th firm;
\( X_{ij} = \) Vector of actual \( j \)th inputs used by the \( i \)th firm;
\( \beta = \) Vector of production coefficients to be estimated;
\( v_i = \) Random variability in the production that cannot be influenced by the firm and;
\( \mu_i = \) Deviation from maximum potential output attributable to technical inefficiency.

The model is such that the possible production \( Y_i \), is bounded above by the stochastic quantity, \( f(X_i; \beta) \ exp(V_i) \) (that is when \( \mu_i = 0 \)) hence, the term stochastic frontier.

Given suitable distributional assumptions for the error terms, direct estimates of the parameters can be obtained by either the Maximum Likelihood Method (MLM) or the Corrected Ordinary Least Squares Method (COLS).

However, the MLM estimator has been found to be asymptotically more efficient than the COLS (Coelli, 1995). Thus, the MLM has been preferred in empirical analysis.

In the context of the stochastic frontier production function, the technical efficiency of an individual firm is defined as the ratio of the observed output to the corresponding frontier output, conditional on the levels of inputs used by the firm. Thus, the technical efficiency of firm \( i \) is:

\[
Te_i = \exp(-\mu_i), \text{ that is} \quad (2) \quad Te_i = \frac{Y_i}{Y_i^*} \tag{3}
\]

\[ = f(X_i; \beta) \ exp(\nu_i - \mu_i) / f(X_i; \beta) \ exp(\nu_i) \exp(-\mu_i). \]

\( Te_i = \) Technical efficiency of farmer \( i \); \( Y_i = \) observed output

and; \( Y_i^* = \) frontier output. The technical efficiency of a firm ranges from 0 to 1. Maximum efficiency in production has a value of 1.0. Lower values represent less than maximum efficiency in production.
Several empirical applications have followed the stochastic frontier specification. These studies are basically based on Cobb-Douglas function and transcendental logarithmic (translog) functions that could be specified either as production or cost function (Udoh & Akintola, 2001). The first application of the stochastic frontier model to farm level data was by Battese and Corra (1977) who estimated deterministic and stochastic Cobb-Douglas production frontiers for the grazing industry in Australia. The variance of the farm effects was found to be a highly significant proportion of the total variability of the logarithm of the value of sheep production in all states. Their study did not, however, directly address the technical efficiency of farms. Kalirajan (1981) estimated a stochastic frontier Cobb-Douglas production function using data from rice farmers in India and found the variance of farm effects to be highly significant component in explaining the variability of rice yields. Similarly, Bagi (1984) employed the stochastic frontier Cobb-Douglas production function model to investigate differences in technical efficiencies of small and large crop and mixed enterprise farms in West Tennessee. The study found that the variability of farm effects was highly significant. The mean technical efficiency of mixed enterprise farms was found to be smaller (0.76) than for crop farms (0.85).

The use of the stochastic frontier analysis in studies in agriculture in Nigeria is a recent development. Such studies include that of Udoh (2000), Okike (2000) and Amaza (2000). Udoh used the Maximum Likelihood Estimation of the stochastic production function to examine the land management and resource use efficiency in South-Eastern Nigeria. The study found a mean output-oriented technical efficiency of 0.77 for the farmers, 0.98 for the most efficient farmers and 0.01 for the least efficient farmers. Okike’s study investigated crop-livestock interaction and economic efficiency of farmers in the savanna zones of Nigeria. The study found average economic efficiency of farmers was highest in the Low-Population-Low Market domain; Northern Guinea and Sudan Savannas ecological zones; and Crop-based Mixed Farmers farming system. Available literature indicates that urban agriculture in Nigeria is yet to benefit significantly from application of the stochastic frontier model. This may not be unconnected with the fact that urban farming is a relative new venture that has only recently started gaining attention as a complement to rural farming. Likewise empirical research effort in urban agriculture is also new.

Mussa et al (2012) uses data generated through a survey from rural households in Ethiopian central highland districts to assess farm-level resource use efficiency in the production of major crops including teff, wheat and chickpea in the mixed crop-livestock agricultural systems of Ethiopia, under conditions of diminishing land resource and environmental constraints. Data Envelopment Analysis (DEA) results show that smallholder farmers are resource use inefficient in the production of major crops with mean technical, allocative and economic efficiency levels of 0.74, 0.68 and 0.50, respectively. A Tobit model regression results on the determinants of inefficiency reveal that livestock ownership and participation in off-farm activities are associated with reduced level of resource use inefficiency. Furthermore, large family size and membership to associations contribute to higher level of resource use inefficiency. The findings suggest that resource use efficiency would be significantly improved through a better integrated livestock and crop production systems; expansion and promotion of off-farm activities; and reform of farmer’s associations.

The two types of analysis used as above is described as below

Data Envelopment Analysis (DEA)

The history of efficiency measurement goes back to the influential work of Farrell (1957) who defined a simple measure of firm efficiency. In the approach, Farrell (1957) proposed that
efficiency of any given firm is composed of its technical and allocative components. According to Farrell, technical efficiency (TE) is associated with the ability of a firm to produce on the iso-quant frontier while allocative efficiency (AE) refers to the ability of a firm to produce at a given level of output using the cost-minimizing input ratios. On the other hand, economic efficiency (EE) is the combination of technical efficiency and allocative efficiency. Thus, it is defined as the capacity of a firm to produce a predetermined quantity of output at a minimum cost for a given level of technology. For estimation of these efficiencies a number of methods have been developed. These methods are broadly classified as parametric and non-parametric Methods.

DEA was first introduced by Charnes et al. (1978) and it has served as the cornerstone for all subsequent developments in the nonparametric approach (Hadi-Vencheh and Matin, 2011). As discussed by several researchers (Coelli et al.,2005; Headey et al., 2010), DEA has several advantages: it does not require a priori specific functional form for the production frontier, it can handle multiple outputs and inputs and it is also possible to identify the best practice for every farm. Furthermore, it also does not require the distributional assumption of the inefficiency term (Coelli et al., 2005). Regarding its potential disadvantages, the technique is sensitive to extreme observations and a hypothesis testing using DEA is not possible. Moreover, DEA attributes all deviations from the frontier to inefficiency. However, despite its weaknesses, in this study DEA is found appropriate and adopted to estimate efficiency of multiple crop producer farmers.

Suppose there are \( n \) homogenous Decision-Making Units (DMUs), in order to produce \( r \) number of outputs (\( r=1,2,3,...,k \)) \( s \) number of inputs are utilized (\( s=1,2,3,...,m \)) by each DMU \( i \) (\( i=1,2,3,...,n \)). Assume also that the input and output vectors of \( i^{th} \) DMU are represented by \( x_i \) and \( y_i \), respectively and data for all DMUs be denoted by the input matrix \( X_{m \times n} \) and output matrix \( Y_{k \times n} \). Accounting for financial limitations or imperfect competitive market effects, the DEA model for variable returns to scale (VRS) which was developed by Banker, Charnes and Cooper (BCC) (Banker et al., 1984) is used. The model allows for a given change in inputs use to result in a non-proportional change in output.

Thus, following Banker et al. (1984), the output maximization process to measure technical efficiency for each DMU can be expressed as:

\[
\begin{align*}
\text{Maxi} & \quad \phi \lambda, \phi \\
\text{Subject} & \quad \text{to} \\
& \quad x_i - X\lambda \geq 0 \\
& \quad - \phi y_i + Y\lambda \geq 0 \\
& \quad N1' \lambda = 1 \\
& \quad \lambda \geq 0
\end{align*}
\]

(1)

where, in the restriction \( N1\lambda = 1 \), \( N1' \) is convexity constraint which is an \( N \times 1 \) vector of ones and \( \lambda \) is an \( N \times 1 \) vector of weights (constants) which defines the linear combination of the peers of the \( i^{th} \) DMU. \( 1 \leq \phi \leq \infty \) and \( \phi - 1 \) is the proportional increase in outputs that could be achieved by the \( i^{th} \) DMU with the input quantities held constant and \( 1/\phi \) defines a technical efficiency score which varies between zero and one. If \( \phi = 1 \) then the farm is said to be technically efficient and if \( \phi < 1 \) the farm lies below the frontier and is technically inefficient.
Similarly, to estimate economic efficiency (EE), a cost minimizing DEA is specified as:

\[
\begin{align*}
\text{Min } & \sum \lambda_i W_i x_i' \\
\text{Subject to:} & \quad -y_i + Y \lambda \geq 0 \\
& \quad X_i' - \lambda X \geq 0 \\
& \quad \sum \lambda = 1 \\
& \quad \lambda \geq 0
\end{align*}
\]

(2)

Where \( w_i \) is a transpose vector of input prices for the \( i^{th} \) DMU and \( x_i' \) is the cost-minimizing vector of input quantities for the \( i^{th} \) farm given the input prices \( W_i \) and total output level \( y_i \). Economic efficiency is measured as the ratio of potential minimum cost of production \( (w_i x_i') \) to the actual cost of production \( (W_i X_i) \) as 

\[
EE = \frac{w_i x_i'}{W_i X_i}
\]

Allocative efficiency can be estimated as the ratio of economic to technical efficiencies as 

\[
AE = \frac{EE}{TE}
\]

In order to generate the technical, economic and allocative efficiency scores DEAP Version 2.1 computer program described in Coelli (1996) is used.

