Agro-Ecosystems: An Assessment

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Agro-ecosystems stand out from the natural ecosystems as they have been converted from the latter and managed by human beings for their own use. These may often overlap with forests, grasslands and coastal ecosystems where agricultural plots/croplands form part of a mosaic of land uses. Around 37 per cent of the global land (excluding Greenland and Antarctica) is under agriculture including the managed pastures (FAO, 2000a). Global agriculture provides 95 per cent of all animal and plant protein. Beyond the economic value of the goods produced, agro-ecosystems also provide employment to millions. Nearly 45 per cent of the world's population is reported to be living in households dependent on agriculture and the labour directly engaged in agriculture makes 46 per cent of the world's total labour force (WRI, 2000).

Reported declining trend in their condition and capacity notwithstanding, it is remarkable that agro-ecosystems have been successful in terms of their ability to keep pace with the increasing demands of the ever growing human and livestock populations for food, feed, fibre and other items. There appears to be little scope for bringing more land under agriculture in future and it has become essential to obtain more output from a given area. Intensification of agricultural production has progressed rapidly as irrigated farmland expanded, the use of purchased inputs and adoption of new technologies grew, fallowing time decreased and cropping intensity increased. However, agriculture faces enormous challenge of meeting the food needs of an additional 1.7 billion people projected as the population increase over the next 20 years, particularly when almost 65 per cent of cropland worldwide has already undergone some degree of soil degradation and over pumping of groundwater by farmers exceeds the recharge rates in many areas.

Recent Findings (WRI, 2000)

- Food production is still likely to continue to rise significantly in coming years in response to the increase in demand but soil health appears to be deteriorating at an alarming rate. Continuously adding more purchased inputs supported by new technologies may offset a part of this setback but regional disparities are likely to widen, hitting the poor the hardest.
- Water quality is on the decline. Adverse impact on the quality of downstream groundwater is bound to increase due to heavy leaching of chemical inputs (fertilizers, pesticides, etc.) while problems of water logging and salinization will pose more serious threat under irrigated agriculture wherever drainage facilities are inadequate.
- With nearly 17 per cent dependence of croplands on irrigation, agriculture is currently the largest user of freshwater globally. Hard competition with other kinds of water use, particularly for drinking and industrial needs, is likely to grow further and pose a serious problem.
- Agricultural biodiversity, the cream of natural biodiversity selected and enhanced by humans for their use over the past ten centuries, is on the fast decline track – both in terms of crops and also their traditionally grown varieties. Narrowing genetic bases and increasing crop and varietal uniformity over large contiguous areas usually mean more vulnerability to widespread incidence of diseases and pests and this may imperil food security, global trade in agricultural produce and products and, most of all, the livelihoods of small farm families. (Box-1).
- Regarding carbon storage, signals are unclear at present. Data collection methodologies and analysis techniques remain contested. Agro-ecosystems, overlapping grasslands and forests to some extent, store 26 to 28 per cent carbon and their management styles can impact concentration of carbon dioxide in the atmosphere. This concentration has increased significantly during the last century but apportioning contributions to different ecosystem categories is difficult at present.

To sum up, these findings paint a grim picture despite low resolution but they are mostly along the accepted lines and convincing also. It is widely believed that the web of life is flaying but inferences vary regarding the extent and reversibility of the damage to life support

Box 1. Agro-biodiversity and Agricultural Ecosystems

Agricultural biodiversity (or agro-biodiversity) is a sub-set of biodiversity that is the result of the careful selections and innovative developments of farmers, herdsmen and fisher folk over more than ten thousand years and also includes progenitors and close relatives of cultivated plants and domesticated livestock. Agricultural biodiversity has also been remarkably increased by the contributions of professional breeders engaged in plant and livestock improvement programmes. In general, agro-biodiversity refers to the variety and variability of plants, animals (including pollinators and predators) and microbes on earth that are important to food and all other agricultural production systems along with management systems and traditional practices used by farmers and farming communities.

Agricultural ecosystems (or Agro-ecosystems) are those highly diverse ecosystems that are used for agriculture in similar ways, with similar components, similar interactions and functions. These include the genetic resources, the physical environment, the human management practices and their interactions. Their processes are reflected in functioning of farming systems comprising croplands, animal husbandry, pastures, aquaculture, agro-forestry and other land use systems. They may be managed as monocultures, polycultures or mixed systems in numerous combinations like crop-livestock systems and agro-silvi-pastoral systems.