Tobit regression model analysis

The Tobit regression model is an econometric model that is employed when the dependent variable is limited or censored at both sides. The concept was first proposed by Tobin (1958) in the research of the demand for consumer durables and then it was first used by Goldberger (1964). If the data to be analyzed contain values of the dependent variable that is truncated or censored, the ordinary least squares (OLS) is no longer applicable to the concept of estimated regression coefficients. If OLS is directly used it will lead to biased and inconsistent parameter estimation whereby the Tobit model, that follows the concept of maximum likelihood, becomes a better choice to estimate regression coefficients (Chu et al., 2010). Thus, Tobit regression model is appropriate for this study based on the following justification regarding the nature of the dependent variable.

It is assumed that farmers in the current study areas operate under the same policy and institutional environments and face exogenous variables denoted as \( Z_t \) and that these conditions determine farmers’ decision to choose set of input vector \( x \) and produce output vector \( y \). In the production process a given farmer is considered to be full efficient if it operates along the boundary of the frontier \( (Y^*) \) which also defines the level of technology in the system. The boundary of the frontier represents a locus of output points constructed by best practice farms without a room for further improvement in their production process. In this case the output of efficient firms \( (Y_i) \) to the potential output along the frontier is equal \( (Y^*=Y_i) \). Relative efficiency measures, computed as the ratio of actual (realized) to the potential (frontier) output level \( (Y_i/Y^*) \) (Karagiannis and Tzouvelekas, 2009), of efficient farms will be unity \( (Y_i/Y^*=1) \). On the other hand, firms which are relatively inefficient operate at points in the interior of frontier and score less than unity \( (Y_i/Y^*<1) \) but greater than zero. In this case unless the farmer loses his/her crop due to complete crop failure as a result of pest and diseases infestation or drought, efficiency score will not be zero which is not applicable in the current study case. Therefore, while the scores are bounded between zero and one (two-limit) with the upper limit set at one, the distribution is censored
at both tails.
Thus, following Amemiya (1985), the two-limit Tobit regression model of the following form was estimated:

\[ U_i^* = \beta_0 + \sum_{j=1}^{k} \beta_j Z_{ij} + \mu_i \]

where:
- \( i \) refers to the \( i^{th} \) farm in the sample,
- \( U_i \) is inefficiency scores representing technical and economic inefficiency of the \( i^{th} \) farm
- \( U_i^* \) is the latent inefficiency,
- \( \beta_j \) are parameters of interest to be estimated and
- \( \mu_i \) is random error term that is independently and normally distributed with mean zero and common variance of \( \delta^2 \) (\( \mu_i \sim \text{NI}(0, \delta^2) \)).

\( Z_{ij} \) are socio-economic, institutional and demographic variables.

\[ U_i = 1, \quad \text{if} \quad U_i^* \geq 1 \]
\[ U_i = U_i^*, \quad \text{if} \quad 0 < U_i^* < 1 \]
\[ U_i = 0, \quad \text{if} \quad U_i^* \leq 0 \]  

(3)
LINEAR PROGRAMMING

Linear programming was developed by George B Dantzing (1947) during second world war. It has been widely used to find the optimum resource allocation and enterprise combination.

The word linear is used to describe the relationship among two or more variables which are directly proportional. For example, doubling (or tripling) the production of a product will exactly double (or triple) the profit and the required resources, then it is linear relationship.

Programming implies planning of activities in a manner that achieves some optimal result with restricted resources.

**Definition of L.P.**

Linear programming is defined as the optimization (Minimization or maximization) of a linear function subject to specific linear inequalities or equalities.

\[
\text{Maximize } z = \sum_{i=1}^{n} c_i x_i \\
\text{Such that } \sum_{j=1}^{n} a_{ij} x_j \leq b_i \quad i = 1 \text{ to } m
\]

\[x_j = 0\]

\[c_j = \text{Net income from } j^{th} \text{ activity } x_j\]

\[x_j = \text{Level of } j^{th} \text{ activity}\]

\[a_{ij} = \text{Amount of } i^{th} \text{ resource required for } j^{th} \text{ activity}\]

\[b_i = \text{Amount of } i^{th} \text{ resource available.}\]

**Assumptions of Linear Programming**

- **Linearity**: It describes the relationship among two or more variables which are directly proportional.
- **Additivity**: Total input required is the sum of the resources used by each activity. Total product is sum of the production from each activity.
- **Divisibility**: Resources can be used in fractional amounts. Similarly, the output can be produced in fractions.
- **Finiteness of activities and resource restrictions**: There is limit to the number of activities and resource constraints.
- **Non negativity**: Resources and activities cannot take negative values. That means the level of activities or resources cannot be less than zero.
- **Single value expectations**: Resource supplies, input- output coefficients and prices are known with certainty.

**Advantages of L.P**

- Allocation problems are solved
- Provides possible and practical solutions
- Improves the quality of decisions.
- Highlights the constraints in the production.
- Helps in optimum use of resources.
- Provides information on marginal value products (shadow prices).
Limitations

- Linearity
- Considers only one objective for optimization.
- Does not consider the effect of time and uncertainty
- No guarantee of integer solutions
- Single valued expectations.

<table>
<thead>
<tr>
<th>Complete budgeting</th>
<th>Partial budgeting</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. It is adopted when drastic changes in the existing organization are contemplated</td>
<td>1. Adopted when minor changes are introduced on the farm.</td>
</tr>
<tr>
<td>2. All the available alternatives are Considered</td>
<td>2. Considers few or only two alternatives</td>
</tr>
<tr>
<td>3. It is a method of estimating expected income, expenses and profit for the farm as a hole</td>
<td>3. It is used to calculate expected change in profit for a proposed minor modification</td>
</tr>
</tbody>
</table>

**Farm budgeting**

<table>
<thead>
<tr>
<th></th>
<th>Linear programming</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Method of estimating expected income, expenses and profit for the farm business</td>
<td>1. Optimization of linear function subject to linear inequalities or equalities.</td>
</tr>
<tr>
<td>2. Non mathematical tool</td>
<td>2. Mathematical programming mode is</td>
</tr>
<tr>
<td>3. It is a trial and error method</td>
<td>3. It offers a mechanical process of calculations in the selection of products</td>
</tr>
<tr>
<td>4. Computation becomes tedious and cumbersome.</td>
<td>4. Computations are easy.</td>
</tr>
</tbody>
</table>
Integrated-farming systems for different agro-ecosystems

Major categories of farming system

The delineation of the major farming systems provides a useful framework within which appropriate agricultural development strategies and interventions can be determined. The decision to adopt very broad farming systems inevitably results in a considerable degree of heterogeneity within any single system. However, the alternative of identifying numerous, discrete, micro-level farming systems in each developing country - which could result in hundreds or even thousands of systems worldwide - would complicate the interpretation of appropriate regional and global strategic responses and detract from the overall impact of the analysis. Only the major farming systems have, therefore, been identified and then mapped in order to estimate the magnitudes of their populations and resource bases. Each of these broad systems is characterised by a typical farm type or household livelihood pattern, although significant sub-types are described where appropriate.

The classification of the farming systems of developing regions, may be based on the following criteria:

- available natural resource base, including water, land, grazing areas and forest; climate, of which altitude is one important determinant; landscape, including slope; farm size, tenure and organization; and
- dominant pattern of farm activities and household livelihoods, including field crops, livestock, trees, aquaculture, hunting and gathering, processing and off-farm activities; and taking into account the main technologies used, which determine the intensity of production and integration of crops, livestock and other activities.

Based on these criteria, the following eight broad categories of farming system have been distinguished:

- Irrigated farming systems, embracing a broad range of food and cash crop production;
- Wetland rice based farming systems, dependent upon monsoon rains supplemented by irrigation;
- Rainfed farming systems in humid areas of high resource potential, characterised by a crop activity (notably root crops, cereals, industrial tree crops - both small scale and plantation - and commercial horticulture) or mixed crop-livestock systems;
- Rainfed farming systems in steep and highland areas, which are often mixed crop-livestock systems;
- Rainfed farming systems in dry or cold low potential areas, with mixed crop-livestock and pastoral systems merging into sparse and often dispersed systems with very low current productivity or potential because of extreme aridity or cold;
- Dualistic (mixed large commercial and small holder) farming systems, across a variety of ecologies and with diverse production patterns;
- Coastal artisanal fishing, often mixed farming systems; and
- Urban based farming systems, typically focused on horticultural and livestock production.
Classification of Farming Systems:

A) According to the Size of the Farm:

a) Collective farming.
b) Cultivation farming: i) small scale farming ii) large scale farming.

B) According to the Proportion of Land, Labour and Capital Investment:

a) Intensive cultivation.
b) Extensive cultivation.

C) According to the Value of Products or Income or on the basis of Comparative Advantages:

i) Specialized farming.
ii) Diversified farming.
iii) Mixed farming.
iv) Ranching.
v) Dry farming.

D) According to the Water Supply:

i) Rained farming.
ii) Irrigated farming.

E) According to:

I) Type of Rotation:

a) lay system:i)) unregulated lay farming
ii)) regulated lay system.
b) Field system.
c) Perennial crop system.

II) Intensity of the Rotation:

a) Shifting cultivation.
b) Lay or fallow farming.
c) Permanent cultivation.
d) Multiple cropping.

F) Classification According to Degree of Commercialization:

a) Commercialized farming.
b) Partly commercialized farming.
c) Subsistence farming.
G) Classification According to Degree of Nomadic:

a) Total nomadic.
b) Semi nomadic.
c) Partial nomadic.
d) Transhumant.
e) Stationary animal husbandry.

H) Classification According to Cropping and Animal Activities:

I) Classification According to Implements Used for Cultivation:

a) Spade farming.
b) Hoe farming.
c) Mechanized or tractor farming.

In an effort for a holistic integration of farming enterprises with cropping with the objectives of increasing income and recycling of farm wastes and byproducts to sustain the soil productivity under varied agro-ecological situations, studies on IFS involving various components like livestock, fishery, agroforestry etc, were carried out. The approaches were to find out viable components for dryland, irrigated upland and wetlands.

Irrigated low and uplands

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.

**Dyke-Pond Systems**

In many parts of Asia, the productive use of land and water resources has been integrated by transforming wetlands into ponds separated by cultivable ridges. Overall integrated farming systems that include semi-intensive aquaculture are less risky for the resource-poor farmer than intensive fish farms, because of their efficiency derived from synergism, their diversity of produce, and their environmental soundness. In many traditional systems aquaculture goes beyond fish production and cash income as pond water and pond biota perform many ecological, social, and cultural services on an integrated farm. Thus aquaculture and water management act as an engine driving the sustainability of the entire farming system (Lightfoot 1990).

An example of integrated agriculture–aquaculture system is the dyke-pond system, which has existed for centuries in South China. The history of the dyke-pond system may be traced back to the middle of the ninth century in the Pearl River delta region of China.

The dyke-pond system serves two major functions: (a) achievement of a general ecosystem balance through the harmonization of well-coordinated activities and functions embedded in the ecosystem, and (b) transformation and regeneration of organic substances based on a multi-layer trophic ecosystem structure, which helps contribute successfully to sustainable economic development. The system contains two interrelated systems of dyke and pond; the dyke is the land ecosystem for the growth of crop whereas the pond is the water ecosystem, consisting of fish and aquatic plants. The dyke-pond system can be of various kinds depending on the crops planted on the dyke such as mulberry dyke-fishpond, sugar cane dyke-fishpond, banana dyke-fishpond, and so on. The input and output of material and energy in the dyke-pond system are basically balanced. (Ruddle & Chung, 1988 and Korn, 1996).

Experience showed that the economic return from the integrated mulberry dyke-fish pond system were greater than those obtained from cultivating fruit trees or rice on the dyke. It was found that such integrated management is beneficial to mulberry and fish, as well as for development of sericulture. Moreover, pond mud enriched with silkworm excrement and other wastes can be used to fertilize the pond and feed the fish. Mulberry leaves are fed to the silkworms, whose excreta are used as fish food, and the fertile pond mud, consisting of fish excreta, organic matter, and chemical elements, is brought up from the bottom and used as manure for the mulberry trees.

In this system, the mulberry tree represents the first trophic level. Photosynthesis takes place in its leaves, which are fed to the silkworms for yarn production (the primary consumers) whose excreta and chrysalises are in turn fed to fish (the secondary consumers). The aquatic organisms in the pond are the reduction agents that decompose fish excreta and algae, break down the organic matter in the pond, and produce nitrogen, phosphorus, and potassium. The pond supplies the dyke with the fertile mud, which after decomposition is used as a primary source of fertilizer for the mulberry trees.

Moreover, the leaf fodder of mulberry is reported to be rich in crude protein, ether extract, calcium, ascorbic acid, potassium, iron and thus can be profitably utilized as a supplement to poor quality roughages (Singh and Harinder). Mulberry leaves can also be used in poultry ration. Incorporation of shade dried mulberry leaves in layer’s mash to the extent of 6 % showed an increase in egg
production with desirable yolk colour without any adverse effect on body weight and egg quality (Narayana & Setty, 1977). Mulberry leaves, owing to their high carotene content, can form a valuable source of vitamin A for the health of poultry birds and increased egg production.

In India such integrated systems have not been systematically evolved so far, however in many places, the pond mud is used for terrestrial crop and pond embankment for papaya, coconut, banana plantation and at times for growing vegetables.

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, mirgal/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 Bangkok 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 (ratton)-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></td>
<td>Crop</td>
<td>Poultry</td>
<td>Pigeon</td>
</tr>
<tr>
<td>Cropping alone</td>
<td>12995</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Crop + fish + poultry</td>
<td>26352 (89.0)</td>
<td>1205 (4.1)</td>
<td>2052 (6.9)</td>
</tr>
<tr>
<td>Crop + fish + pigeon</td>
<td>24854 (85.2)</td>
<td>2545 (8.7)</td>
<td>1774 (6.1)</td>
</tr>
<tr>
<td>Crop + fish + goat</td>
<td>25725 (68.3)</td>
<td>1975 (5.2)</td>
<td>9979 (26.5)</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 22.5</td>
<td>1.96 88.2</td>
<td>65.7</td>
</tr>
<tr>
<td>P₂O₅</td>
<td>2.5 17.5</td>
<td>1.02 45.9</td>
<td>28.4</td>
</tr>
<tr>
<td>K₂O</td>
<td>1.05 7.4</td>
<td>0.72 32.4</td>
<td>25.0</td>
</tr>
<tr>
<td>Nutrient</td>
<td>Raw pigeon dropping</td>
<td>Pond manure</td>
<td>Additional nutrient gained</td>
</tr>
<tr>
<td>----------</td>
<td>---------------------</td>
<td>-------------</td>
<td>----------------------------</td>
</tr>
<tr>
<td></td>
<td>% kg/700 kg</td>
<td>% kg/4500 kg</td>
<td>(kg)</td>
</tr>
<tr>
<td>N</td>
<td>1.82</td>
<td>0.84</td>
<td>25.1</td>
</tr>
<tr>
<td>P$_2$O$_5$</td>
<td>0.56</td>
<td>0.30</td>
<td>9.6</td>
</tr>
<tr>
<td>K$_2$O</td>
<td>0.98</td>
<td>0.56</td>
<td>18.3</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Nutrient</th>
<th>Raw goat dropping</th>
<th>Pond manure</th>
<th>Additional nutrient gained</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>% kg/810 kg</td>
<td>% kg/4500 kg</td>
<td>(kg)</td>
</tr>
<tr>
<td>N</td>
<td>1.4</td>
<td>0.70</td>
<td>20.2</td>
</tr>
<tr>
<td>P$_2$O$_5$</td>
<td>0.85</td>
<td>0.62</td>
<td>21.0</td>
</tr>
<tr>
<td>K$_2$O</td>
<td>0.70</td>
<td>0.48</td>
<td>15.9</td>
</tr>
</tbody>
</table>

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$_2$O$_5$ and K$_2$O, 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$_2$O$_5$ and K$_2$O 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$_2$O$_5$ and K$_2$O, 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. finger lings 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 m$^2$).
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 22nd 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 Bapcock’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 m³ 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
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 cowdung 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(macro 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 studies 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>Total</td>
<td>1.00</td>
</tr>
</tbody>
</table>
Farm Stead:

<table>
<thead>
<tr>
<th>Dairy Unit</th>
<th>3 jersey cows + 2 calves</th>
</tr>
</thead>
<tbody>
<tr>
<td>Biogas Unit</td>
<td>2 m 3 capacity</td>
</tr>
<tr>
<td>Mushroom Production</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.