Source: FAO, 1999

systems. The World Resources Report (WRR) takes due note of this point while stating that "we currently lack much of the baseline knowledge we need to assess ecosystem conditions adequately on a global, regional, or sometimes even on a local scale" (WRI, 2000). It also pleads for vigorous support to a more comprehensive Millennium Ecosystem Assessment that is likely to begin soon. It concludes on a positive note that useful experiences are available around the globe to check, contain and repair the observed damages, in great measure if not fully. There are still workable options but time for action is running out.

Developing Countries Perspective

Extent

Findings of the WRR (WRI 2000) bring out several contrasting features between the developed and developing worlds when global generalizations are attempted to be resolved at the regional and national scales. Firstly, data collection, storage and reporting systems are not yet adequately developed in a large number of developing countries where short cuts often substitute systematic surveys. Secondly, averages based on selected information are used to show the trends but these scores mask more meaningful information than what they convey. For example, WRR quotes FAO (2000a) statistics to state that 69 per cent of agro-ecosystems consist of permanent pastures while the remaining 31per cent are under crops on the global scale (FAO, 2000a). However, pastureland makes up 89 per cent of agro-ecosystem area in Oceania, 83 per cent in Sub-Saharan Africa, 82 per cent in South America and 80 per cent in East Asia. On the other hand, croplands occupy 92 per cent of agro-ecosystem area in South Asia and 84 per cent in Southeast Asia. Crops cover nearly 94 per cent of agro-ecosystem area in India. There is further significant variation even in croplands when we compare areas under annual grain crops, fibre crops, oilseeds, vegetables, fruits, plantations and other crops. While knowing global trends serves a useful purpose in developing global strategies and funding priorities, policy decisions and administrative measures relate to the scenario at the national, state or even smaller administrative boundaries where ecosystems function and people live in them. This discussion suggests that local people need to be involved in the assessment of the condition and capacity of ecosystems rather than relying on information that is gathered for a different purpose altogether but used for making assessments.

It is noteworthy from the reported data that agro-ecosystems cover nearly 36 million km^2 occupying about 28 per cent of land area with sizeable differences in regional shares. Combined share of Asia, Africa and South America is 64 per cent while that of Europe, Russia and North America is 35 per cent. It is also remarkable that out of the estimated 2.8 billion people living in or near agro-ecosystems, nearly 2 billion live in Asia. These findings have obvious policy and planning implications.

Conversion

When farmers convert a natural ecosystem to agriculture, they usually change both the composition of the ecosystem and how it functions. Agriculture in converted areas may also increase pressures on surrounding ecosystems through the introduction of non-native species that may become invasive and displace indigenous species. It is notable that bio-invasions are considered second only to habitat loss (usually through conversion) as a threat to global biodiversity. Not all conversions are, however, equally damaging. Some, like the traditional agro- forestry

systems in many Asian countries, may retain several features of the original ecosystem. Synergistic cultivation of the shade-loving large cardamom in forest area in Sikkim state of India by the Lepcha community illustrates this point in actual practice.

FAO statistics reveal that the total area under agriculture has expanded by about 8 per cent globally during the 30 years period beginning 1966. At national scale, however, land conversion, both to and from agriculture, has taken place at much higher magnitude with contrasting patterns observed in the industrialized and developing countries. Components of these aggregate values are more relevant from an ecosystem perspective since they show the dynamics of change. The overall expansion at the global level notwithstanding, agricultural area actually decreased in the United States, Europe and also in Oceania though for different reasons. Whereas South Asia's total agricultural area has remained almost unchanged during the past 20 years, agricultural land increased by nearly 0.8 per cent per year during 1986-96 in China and Brazil and by 1.38 per cent per year in West Asia (FAO, 2000b). These dynamic patterns of conversion at the national and regional level and also the causal factors are of greater relevance to the ecosystems management. Number of people engaged in agriculture and the sizes of operational farm holdings are also important considerations to give human face to agro-ecosystems.

Intensification

With the demand for agricultural produce rising steeply and good agricultural land becoming scarcer, inputs (like irrigation, fertilizer, pesticides, mechanical operations and labour) began to be applied more intensively during the last three decades to increase agricultural production. Number of crops harvested per unit area in a year also increased in many countries. While global expansion of agricultural area has been modest in recent decades, intensification has grown rapidly (WRI, 2000). Even if yields continue to grow under these conditions, this does not necessarily indicate that agro-ecosystems are in good shape because increased inputs often mask the underlying soil degradation.