Rainfed and dryland

Integrated farming system (IFS) for Dry Land

Integrated farming system for dry lands suggested for Coimbatore and Aruppukottai, Tamil Nadu, are described below:
Model for Coimbatore, Tamil Nadu (mean Annual rainfall; 640 mm).

Crop Components for One Hectare:

<table>
<thead>
<tr>
<th>Cropping</th>
<th>Area ( ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>i) Sorghum + cowpea both grain purpose</td>
<td>0.20</td>
</tr>
<tr>
<td>ii) Sorghum + cowpea both fodder purpose</td>
<td>0.20</td>
</tr>
<tr>
<td>iii) Leucaena ( tree fodder)+ Cenchrus ( grass fodder)</td>
<td>0.20</td>
</tr>
<tr>
<td>iv) Aracia Senegal ( tree fodder) + grass</td>
<td>0.20</td>
</tr>
<tr>
<td>v) Prosonic cineraris ( tree fodder ) + grass</td>
<td>0.20</td>
</tr>
</tbody>
</table>

Animal Components: Telicherry goat: 6 (5 female + 1 male – stall fed) Conventional cropping system = 0.20 ha (sorghum+ cowpea- grain purpose). The animal components, tell cherry goat, numbering 6 (5 female+ 1 male) were kept in a shed (6 * 4 m). The goals were stall fed form the cropping components. Two kg each of green and dry fodder and 100 g of concentrate were given to each animal. At the end of second year. All the 4 male goats were disposed retaining one number. From the end of third year onwards, 20 female and one male were retained and remaining disposed. The litter form the goat shed was used for composting and recycled as manure. A farm pond was dug in an area of 300 m2 and the rain water harvested was utilized for pot watering the tree saplings.

Economic returns from the system: additional revenue of Rs. 3750ha / year was obtained from IFS over CCS. The employment generation under IFS was 153- man days/ ha / year whereas it was only 40- man days/ ha/ year in the CCS (sivasankaram et al. 1995).
Bio-diverse Multi-tier System (Rainfed land)

Rainfed agriculture is being adversely affected by four-fold problems of land degradation, degeneration of bio-diversity due to open grazing, climate change, and poverty driven over utilization of natural resources. All these problems together lead to increasing challenges for sustainability of dryland crop production.

These problems can be reversed, stopped, or at least reduced by adopting economy driven enterprises within the farming system and thus farmers can have higher and staggered income from the small land holding. A bio-diverse multi-tier system of farming, a kind of integrated cropping system, can thus be the answer. This system envisages a coupling of multipurpose trees, horticultural plants, health herbs, food/oilseeds/pulses, etc., with livestock rearing. The tangible benefit from this system could be the efficient nutrient and hydrological cycling, which can impart resilience by building soil quality with time. The staggered income is envisaged from the annual crops and livestock periodically from the horticultural plants of short duration species on long duration from woody species and from the bi/tri annual species and others in the system.

Over a period of time farming systems have evolved in semiarid tropics to suit the requirements for maintaining soil fertility and production related issues. The soil and water conservation measures coupled with vegetative cover on the agricultural lands can provide fodder and fuel, shade and shelter, wind break effect through vegetative barriers, sustain livestock etc., in order to provide livelihood security to the farmers.

Crop + goat (Tamilnadu)

An integrated farming system study involving grain crop, fodder crop, fodder trees, perennial grasses and goat rearing in an area of one hectare of rainfed land was carried out at Coimbatore from 1987 to 1992. Generally in dryland farmers raise only fodder sorghum yielding 3 to 10 tonnes of fodder/ha depending upon the rainfall. In the integrated approach, the cropping pattern was modified by including both sorghum grain crop (0.2 ha) and sorghum fodder crop (0.2 ha). To meet the fodder requirements of goats, 0.2 of land was raised with subabul and Cenchurus ciliaris, a pasture grass as an intercrop. Trees like Acacia, Senegal and Prosopis cineraria were raised in 0.20 ha. The goat unit comprised of Tellichery goats 20 eves and 1 buck.

The results revealed that through short duration field crops and perennial crops the feed requirement for one productive unit consisting of 20 eves and one buck for all the 365 days can be met. After 5 years, the perennial fodder trees could bear the shock and yield sufficient quantity of loppings to supplement the feed requirement of 21 adults along with millets, legumes and perennial grass linked. The Tellichery goat will be a good breed to build up body weight for every unit of feed secured through different sources under rainfed conditions. It is a dual purpose animal, where it gives 800 to 1000 ml of milk after satisfying the full requirement of dependent kids on it every day. Twenty productive females could give 45 kids per annum. Each kid at the time of weaning will weigh around 12 kg. Moreover the unit of 21 animals with different stages of kids under deep litter system would give 11.2 to of valuable manure. This when applied to the soil, will not only an excellent source of primary, secondary and micro nutrients for the crops but also absorb more moisture, retained in the soil and releases to the crop approximately for better yield.

The net income from the farming system was Rs 5671/ha/year and that of control Rs 1919/ha/year. Out of the total income from the IFS, 59% was from goat rearing. The additional net income, realized
from IFS was Rs 3752/ha/year as compared to cropping alone. The additional employment gained through IFS over cropping was 314 man days/ha/year.

The organic manure like litter from the goat unit can readily be used for soil application and thus will help in enriching the soil. Goat droppings are found to be a good energy source, which can also be linked with biogas unit before it is utilized as manure. This will generate good volume of gas (22 kg of goat droppings will generate one cubic meter of gas as against 30 kg of cattle dung) as well as enhance nutrient availability. Thus through recycling of organic in the Farming System approach, the potential of each produce can be exploited to a greater extent. The data collected on the availability of organic source of nutrient through 20+1 goat reared under deep litter system are presented below (Rangasamy 1995).

Table 1. Nutrient gain from 20 + 1 productive Tellichery goats unit under deep litter system

<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>No of kidding/year</td>
<td>1.5</td>
</tr>
<tr>
<td>No of kids/kidding</td>
<td>1.5</td>
</tr>
<tr>
<td>No of kids/year/adult</td>
<td>2.25</td>
</tr>
<tr>
<td>No of kids from 20 adults/year</td>
<td>45</td>
</tr>
<tr>
<td>Mean weight of dropping/day</td>
<td>adult 900 g, kid 110 g</td>
</tr>
<tr>
<td>Mean weight of dropping/year</td>
<td>8600 kg</td>
</tr>
<tr>
<td>Coir waste used for the stall/year</td>
<td>2600 kg</td>
</tr>
<tr>
<td>Deep litter waste obtained/year</td>
<td>11200 kg (8600 + 2600)</td>
</tr>
<tr>
<td>Nutrient content of deep litter waste (%)</td>
<td>1.75 N, 0.95 P and 0.82 K</td>
</tr>
<tr>
<td>Total nutrient (kg) available from the goat unit/year</td>
<td>200 N, 106 P and 91 K</td>
</tr>
</tbody>
</table>

Hill regions

The north-eastern hill region of India are unique in their physiographic characteristics of land, varied agro-climatic conditions, land tenure system and cultivation practices from the rest of the country. The region falls under high rainfall zone and is characterized by hilly terrain with wide variation in elevation from 100 m to 5500 m. Majority of the farmers are maintaining dairy cattle and major portion of green fodder comes from lopping of the fodder trees and locally available grasses. Crops and cropping patterns of such land uses will differ depending on the type of enterprise such as milk, beef, mutton, wool, pork and poultry production. Combination of cultivated of perennial legumes, grasses, shrubs and trees can extend availability of green fodder upto February at low altitude, thereby shortening the requirement of conserved fodder for lean season feeding. Land upto 100% slope having soil depth greater than 1m can be used for agri-horti-silvipastoral system. This system has the potentiality of maintaining 1.18 livestock unit/ha of land use.

In Himachal Pradesh studies undertaken by AICRP-IFS Palampur centre revealed that 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. On an average, livestock based farming system was the major activity for more than 65% marginal farmers, 36% small farmers, 37% medium farmers and 23% large farmers. Cereals based farming systems was the
main activity of the small (39.4%), medium (42.6%) and large farmers (44.3%). However, irrespective of the farm size, overall the livestock based farming system (50%) was the main activity followed by cereals based (28.3%), fruit based (15.6%) and vegetable based (5.8%) farming system in that order.

Agroforestry-based Land Management Systems of Indian Himalayas

The forest cover in India is a mere 19.27-% of the total geographical area and is grossly inadequate to meet the nation’s requirements for forest products, maintenance of ecological processes and environmental stability. Agroforestry, which is a combination of trees, agriculture and other land use technologies, has the potential for meeting the above requirements. The three basic types of agroforestry systems are agrisilvicultural, silvipastoral and agro-silvipastoral. One of the essential characteristics of agroforestry system is its site-specificity. Five major agro-ecological zones for agroforestry have been identified in India.

In the mid-western Himalayas, of all the systems, the agro-horti-silvicultural system is highly diverse in vegetation composition and has the highest productivity of 25.8 mt/ha/year. In the Shivaliks, the well-known tree species are Acacias, Leucaena leucocephala, Dalbergia sissoo, Melia azedarach, Eucalyptus hybrida and Emblica officinalis. These trees are grown with local fodder grasses such as Chrysopogon fulvus and Heteropogon contortus. Bhabbar (Eulaliopsis binata), which is a commercial grass, used in the manufacture of paper, has also done very well in association with most of the above tree species. These two-layered agroforestry systems involving trees and grasses have demonstrated their superiority over traditional rainfed crops on poor quality soils. Moreover, on sloping non-arable lands in the Shivaliks, World Bank-assisted projects implemented from 1980 to 1999 with people’s participation have helped in conserving natural resources and in substantially augmenting production and income from these agroforestry systems. In the alluvial plains of Punjab, Haryana and Uttar Pradesh poplar has done exceedingly well in association with a large number of annual crops particularly wheat, sugarcane and vegetables. In agroforestry system internal rates of return varied from 38 to 40.5 % with wheat and fodder intercrops for first seven years in an eight-year rotation cycle. Eucalyptus is staging a come back in boundary plantations, windbreaks and shelterbelts where it has been found profitable after allowing for depression in crop yields. Agroforestry interventions should examine the management in terms of farmer livelihood strategies rather than trying to merely increase supply of forest products. There is a need to improve market information and reduce market constraints to tree growing. Public investment is needed in research to improve the genetic quality of the planting material, and to refine existing agroforestry practices/models. Enhanced investment is required for improving extension services and develop mechanisms for transferring agroforestry technology from the research institutes to the farmers and other user agencies.

Farming on Sloping Lands of Asia:

Some success stories about sloping upland farming in Asia reveal that by taking advantage of specific niches, ecologically stable and economically productive production systems can be evolved. The three examples of success stories reflect a better understanding of the niche potentials of sloping marginal uplands and the opportunities for using them in sustainable ways. Fruit farming on sloping lands extends the availability of agricultural land resources. Cardamom farming demonstrates the use of local biodiversity as a good source of new crops for developing niche-based upland farming. Sea buckthorn example shows that soil and water conservation can be complementary to food security and poverty alleviation and that forests can also provide benefits of economically productive farming.
The issues of sustainable management of sloping upland farming systems are as diverse as the areas themselves. On top of all issues is the neglect of understanding to apply an upland perspective that is so essential for formulating sloping land sensitive development strategies. It is also equally important to recognize that development issues in the sloping upland areas – such as sustainable agriculture, removing poverty, marginal environment, gender equity and inaccessibility are intertwined and call for an integrated approach. A range of issues emerge from the misconceptions, biases and neglect of sloping uplands farming.

Joint global efforts, joined by both poor and rich nations, are needed to address host of above issues. Today, the issues may be less of whether or not to use the sloping marginal uplands for farming, but of how to use these land resources in better and more sustainable ways to the advantage of both land and people.

Technologies for increasing productivity of steep lands include biological and physical or mechanical measures. Widely promoted biological measures are forestry, agroforestry (e.g., alley farming), and contour grass strips (e.g., vetiver contour strips). Common physical measures include stone retention walls and various types of manually or mechanically constructed terraces. The choice of appropriate land modification technologies must be determined by soil and climate conditions and socioeconomic constraints of the site in question. At any rate, maintaining an effective surface cover (live or dead) during the onset of rainy season is of paramount importance for controlling runoff and erosion.

Historically, bench terraces, manually constructed over an extended period of time were common practices of converting steep land for agriculture. Modern approach to steep land use increasingly favors biological measures, such as alley cropping and contour grass strips. Notable international efforts of technology transfer are: (a) the Alley Farming Network of International Institute of Tropical Agriculture (IITA); (b) the Vetiver Grass Network of World Bank; (c) Asian Sloping Land Network coordinated by International Board for Soil Research and Management (IBSRAM); and (d) the Sloping Agricultural Land Technology (SALT) Initiative of International Center for Integrated Mountain Development (ICIMOD).

Sustainable management of steep lands for agricultural production cannot be achieved by onsite technological improvements alone. It must be supported by governmental and private institutions that are capable of implementing conservation policies, providing technical and financial assistance to steep land communities, and generating public awareness of the effects of upstream (onsite) land degradation (deforestation, soil erosion) on short-term economic benefits and long-term ecological and environmental consequences downstream (offsite).

The advancement in computing technologies enables both planners and practitioners using Geographical Information System (GIS) and remote sensing techniques to determine site-specific ecological and economic feasibilities for steep land use and conservation. Various watershed management models, land use policy guidelines, erosion prediction and decision support systems are being developed which integrate downstream agricultural and economic development with upstream land use, restoration and conservation. However, regional and worldwide applications of these models depend on continued efforts in building soil, climate and socioeconomic database.

The widening economic gaps between upstream and downstream communities in many densely populated regions could be socially and environmentally explosive. If the poor communities in the steep lands were left helpless, excessive deforestation and erosion in the hills would further undermine the economic welfare and environmental quality of the societies in the plains and valleys. Evidently, this is not merely a technological issue but a political one as well.
Island

Integrated farming system models have been developed for the Andaman and Nikobar Islands –

1. Coconut – cum fodder – cum milch cattle: Mixed farming by raising fodder grass coconut has been found profitable; grass in coconut has been found profitable, grass like hybrid Napier or leguminous fodder like Stylo in Coconut garden can support 4- 5 dairy animals. Animal supply large qualities of cattle manure applied to coconut garden improve the soil fertility.

2. Coconut – cum fish culture in salt affected lands: Coconut grows successfully even in salt affected paddy fields if the fields are within the approach of brackish water. The bunds of fields at water entrance gate should be raised to maintain the required level of water. Field bunds should also be raised a per the requirement. Water will be exchanged and thus fish raising can be taken up together with coconut in dry period. In rainy season, salinity tolerant rice varities could be cultivated in the same field with coconut and fish culture.

3. Fruits- fodder- milch cattle: The space available between the fruit trees can be utilized for growing fodder crops such as cow pear, rice bean, germ gram and black gram. The fodder could be used for feeding the cattle and cattle manure could be applied to the fruit trees and fodder crops.

4. Coconut-cum-fodder-cum-fish or prawn culture: This system is suitable for tidal marshy area. The coconut palms are grown on platforms raised upto the highest tidal level and fish and prawn in channels between the coconut plantations. On platform with coconut trees, fodder crops like Guatemala grass, thin Napier and guinea grass could be raised successfully with an average forage yield of 290, 190 and 184 q/ha respectively under high salinity conditions.
Resource recycling and flow of energy in different farming systems

Recycling of organic wastes such as crop residues, dung and urine from domesticated animals and wastage from slaughter house, human excreta and sewage, bio mass of weeds, organic wastes from fruit and vegetables production and household wastes, sugarcane trash, oilcakes, press mud and fly ash from thermal power plants. Material not suitable for direct application can better apply by composting and vermicompost.

The ultimate goal of sustainable agriculture is to develop farming system that are production and profitable, conserve the natural resources base, protect the environment and enhance health and safety, and to do so over the long term.

Two farming system have been proposed for ensuring sustainability. There are low input sustainable agriculture (LISA) and organic farming.

Low Input Sustainable Agriculture (LISA):

In this system minimal use of external production inputs is made. The production costs are obviously lower. The over all risk of the farmer is considerably reduced. Besides, the above advantages, pollution of surface and ground water is avoided and healthy food with very little or no pesticide residues are ensured. These systems held promise for both short and long term profitability. However, the system suffers from one serious drawback – continuation of low external input agriculture will perpetuate to the vicious circle of low inputs low yields which the third world countries with ever increasing population pressure can ill offered.