Area under irrigation grew from 153 mha in 1966 to 271 mha during the last three decades. Although the irrigated land forms just about 5.5 per cent of all agricultural land and 17.5 per cent of the cropland yet irrigation is more extensive in some regions than in other. China and India together have nearly 41 per cent of global irrigated area while Western Europe and USA hold additional 12.5 per cent. In marked contrast, the arid and semi-arid regions of Sub-Saharan Africa and Oceania (mostly Australia) contain only 3 per cent of the world's irrigated land.

Market-oriented irrigated agriculture tends to turn traditional subsistence but low risk farming into high-risk commercial farming. In many developing countries like India crop failures are not uncommon pushing the farmers to face great hardships, particularly when inputs have been purchased on loans from money-lenders. Soil salinization, caused by poor irrigation management, and loss of soil fertility due to over-cultivation and imbalanced application of fertilizers further add to the problems of illiterate and resource-poor farmers. Absence of ownership rights, insecurity of land tenure and little direct access to market impose additional limitations to a losing proposition.

Economic Importance and Livelihoods

Agriculture is most important to the economies of low-income countries, accounting for nearly one-third of their Gross Domestic Product (GDP). This share is even more than 50 per cent in many parts of Sub-Saharan Africa. In the group of middle-income countries, contribution of agriculture to national GDP is around 12 to 25 per cent. GDP of high-income countries of North America and Western Europe, on the other hand, is remarkably dominated by other economic sectors and the contribution of agriculture is just 1 to 3 per cent even though the value of the agricultural output in these countries represents 79 per cent of the real market value of world's total agricultural products (WRI, 2000).

It appears that the conventional measures of agriculture's share of GDP grossly underestimate agriculture's contribution to national economies. For example, agricultural share in GDPs of the Philippines, Argentina and the United States is stated to be 21 per cent, 11 per cent and 1 per cent respectively but the total value of agriculture, including manufacturing and services further along the marketing chain, turns out to be 71 per cent, 39 per cent and 14 per cent of their total GDPs.

In addition to agro-ecosystems' contribution in terms of economic goods produced by them, they also provide employment to millions. Agricultural labour makes nearly 46 per cent of the global labour force. A comparison of the industrialized countries with developing ones in this respect brings out striking difference with obvious

policy implications. In North America, just 2.4 per cent of the labour force is directly-engaged in agriculture while this per cent is 56 to 65 in East, South and Southeast Asia and also in sub-Saharan Africa. Pre-dominance of agricultural labour in most of the developing countries represents in a way the livelihood, employment, income and cultural heritage.

Human Nutrition and Food Security

Crop production appears at present to have the potential to continue to provide for adequate human nutrition. Globally, agro-ecosystems produce enough food that can provide every person on earth the minimum human nutrition of around 2700 kcal per day (FAO, 2000a). However, many people do not have adequate access to that food with the result that nearly 800 million people remain hungry and undernourished, most of them in Sub-Saharan Africa, the Caribbean and South Asia.

In case the global population rises to 7.5 billion people by 2020 as projected, the demand for cereals and meat is expected to grow by 40 per cent and 58 per cent respectively with 85 per cent of this increase coming from the developing countries. Also, the demand for roots and tubers is expected to grow by 37 per cent, with 97 per cent of this increase coming from the developing world (FAO, 2001). Furthermore, if the poverty alleviation programmes make the expected headway, there will be an additional increase in demand for food as the poor and malnourished may like to use their enhanced income to buy food that they were not able to afford earlier.

Long-term capacity of agro-ecosystems depend primarily on natural processes and human management practices, how they degrade, maintain, or improve soil health status, water availability (also quality) and nutrient balance. Agricultural productivity has already been greatly reduced in about 24 per cent of agricultural land while additional 40 per cent are considered to be strongly and very strongly degraded (beyond rehabilitation). Most severely affected areas happen to be in South and Southeast Asia where populations are among the densest and agriculture most extensive (WRI, 2000). Soil nutrient balances are also reported to be negative in most crops and cropping systems in Latin America and the Caribbean indicating decline in soil fertility. Nutrient depletion is also widespread in Sub-Saharan Africa. Other areas where the capacity of agro-ecosystems to produce food appears to be most threatened ("Hot Spots") include northeast Brazil and sections of Argentina, Bolivia, Colombia and Paraguay.

Soil degradation may have more immediate impact on the food supply in developing countries as agricultural productivity is estimated to have already declined significantly on around 16 per cent of their agricultural land, especially on cropland in Africa and Central America. Estimates show that about 74 per cent of Central America's agricultural land, 65 per cent of Africa's and 38 per cent of Asia are degraded and have reduced productivity (WRI, 2000).

The economic and social impacts of soil degradation have been far greater in developing countries than in the case of industrialized countries where decline in soil status is often masked by application of high levels of fertilizer and other inputs. In addition, their most important grain producing areas have deep and geologically young soils that can withstand considerable degradation without showing adverse effect on yield.

A striking feature of global agriculture is its focus on relatively few species. Only about 120 crops are economically important while more than 90 per cent of the caloric intake of world's human population comes from just 30 crops. This somewhat narrow base notwithstanding, there has traditionally been immense genetic diversity within these crop species, and this diversity, conserved and enhanced by farm families over the past ten centuries, has historically helped to maintain the productivity of agro-ecosystems and it is still a valuable reservoir of genetic material for modern plant breeding and also for the candidate genes manipulated through biotechnology and genetic engineering tools.

Crop genetic diversity is however, on decline today. Modern high yielding varieties are taking on more uniform characteristics, and these varieties are planted over large areas in monocultures. This tendency is not limited to high-income countries where the commercialization of agriculture is most prevalent. Modern superior crop varieties are displacing traditional varieties throughout the world, threatening the loss of an enormous genetic resource and increasing the vulnerability of large areas of homogeneous crops to incidence of virulent pests and disease epidemics. Across all developing countries, modern varieties were reportedly grown on 74 per cent of rice area in 1991, 74 per cent of wheat in 1994 and 60 per cent of maize in 1992 replacing the locally adapted cultivars.

Special Features of Agro-ecosystems in Developing Countries

- The earliest agro-ecosystems began developing around

ten centuries ago in some areas that now happen to be in the developing world.

- The eight distinct Centres of Origin of Cultivated Plants, outlined by Vavilov and his team in 1920s, also occur in the developing countries. Putative progenitors and their closely related wild forms continue growing and evolving there constituting the valuable reservoir of genes for resistance to pathogens and pests and also for adaptation to abiotic stress environments.

Box 2. On-farm Conservation of Agro-biodiversity

Genetic diversity in cultivated plants is important to farmers for reducing the risk of widespread incidence of diseases and pests damaging their crops. It is equally important to plant breeders and bio-technologists, whether working in public sector organizations or in biotech corporations, as it serves as the reservoir of genes for obtaining the target genes controlling the desired traits. It is also important to conserve this genetic diversity for use of future generations enabling them to meet their needs and also to face the unforeseen changes in climate and soil degradation or the sudden appearance of insect virulent forms of pathogens and insect pests in coming years.

There are about half a million seed samples of different crops kept under long-term storage in gene banks of Future Harvest International Research Centres and placed under auspices and supervision of the FAO. More than twice this number is also stored in *ex situ* collections stored in national gene banks. While this kind of germplasm collection and storage in gene banks promotes their evaluation and utilization by breeders and other researchers, it also cuts off further evolutionary development of these materials. Notwithstanding the risks involved in storage, this approach of conservation requires frequent testing of these samples to check their viability and also their seed multiplication for replacement when the viability falls below a prescribed level. A less-expensive and nature-friendly method is being practiced by farmers over the past nearly ten thousand years to achieve the twin objectives of on-farm conservation and furthering the co-evolution of resistant genes in crop varieties. *In situ* on-farm conservation of agro-biodiversity is also the best way to maintain and promote traditional knowledge of the farming systems in which the farmers' varieties have evolved.

Source: Swaminathan, 1998

- Genepool of plants picked up by early humans for their food security increased remarkably as the agriculture spread and farm families continued to conserve, enhance through continuous selections, share and exchange seed and propagation materials. This is reflected in the recognition of areas of crop diversity around the world, mostly in the developing countries. Their heritage of agricultural biodiversity and associated knowledge continued to evolve in the public domain for common good. The focus remained on food security and healthcare. Trade concerns developed much later. Ancient wisdom documented in old scripts, preserved in India among other centres of learning, considered agriculture occupation as the most respected by the society while trading came next to it. A glaring association between agro-biodiversity-richness and economic poverty is, however, visible at present around the globe reflecting the advantage of research and technology in adding value to crop genetic diversity.
- Agricultural research continues to be primarily in the public sector in the developing countries even at present and Farmers' Rights are widely respected with priority accorded to recognize them legally. This is in marked contrast to the paradigm shift to proprietary research linked to claims for intellectual property rights, often devoid of bio-ethics and bio-safety considerations, as observed in some highly industrialized countries and also reflected in provisions of WTO-TRIPS agreement (UNEP 2000; WWF 2000).
- Agriculture and related activities continue to remain the predominant sector for employment to growing populations in developing countries and the health and capacity of agro-ecosystems are of prime concern to them. Agriculture is contributing a large share to GDP of these countries but growth and investments in this sector are not rising as required to achieve sustainability. Operational holdings are small and getting smaller in most of these countries while land tenure is insecure and the reforms are overdue. Poor development of direct linkage to markets and on-location value-addition through post-harvest processing are linkage factors to economic progress of farm families comprising the rural and tribal population.
- Farm families in developing countries have been practicing on-farm *in-situ* conservation and enhancement of agricultural biodiversity through successive generations (Box 2). Their past and present contributions need legal recognition in the form of Farmers' Rights and also positive incentives