High input system, on the other hand, will fail sooner or later, as they are not economically and environmentally sustainable. What is the solution then? The optimal input farming system has the premise of low input per unit of output and lays emphasis on low of diminishing returns. Four factors are most important for better growth of plant:

1) Soil – 45%
2) Organic matter – 5%
3) Air – 25%
4) Water = 25%

Organic Farming and Waste Recycling:

Organic farming is the backbone of sustainable agriculture. Organic farming mainly depend on Organic recycling: Industrial agriculture chemicals like fertilizer, pesticide, herbicide etc are not used or used to minimum extent necessary in this kind of farming. Organic farming may result in compatible performance as conventional agriculture and crops growth with high organic manure application could tolerate the pest and disease attack better. It is is sound and sustainable way of growing more food.

Organic recyclable waste include – crop residues, waste, farm industrial waste, multiple and sewage wastes. They are valuable sources of plant nutrient and humans in tropical and subtropical soils found in India, there is general deficiency of organic carbon and plant nutrients due to rapid loss of this
component by bio-degradation. To make up for these losses, extensive utilization of organic residues in agriculture is essential. In addition they also protect the soil from erosion.

In India, there is a general potential for utilization of crop residues/straw of major crops. About 141.2 MT straws available and from that, contribute about 0.7, 0.84, and 2.1 MT N.P.K respectively. If considering 50% crop residue utilized as animal feed, the rest can recycle. Crop residue has wide C: N ratio due to this, immobilization nutrients. Care should be taken that before use, composing with efficient microbial inoculants.

1. Sugarcane Trash Compost: Fresh sugarcane trash contains 0.36% N with a wide C:N ratio of 122:1. The composted trash contains – higher content of N (1.09) with reduced C:N ratio (20.1). Per hector availability of trash is about 6-8 (over all country about 19 – 38) million tones).

2. Bio-gas Slurry: Organic manures from animal wastes are very important nutrient sources in building up soil fertility. In India, estimated production of dung and urine abort 1002 and 658 million tones respectively. They contribute about 5.7 million tones of N P K with proper utilization. Biogas advantages as fuel (gas) and fertilizer (slurry) Dry slurry contains abort 1.8% N, 1.10 % P₂O₅ and 1.50% K₂O.

3. Vermicompost: The average nutrient content of vermicompost is much higher than that of F.Y.M. vermicompost contains 1.60 % N, 0.54% P₂O₅ and 0.80% K₂O. The C:N ratio of vermicompost is much lower (1.6) than the FYM (1.30).

4. Industrial Wastes: Among the industrial by products, spent wash from distilleries and molasses and press mud from sugar factories have good manurial value. It is important to use only well decomposed press mud at 10 tones / ha. Addition of press mud improves the soil fertility it is reclamation agent in saline and sodic soils. Coir waste is the by product of coil industry. Well decomposed coir waste of 12.5 t/ha with recommended fertilizer to ground nut and maize increase yield.

5. Municipal and Sewage Wastes: This is one of the important components of organic wastes. In India, the total municipal refuse is abort 12 million tones / annum containing 0.5 %N,0.3%P, & 0.3%K. Sewage (liquid portion) sludge (solid portion) is available to on extent of 4 million tones /annum containing 3 % N,2 % P & 0.3% K. Such organic waste can be used carefully it may contains metals thus hazard to plants, animals & human beings.

6. Crop residues: Residues left out after the harvest of the economic portion are called crop residues /straw. Cereal straw and residues contains abort 0.5% N, 0.6% P and 1.5 %. The crop residues can be recycled by way of incorporation compost making or mulch material.

7. Rice Husk: It is major by-product of the rice milling industries. It is poor source of manure and nutrient 0.3 % N, 0.2 % P and 0.3 K. Rice husk should be incorporated into the wet soil and can be used in saline and alkaline soils to improve the physical condition. It can also be used as a bedding material for animals.
Integrated Farming system at Siruguppa, Karnataka, under canal irrigation of Tungabhadra project 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 was 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 for crops. 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. Ravishankar et. al., (2007) and Jayanthi et. al., (2003) also reported the similar findings. Among the cropping sequences under 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). Sharma and Das (1988) reported that integration of fish-livestock-crop was beneficial.

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 returns obtained from all the components was Rs. 22,887 with an increase of 32.3% higher than conventional rice-rice system. Bahera and Mahapatra (1998) also reported increase in returns through IFS. Similarly, Sonjoysa, 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       |           |                           |                          |                  |           |
| 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). Among the various components, goat recorded the highest benefit cost ratio (2.75) followed by fish (2.23) due to low cost of cultivation. This was followed 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 (0.33ha) 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 components and for products from animal components.
Specific energy was less in the IFS (3.09 MJ/kg) over conventional rice-rice system (5.09 MJ/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 MJ/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>
<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>
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<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>720</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>395</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></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</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

**Resource and energy flow in Crops + Livestock + Fish + poultry IFS (1 ha) under wetland/irrigated lands**

Dairy forms an important component in farming system especially under garden land conditions. Crop + livestock farming system is a broad system that is suitable for different ecosystems. Integrating fish with crop + dairy farming system is ideal for wetland system. Crop + poultry is also ideal in wetland system. Therefore, adding poultry component would help recycling resources better and generating additional income. About 0.04 ha has allotted to the fish pond. Fish pond has to be excavated to a depth of 1.5 m. Fifteen days old fingerlings of different fish species have been stocked in varied proportions (silver carp/rohu/mrigal/grass carp at 4:2:3:1 ratio with a total of 7500 fingerlings/ha). No artificial feeding has been done. Harvest of fish commences from tenth month. Washings of the cowshed have been diverted to the the fish pond. A poultry shed with a pliant area of 2.2 m² has been erected at one corner of the fish pond. Bottom of the poultry shed has been provided with wire mesh (3m x 3m) to facilitate free fall of poultry droppings into the fish pond. Twenty Bapcock chicks (18 weeks old)
have been reared in the shed. Poultry feed has been managed with recycling of farm wastes and the produce obtained from the crop components. Alfalfa + grass mixture cultivated around the fish pond was also used for feed poultry as well as fish. The birds will start laying eggs around 22nd week upto 72 weeks, when they were culled out. Each bird was fed with feed of 100-200 g/day. The feed ingredients were maize, rice bran, groundnut cake, fish meal, shell grit, dicalcium phosphate and vitamins.

**Resource and energy flow in Crops + Goat + Agroforestry IFS Model under drylands**

**Component description**

IFS model has been proposed for 1 ha area. Crop and goat association is common in drylands. Goats are essential browsers and eat plants which any other animal won’t touch. They eat more of tree fodder and hence 40-50% of green fodder should contain tree leaf fodder, the rest with other grass species. Therefore, integrating agroforestry with crops + goats farming system is a better proposition. About 0.3 ha has been allotted to Agroforestry which can support 8+1 units of goats nicely. Composting or vermicomposting activity has also been proposed for effective recycling of farm waste and weeds.

| Goats: 1.5-2.0 kg green fodder and 100 g of concentrate per animal per day. |
| Space requirement: 4.5 to 5.4 sq. m. |
Fig 1. Resource flow model of integrated farming system - wet land (1.0 ha) (Crops + Livestock + Fish + Poultry)
Fig 2. Resource flow model of integrated farming system - dry land (1.0 ha) (Crops + Goat + Agroforestry)
Farming system and environment

All over the world, farmers work hard but do not make money, especially small farmers because there is very little left after they pay for all inputs (seeds, livestock breeds, fertilizers, pesticides, energy, feed, labour, etc.). 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 (or integrated agriculture) is a commonly and broadly used word to explain a more integrated approach to farming as compared to monoculture approaches. It refers to agricultural systems that integrate livestock and crop production or integrate fish and livestock and may sometimes be known as Integrated Biosystems. In this system an inter-related set of enterprises used so that the “waste” from one component becomes an input for another part of the system, which reduces cost and improves production and/or income. IFS works as a system of systems. IFS ensure that wastes from one form of agriculture become a resource for another form. Since it utilizes wastes as resources, we not only eliminate wastes but we also ensure overall increase in productivity for the whole agricultural systems. We avoid the environmental impacts caused by wastes from intensive activities such as pig farming.

Integrated farming systems: Environmental Sustainability in Full Circle

In recent years, food security, livelihood security, water security as well as natural resources conservation and environment protection have emerged as major issues worldwide. Developing countries are struggling to deal with these issues and also have to contend with the dual burden of climate change and globalization.

It has been accepted by decision makers across the globe that sustainable development is the only way to promote rational utilization of resources and environmental protection without hampering economic growth. Different countries around the world are promoting sustainable development through sustainable agricultural practices which will help them in addressing socio-economic as well as environmental issues simultaneously.