Box 3: Farmers' Rights

Farmers' Rights were recognized by the FAO Council in its resolution 5/89, balancing thereby the Breeders' Rights approved vide resolution 4/89, as "rights arising from the past, present and future contribution of farmers in conserving, improving and making available plant genetic sources, particularly in the centers of origin/ diversity". Through an Annex of the International Understanding on Plant Genetic Resources (IU), parties agreed that Farmers' Rights would be recognized through an international fund.

How Farmers' Rights will be operationalized is of critical importance to the continuing on-farm (*in situ*) conservation of crop genetic resources. These rights have not been precisely defined but two perceptions have emerged, namely, interpreting them as a legal concept or considering them as a general political concept. The former envisages them an alternative form of intellectual property rights covering, for example, the products of farmers' selections and breeding effort while the latter considers them in the form of various entitlements expecting an international fund to finance crop genetic resources' concerns and relevant developmental work.

Unfortunately, the proposed international fund under the FAO has not yet been established. In the meantime, legal protection of Breeders' Rights is being pressed as an obligation under Article 27 (3b) of the TRIPS Agreement of the World Trade Organization. The 1978 version of the International Convention for the Protection of New Varieties of Plants (UPOV) allows a farmer to re-sow the seed harvested from protected varieties for his own use (farmers consider this as their "right" while some term it as a "privilege"). The 1991 version is more specific as it states that the discretion rests with national governments in deciding whether or not to uphold the Farmers Rights while restricting the Breeders' Rights. It is also obvious that farmers' varieties would need to be sufficiently distinguishable and describable in order to be eligible for protection under the new Protection of Plant Varieties and Farmers' Rights; varieties that satisfy a stricter criterion qualifying for stronger and/or longer protection.

Source: Dutfield, 2000; Swaminathan 1996

at the local, national and global levels. Providing opportunities to rural farm families for increasing their income through generating off-farm jobs for them needs priority attention (Box 3).

- Global food security and also the farmers' aspirations look towards synergistic linkage between public and private sectors with the strong support of international institutions and funding agencies to reap benefits from traditional good practices combined with advances in biotechnological research. This development is also expected to contribute significantly to efforts aimed at maintaining and promoting the health and capacity of agro-ecosystems (Box 4).

Box 4. Farmers' Livelihood Security

Multilateral agreement under the World Trade Organisation (WTO) contains a series of interlocking agreements whose provisions set out the rules governing the international trade. Its non-discrimination rules forbid the member states to treat the foreign products less favourably than domestic 'like products' or from treating the products imported from one member state less favourably than like products from another member. Its Article XI prohibits quantitative restrictions (QRs), like quotas or bans, on imports or exports with certain specified exemptions.

India joined the WTO on 1st January 1995 accepting obligatory structural adjustments. Six separate complaints, including one of the United States, were lodged against India with the WTO Dispute Settlement Body in 1997 alleging continued application of QRs on imports. With its heavy dependence on agriculture and small industries that sustained mass employment and contributed significantly to national Gross Domestic Product (GDP), India was among the nations that were resorting to protection through QRs. Following negotiations, an agreed schedule for removing all the QRs by 1' April 2001 was formally notified by India to the WTO. This commitment was met by India by removing QRs on the remaining 715 commodities on that date. Removal of QRs raised the public concerns apprehending that the WTO regime was skewed in its application against the interests of the developing countries.

Indian economy is essentially agriculture-based and this sector directly engages about 64 per cent of the labour force. It also contributes nearly 26 per cent of GDP and about 18 per cent of the total value of the country's exports. Its role is particularly important since it is source of livelihood to over 700 million people with total dependence of farm families (land also the landless labour) managing 1,066 million operational farm holdings.

Removal of QRs and consequent likely spurt in import of food items may pose a serious threat to the livelihood of farm families and associated farm labour. It is being pleaded that protection of livelihood of farmers in agro-based developing economies needs to be treated as the basic human right and this right should be specifically protected under the WTO rules in recognition of the unique contributions of farmers towards developing & enhancing and on-farm conserving the agricultural biodiversity. One way of doing this may be to introduce a "Livelihood Security" Box in the provisions of the WTO giving an option to developing countries like India, China and others to deny import of food items to provide livelihood security to farmers.

Source: Swaminathan, 1995

Issues and Policy Implications

Production of Goods and Services by Agro-ecosystems

Agricultural ecosystems not only produce food and meet other basic requirements of human and livestock populations but they also serve as the backbone of national economies of most of the developing countries and also function as major driving force propelling global market systems creating demands and purchasing power. Around 45 per cent of the world's human population and nearly 46 per cent of the global labour force are directly linked to agriculture. Keen interest and increasing concerns about agro-ecosystems notwithstanding, national policy makers find it increasingly difficult to identify the issues involved and to fully appreciate their policy implications. This section attempts to capture WRR's major findings and identify the issues and their policy implications from the developing country perspective.

Major Findings	Issues	Policy Implications
Food Production		
Food production is likely to continue rising for some more time but it already faces constraints and severe regional imbalances.	• Sustainability of the use of natural resources	Developing National Policy on sustainable use of natural resources.
	– Assessment of sustainability	Developing suitable indicators in national/local context and promoting their use
	• Increasing soil degradation	Developing National Land Use Policy.
	– Soil erosion	Promoting soil conservation measures.
	– Water logging	Linking irrigation with adequate drainage.
	– Soil salinity/alkanlinity	Improving water management and adopting reclamation measures based on salt tolerant crops and trees, soil amendments and leaching where feasible.
	• Decreasing water availability and quality	
	– Increasing sectoral competition for water use	Developing National Water Policy with long-term perspective and preparing medium and long-term action plans.
	– *Receding groundwater level* in many areas	*Encouraging* appropriate cropping schemes and crop rotations.
	– Excessive use of chemical fertilizers and pesticides	Promoting soil-test based application of fertilizers and integrated pest and nutrient management.
	• Shrinking agrobiodiversity	Reducing dependence on one or a few crops/varieties/crop rotations and promote market-linked diversification of farming systems.
	• Changing climate and atmospheric carbon	Improving data collection, analysis and modeling techniques.
		Making advance preparations by increasing resilience in agro-ecosystems and developing suitable options.
Projected Food Demands:		
Global population is projected to rise to 7.5 billion by 2020. Demand for cereals and meat is is expected to grow by 40 per cent and 58 per cent respectively with 85 per cent increase from the developing countries. Likewise, the demand for roots and tubers is expected to grow by 37 per cent	• Improving productivity	Increasing budgetary support to Natural Resource Management.
	• Intensification of production system	Increasing focus on research and providing more funds.
		Developing further 'Green Revolution', that has been achieved by many developing countries in several cereal crops, into a sustainable 'Ever Green Revolution' by adopting the emerging new innovative technologies and

Major Findings	Issues	Policy Implications
with 97 per cent of this increase coming from the developing world.		covering more crops. Negotiating transfer of new technologies from the developed countries and corporate sector. Developing post-harvest technology, storage facilities, processing and market linkages. Promoting diversified farming systems with economically feasible and socially acceptable incentives.
Intensification While the global expansion of area under agriculture has been modest during the past three decades, intensification has grown rapidly.	• Sustainability of the agricultural production systems • Sustainable use of natural renewable base resources • Containing adverse impact on other ecosystems	Developing National Agricultural Policy with long term perspective and action plans. Promote integrated nutrient and pest management. Encouraging appropriate cropping systems and diversified crop rotations. Improving use-efficiency of inputs. Focus on better water management practices and conjunctive use of water resources. Supporting green manuring and other practices for increasing organic carbon content of soils. Promoting application of high technological innovations to boost productivity and stabilize production. Ensuring availability and affordable costs of non-renewable purchased inputs. Developing intensification technologies for the benefit of resource-poor farmers with small operational holdings. Providing insurance cover to protect small farmers against high risks involved in high-inputs technology. Supporting diversified farming systems. Developing Village Knowledge & Service Centres based on single-window delivery.
Irrigated Agriculture: Out of the global cropped area under irrigation, 41 per cent lies in China and India, 12.5 per cent in Western Europe and USA, but only 3 per cent in arid and semi- arid regions of Sub-Saharan Africa and Australia.	• Improved water management • Higher water-use efficiency • Better soil healthcare • More productivity • Minimising adverse impacts	Providing more investment in research on irrigated agriculture with a focus on developing new innovative technologies. Reducing water conveyance losses. Promoting conjunctive use of all water resources. Supporting better cropping systems and diversified farming. Ensuring that irrigation must be accompanied by adequate drainage system. Providing soil testing facilities and soil health care service. Developing indicators for monitoring of adverse impacts and be prepared with land reclamation technologies where needed. Encouraging farmers to manage their irrigation water resources themselves by forming Village Water Cooperatives and Self- Help Groups.
National Gross Domestic Product: Agriculture's contribution to national GDPs is more than 50 per cent in many parts of Sub-	• Agriculture-based economic development in low- and middle-income developing countries	Developing National Agriculture Policy and lobbying for higher investment in agriculture.