Within the broad concept of sustainable agriculture "Integrated Farming Systems" hold special position as in this system nothing is wasted, the byproduct of one system becomes the input for other. Integrated farming is an integrated approach to farming as compared to existing monoculture approaches. It refers to agricultural systems that integrate livestock and crop production. Moreover, the system help poor small farmers, who have very small land holding for crop production and a few heads of livestock to diversify farm production, increase cash income, improve quality and quantity of food produced and exploitation of unutilized resources.

Components of integration in a farming system are parkland systems, trees on bunds, wind breaks, silvi-pasture system, agro-horticulture system, block plantations, economic shrubs, live fences, crops with green leaf manure species (mixed/intercrops), integrated animal based systems (fisheries, dairy, piggery, small ruminants, poultry, apiary).
The intensive farming systems of developed countries, such as United Kingdom seek to maximize yield through what is usually described by agricultural economists as Best Management Practice (BMP), which involves the most efficient use of all inputs, including fertilizers, herbicides, seed varieties, and precision agricultural techniques (Goulding et al, 2008). Fertilizers have been central to this approach, which has resulted in a tremendous increase in productivity over that last 40 years. For example, the efficient use of improved fertilizers, combined with new varieties of wheat and the successful use of crop protection chemicals, has increased grain yields from 3 tons per hectare to approximately 10 to 11 tons per hectare today (Goulding et al, 2008). Moreover the current market economic incentives facing many farmers are likely to encourage excess fertilizer application (Scott, 2005). It is generally recognized that if eventually the adoption of market prices for most agricultural goods without any subsidies became a reality, in order to be competitive with the lower production costs of developing countries in South America, Asia, Eastern Europe and the Former Soviet Union, the pressure to intensify even the most UNITED KINGDOM intensive production systems will as well become reality despite the negative consequences on the environment (Goulding et al, 2008).

Agriculture is one of the most successful sectors in terms of productivity growth, has outpaced the rapid growth in demand for its output for the past decades (Shaink el al, 2002). This trend has provided hefty social benefits, such as increased the accessibility of agricultural goods usually at a lower price, provision of jobs and therefore rural sustainability, energy and also positive environmental effects, such as aesthetic value, carbon sequestration by soils and trees, and other additional benefits that are linked with good husbandry such as maintenance of natural habitats and countryside landscape (Shaink et al, 2002; Scott, 2005). However, is largely referenced in literature that the increased use of chemicals either fertilizers or pesticides in agriculture intensive systems is associated with hidden costs due to environmental pollution – in soil, water and atmosphere –, consequently has amplified the negative social effects on the natural environment (eg. Shaink et al, 2002; Scott, 2005 ). This argument is supported by an analysis of the externalities from UNITED KINGDOM agriculture made by Hartridge and Pearce (2001), finding that negative externalities amount to at least £1 billion, and positive externalities offset approximately half of these negative effects (negative/positive external).

**Farmers and fertilizer application**

The main question rises once more, what are the fertilizer application determinants? For a typical farm manager, output is what matters most to the business survival and prosperity. Consequently, farmers apply fertilizers since they represent personal benefits in the form of improved outputs and incomes, however plants absorb fertilizers just up to their needs only, therefore, surplus fertilizer over and above the needs of plants can cause harmful side effects (Scott, 2005) either on the farm profit or in the environment. A given agricultural input bundle might result in wide diverse output levels according to the level at which random factors operate (Gallacher, 2001). Rousevell and Reay (2009) clarify the previous argument stating that land use and therefore fertilizer application changes are driven primarily by farmer decisions, which are affected by the economic environment (output and input prices), soil features, crop and livestock yields, timeliness of field operations, availability of investment capital, subsidies as well as the socio-cultural attributes of individual farmers. The first driver is clearly an agronomic argument, since agronomists agree that crop nutrient uptake is higher in years with good growing conditions (Babcock, 1992), therefore if a farmer applies the optimal amount of fertilizer for mean growing conditions, and in a particular year those conditions are better than expected, there will be too little fertilizer and decrease in
production. On other hand if weather conditions are not conducive, there will be too much fertilizer (Sheriff, 2005), thus a risk-neutral farmer applies fertilizer at a higher rate as long as the expected gain in profit from the increased yield is higher than the expected loss in profit from wasted fertilizer.

Another hypothesis is proposed by Rajsic and Weersink (2008). They argue that while there may be agreement on the functional form of crop response to fertilizer, there will be differences in the optimal rate between locations. Numerous studies have reported that the maximum economic nitrogen rate varies spatially and that the degree of variability can be substantial (Carr et al., 1991). As a consequence there is a need to analyze the spatial variations in order to state the yield potential of the field and/or region, the underlying assumption is that yield potential is directly linked to the productivity of nitrogen, so fields with higher estimated output receive higher rates of fertilizer (Rajsic and Weersink 2008). Dai et al (1993), however, found that nitrogen and soil quality are complements, and soil quality uncertainty and nitrogen availability are linked which will increase nitrogen demand and consequently nitrogen input. Additionally Rajsic (2008), Sheriff (2005) and also Dai et al (1993) argue that one of the main causes for over-fertilization might be related to the uncertainty about weather and soil characteristics that can lead both risk-averse and risk-neutral farmers to over-apply nutrients, therefore the decision to apply a “little extra just in case” is particularly appropriate if the cost of over-application is low compared to the cost of under application (Rajsic, 2008). This idea is supported by Sherriff (2005), arguing that farmers will apply more fertilizer than a crop can use due to a perception that the general recommendations are not appropriate for their individual situations. Smill (1999) argues that the application of N is fairly inefficient in most farms, since farmers are applying nitrogen at levels that exceed those suggested by either government extension services or by the optimal nitrogen appliance (Rajsic and Weersink, 2008). Approximately half of Nitrogen applied during a growing season is typically recovered in the crop biomass throughout that season, therefore this inefficiency represents a noteworthy cost to farmers and an important consequences for ecosystem and human health as Nitrogen moves beyond the farm level in several aqueous or gaseous forms, such as N₂O (Matson et al., 1997, 1998; Galloway, 1998).

In practice evidence suggests that farmers systematically over-estimate the impact of additional nitrogen relative to agronomists’ models and therefore they maintain their beliefs after seeing results from experimental plots (Sri Ramaratnam et al., 1987). If farmers’ perceptions are incorrect, these beliefs will lead to over-application, conversely if their sensitivity is correct, analysts may infer excess nutrient applications where none exist. Thus if weather, the relation between fertilizer prices and output prices and soil features are not main and/or the only drivers behind fertilizer application, which characteristics does the farmer have to apply more or less fertilizer compared to those with the same features and constraints?

**The effect of fertilizers on the environment**

The relatively cheap price of Nitrogen in relation to its yield improvement benefits, and allowing farmers substantial management flexibility, has been a central contributory factor in determining its overuse and consequently the environmental impacts reported below.

It is known that Agricultural emissions of nitrous oxide have fallen by 13 % over the 10 years up to 2005 and the trend is continuing (DEFRA, 2007). However despite this reduction in the UNITED KINGDOM and other major developed countries, the major direct emissions of greenhouse gases (GHGs) are from agriculture methane (CH₄) caused by enteric fermentation by ruminant livestock and manure management, and nitrous oxide (N₂O) from soils (Gibbons, 2005). Additionally methane has a global
warming potential 21 times greater than carbon dioxide while nitrous oxide global warming potential (GWP) is considered 296 times that of the same mass of carbon dioxide (Houghton et al., 2001), consequently fairly small concentrations of this gas are sufficient to induce drastic changes in the atmosphere. At current estimates N₂O contributes about 7% of the greenhouse gas emissions in terms of the GWP (Winiwarter, 2005). As a result, among the gases considered by the Kyoto Protocol, N₂O is ranked third in importance behind carbon dioxide (CO₂) and methane (CH₄) (Winiwarter, 2005). Seinfeld and Pandis (1998) add that N₂O is a very stable compound in the atmosphere, with a mean lifetime of 120 years, so the emissions will have an effect on the global concentrations in the atmosphere for many decades. The same authors argue that N₂O is able to strongly absorb infrared light, thus it also exerts a considerable effect on the earth’s radiation absorption. Therefore it is obvious the magnitude of nitrogen fertilization emissions has a dramatic effect on the environment.