Major Findings	Issues	Policy Implications
Saharan Africa, one-third in other low income countries, 12 to 25 per cent in middle income countries but just 1 to 3 per cent in high-income countries of North America and Western Europe.		According status of industry to agriculture. Providing more budgetary funds for research and extension in public sector plans. Developing promotional schemes for agro-products and provide incentives to entrepreneurs. Promoting public and private sector collaboration for greater investment in agriculture. Promoting agro-based cottage processing and manufacturing industries in rural areas. Developing quality control of agricultural produce and products. Expanding internal and export markets for agricultural produce and products. Negotiating with developed countries to get greater market access for agriculture under WTO.
Dependence of People: The developing countries have nearly 65 per cent of the global area under agro-ecosystems, and Asia alone has over 70 per cent of the people living in or around these ecosystems. Agriculture engages 46 per cent of the Global labour force. While this per centage is 56 to 65 in East, South and Southeast Asia and also in Sub-Saharan Africa, it is just near 2 per cent in North America. Area under agriculture remained almost unchanged in South Asia during the last 30 years but increased substantially in West Asia and Brazil while it decreased remarkably in developed countries.	• Vital role of agriculture in national income generation and human welfare • Agriculture-based planning and model for economic development • Increasing population pressure and decreasing per capita agricultural area • Increasing demand for food and other agricultural produce • Food and Nutrition Security • Livelihood Security • Focus on basic needs for farm families and other farm workers • Use and protection of indigenous knowledge • Documentation of case studies on good practices	Developing national strategy for agricultural development and preparing perspective long-term and medium-term action plans with provision of adequate funds for proper implementation. Increasing investment in research to increase productivity per unit area and per unit time. Negotiating to obtain new technologies and make their best use to enhance productivity and stabilize production gains. Involving local people in technology assessment employing participatory rapid appraisal techniques. Generating more employment in rural areas and provide opportunities to farm families to earn additional income to meet their basic needs. Providing scientific back up to indigenous knowledge of farm communities and making use of the prevailing good practices. Promoting processing of agricultural produce and agro-based manufacturing cottage industries in rural areas to add value to the produce and providing more off-farm employment and livelihood security to farm families. Strengthening Food-for-Work rural development programmes to facilitate access of poor people to food and nutrition. Giving legal recognition to Farmers' Rights and operationalise them as human rights to support on-farm *in-situ* conservation of agricultural biodiversity.

Pressures/Threats faced by Agro-ecosystems and Policy Responses

Both the condition and capacity of an ecosystem are strongly influenced by its location and its dominant physical characteristics. Since agro-ecosystems arose through conversion by humans to serve their needs, they share some basic features with their original natural ecosystems from which they arose. They are also highly diverse in terms of soils, topography, climate, rainfall, crops and livestock and also in culture of the people living in them and their income levels from agriculture/ livestock. It is, hence, more appropriate to identity pressures/ threats and assess policy responses based on different categories of these ecosystems.