Approximately 1% of the anthropogenic Nitrogen input into agricultural systems is emitted as nitrous oxide, with agriculture as a whole contributing to 66% of total UNITED KINGDOM nitrous oxide emissions in 2006, 95% of it via direct emissions from agricultural soils (IPCC, 2006). In addition, fertilizer manufacturing is energy-intensive (Rounsevell and Reay, 2009). Carbon dioxide emissions from ammonia production – most of which is for fertiliser use – made up 0.3% (1.6 million tonnes) of UNITED KINGDOM CO₂ emissions in 2006 (DEFRA, 2006). Nitrogenous fertilizer consumption in the UNITED KINGDOM increased by nearly 300% between 1961 and the late 1980s, regardless of the decline in agricultural land area (roughly 15% in the same time interval) – indicating a large increase in application rates per unit area of land over this period (Rounsevell and Reay, 2009). As stated previously, fertilizer Nitrogen consumption gradually declined after 1990, reaching a rate of around 1.2 million tonnes per year in 2006 (DEFRA, 2008).

As Smil (2000, 2001) argues, Nitrogen (N) is a key input in agriculture, therefore we cannot simply exclude or limit the application of it to meaningless values. We should instead open a new channel of discussion in order to improve or formulate new policies in an enhanced cost-efficient way that decreases damaging effects on the environment and improves farms’ profits. This can only be achieved if each of determinants of fertilizer application are well understood.

Livestock and the environment

ONE OF THE great challenges facing the world over the next decades is to preserve its natural resources while at the same time producing sufficient food to satisfy the demands of a growing human population. World population is expected to grow from 5.5 billion now to about 8 billion in the year 2020. Incomes also continue to grow, especially in the developing world and future projections estimate an annual per capita income growth ranging from about 3% in sub-Saharan Africa and Latin America to about 6% in Asia. Furthermore, there is a strong population move from the rural to the urban areas, again primarily in the developing world. By the year 2000, approximately 44% of the world’s population is expected to reside in urban areas, up from 30% in 1980 (IFPRI, 1995). These trends will have immense consequences on the volume and composition of global food demand, especially in the developing world. Specialists of the International Food Policy Research Institute (IFPRI) estimate that the current demand of 1.7 billion tons of cereals and 206 million tons of meat, may rise by the year 2020 to 2.5 to 2.8 billion tons of cereals and at least 275 to 310 million tons of meat.
At the same time, alarming symptoms of deterioration of the resource base are being observed worldwide:

• **Land degradation.** Although there is substantial discussion on the extent of the problem, between 700 million (Oldeman *et al.*, 1991) and three billion hectares of land (Dregne *et al.*, 1991) are reported degraded because of human activities.

• **Water scarcity and pollution.** Twenty-two countries suffer severe water scarcity (less than 1000 cubic metres per capita per year) and a further eighteen countries have dangerously low levels (less than 2000 cubic metres per capita per year) (World Bank, 1992). In addition, much of the global fresh water supply is unsafe because of pathogens and industrial pollutants.

• **Global warming.** Global temperatures have risen by 0.3 °C to 0.6°C over the last century, together with a 26% increase in carbon dioxide and 115% rise in methane levels of the atmosphere (World Bank, 1992). A further increase of the global temperature by 1.8 °C is foreseen over the next 35 years (International Panel on Climate Change, 1990).

• **Diminishing biodiversity.** About 160 bird and 100 mammalian species are known to have become extinct over the last three centuries and the rate of extinction is increasing (World Bank, 1992). The rate of losses in other animal and plant species may be higher. McNeely *et al.*, (1990) estimates that more than 3,000 plant species and more than 500 animal species are in immediate danger of extinction.

**The role of livestock in this changing world**

The way livestock are kept and milk and meat is produced will be a key factor in the future health of the planet. Animal agriculture is one of the most important components of global agriculture and livestock is one of the main users of the natural resource base:

• livestock use 3.4 billion hectares of grazing land (Sere and Steinfeld, 1996) and the production from about one-quarter of the world's croplands. In total, livestock make use of more than two-thirds of the world's surface under agriculture, and one-third of the total global land area;

• livestock raising is the sole source of livelihood for at least 20 million pastoral families, and an important, often the main, source of income for at least 200 million smallholder farmer families in Asia, Africa and Latin America;

• livestock provide the power to cultivate at least 320 million hectares of land (FAO, 1994), or one-quarter of the total global cropped area. This would otherwise have to be cultivated by hand tools resulting in harsh drudgery, especially for women, or by tractor power with an inevitable drain on foreign exchange;

• livestock provide the plant nutrients for large areas of cropland. For example, estimates carried out (Jensen and de Wit, 1996) showed that, for the tropical irrigated areas, manure provides nutrients of an estimated value of US$ 800 million per year;
• finally, livestock are an important asset for investment and insurance for hundreds of millions of rural poor, in situations where banks are often too remote and the banking systems too unreliable for safeguarding any savings a smallholder might accumulate.

The importance of livestock production can be expected to increase over the next decades. While, in the industrial world, demand for meat and milk will probably plateau, or even decline, in the developing world, income growth and urbanization will fuel a strong increase in demand. Current levels of meat and milk consumption in the developing world are only about one-fifth of those in the industrial world. The surge in demand from present levels of 206 million tons to 275-310 million tons or more per year by 2020, will be especially strong in Asia and Africa where the demand for meat is expected to triple.

Livestock production systems and the main environmental challenges

Based on the degree of integration with crops and its relation to land, the world's livestock sector has been classified into three broad livestock production systems (Sere and Steinfeld, 1996), i.e. grazing, mixed farming and industrial systems. For land-based production forms, i.e. grazing and mixed farming systems, a sub-division is then required to allow for differences caused by agro-ecological conditions and the ways in which livestock affect the natural resource base. The broad categories are:

Grazing systems. These are systems based almost exclusively on livestock production, with little or no integration with crops. They are mainly based on native grassland. In terms of total production, grazing systems are of lesser importance because they supply only 9% of global meat production. Of this, three-quarters comes from Central and South America and of the Organisation of Economic Cooperation and Development (OECD). Livestock interact in these systems with land, water and plant and animal biodiversity, especially wildlife. Agro-ecological conditions strongly define the nature and scope of livestock-environment interactions in grazing systems. The study therefore distinguishes between arid, semiarid and sub humid, humid and temperate grazing systems. In principle, grazing systems are closed systems, where the waste product (manure) is used within the system and does not present a burden on the environment. Resource degradation, especially of land and biodiversity, is now developing in many of the world's grazing areas. For the most part this is occurring where, as a result of external pressures, traditionally well-managed common lands are becoming open access areas. In such open access situations, the interests of individual users conflict with those of the community, causing what economists call "market failures". In these "free for all" situations, degradation is most severe. On the other hand, the grazing systems also offer potential for biodiversity enhancement. Identifying institutions and incentives to correct the market failures and enhance the livestock-environment synergies is thus one of the biggest challenges in this system.

Mixed farming systems. In mixed farming systems, crops and livestock production are integrated on the same farm. Globally, mixed farming systems produce the largest share of total meat (54%), and milk (90%). Regionally, the mixed farming systems of the OECD countries and Asia provide by far the largest share of these products, but also in sub-Saharan Africa, West Asia and North Africa (WANA) and Central and South America, mixed farming is the main system for smallholder farmers. Resource use in mixed farming is often highly self-reliant as nutrients and energy flow from crops to livestock and back. By definition, such a closed system offers positive incentives to compensate for environmental effects
("internalize the environmental costs"), making them less damaging or more beneficial to natural resource base. Because of the completely different approaches needed to address the environmental effects of mixed farming, this study distinguishes between mixed farming in the developing and in the industrial world. The main challenge is to identify those policies and technologies which allow these systems to grow while sustaining their environmental equilibrium.

Industrial systems. These systems cover industrial types of production and small-scale urban or peri-urban production in developing countries. Both monogastric (pig and poultry) and ruminant production systems exist. They provide 37% of the total global meat production. These systems are open both in physical and economic terms. They depend on outside supplies of feed, energy and other inputs. These systems are strongly market driven, making them less resilient to market upheavals than other systems. Because of their many interfaces with the outside world, these systems, if not properly controlled, offer many opportunities to neglect ("externalize") their environmental costs. The challenge is to identify the regulations and incentives which force the polluter to internalize the environmental costs, at a minimum cost to the consumer.

Global overlays. In addition to the site-specific and production system related impacts of livestock, such as land degradation in the arid zones, deforestation in the humid zones or livestock-wildlife interactions in the savannas, there are a number of effects which transcend the specificity of production systems. These are the global overlays, which include the environmental aspects of feed production, the emission of greenhouse gases, the erosion of wild and domestic genetic resources, and the management of waste. As in the industrial system, some of these impacts (for example, processing waste) can be traced to one polluter (called "point source pollution"), and can therefore be controlled with appropriate regulation at the source. The other impacts cannot easily be traced to one polluter ("non-source pollution"), and the challenge is then to find the incentives to encourage all producers to reduce these emissions.