Category of Agro ecosystems	Pressures/Threats	Policy Responses
Rainfed Agro-ecosystems	• Instability in biological productivity caused essentially by the aberrant weather	Focussing on watershed management system considering that water is the foremost critical factor in rainfed farming and rain is the only source of water, directly and through recharging of the groundwater.
	• Wide range in rainfed production systems and uncertain water availability	Strengthening traditional soil and water conservation practices and fine-tuning them with scientific backup since case studies have shown that water availability is not a serious constraint if rainwater is managed properly.
	• Increasing human and livestock pressure	
	• Continued decline in soil organic matter due to poor bio-mass production and inadequate integration of crop and livestock farming	Promoting research through developing inter-disciplinary and multi-institutional consortia based on appropriate linkages and people's participation.
		Adopting area-based planning with a focus on the irrigated production system as a whole rather than on individual crops or livestock to boost economy.
	• Decline in agro-biological diversity	Developing and using suitable indicators for technology assessment, promoting participatory rapid appraisal techniques and involving local people to draw upon indigenous traditional knowledge.
		Promoting integrated nutrient and pest management programmes and also providing proper healthcare for the livestock.
		Encouraging ecologically sound cropping patterns and diversified farming systems.
		Where the annual rainfall exceeds 1150 mm, giving attention to paddy and plantation crops. Promoting inter cropping and also aqua-culture under 750-1150 mm rainfall conditions and employing tubewell protective irrigation while ensuring the recharging process of groundwater.
		Increasing emphasis on oilseeds and legume-based cropping systems and arid horticulture (with drip irrigation) under 500-750 mm rainfall conditions.
		Supporting arable farming linked to Animal husbandry and range land management where average annual rainfall is below 500 mm.

Category of Agro ecosystems	Pressures/Threats	Policy Responses
		Providing strong support and incentives to promote on-farm *in situ* conservation of agrobiodiversity with proper backup *ex situ* conservation in gene banks.
		Giving priority to poverty alleviation programmes and Food-for-Work projects.
Arid Agro-ecosystems	• Growing human and livestock population pressures	Providing greater support to research and technology development.
	• Chronic water shortages and weather aberrations	Promoting 'Composite Mapping' by using database on the status of renewable natural resources, land use and soil degradation status.
	• High vulnerability of soils to wind erosion, weather aberrations, salinity and sodicity in soils and groundwater, low water retention capacity of soils, high infiltration rate, poor structure and crusting of soils with low organic matter content and available phosphorus, low nutrient buffering capacity of soils particularly the micro-nutrients.	Improving and promoting traditional water harvesting and under-ground storage methods under less than 200 mm rainfall conditions.
		Improving technology for dry land cropping including proper moisture conservation, suitable planting methods, mixed and strip cropping and use of drought and salt tolerant crops and varieties.
	• Intensive irrigated cropping in Canal command areas with Inadequate drainage	Upgrading silvi-pastoral system, agro-forestry and range-land management to meet the growing animal grazing needs.
	• Irrigation with saline/brackish waters	Promoting arid horticulture, where feasible, based on sprinkler and drip irrigation systems.
	• Use of heavy machinery for farm operations, particularly on marginal lands	Encouraging integrated nutrient management in dryland farming under canal irrigation or brackish water situations.
	• Growing desertification processes	Providing support to reclamation of degraded lands by using soil amendments combined with land shaping, rainwater harvesting, soil profile modification, more suitable planting techniques and salt tolerant crops and their varieties.
		Strongly supporting the programmes on sand stabilisation using suitable plant species, erecting wind breaks, developing shelter belts and involving local people.
		Promoting participatory crop improvement and technology assessment programmes involving local people in decision-making.
		Monitoring the spread of desertification using satellite imageries and GIS techniques and adopting preventive strategy and action-plan.
		Adopting poverty alleviation projects developing more skills, generating additional income to farm families and promoting Food for Work programmes.
Irrigated Agro-ecosystems	• Long-term sustainability of agricultural production systems	Supporting research on cropping and farming systems best suited to diverse soil, water and climatic situations of irrigated ecosystems.

Category of Agro ecosystems	Pressures/Threats	Policy Responses
	• Depletion in soil fertility and decline in productivity	For the areas having limited water availability, focusing on crop diversification and on development of management practices for diversified farming systems.
	• Decreasing biodiversity and increasing genetic uniformity in crops	Promoting diversification of farming systems, crops and their varieties to avoid increase in genetic vulnerability to widespread epidemics of diseases and pests.
	• Soil salinity/alkalinity and water-logging	Supporting studies on different kinds of physical and chemical degradation of soils due to intensified agriculture coupled with indiscriminate use of irrigation water and non-judicious fertilizer application in irrigated areas.
	• Poor water and nutrient management practices	Providing adequate drainage in irrigated areas. Where natural drainage is impeded, promoting more efficient pressurized water management techniques like sprinklers and drip irrigation.
	• Excessive use of chemical inputs	
	• Over-exploitation of groundwater leading to rapid lowering of water table	Adopting land reclamation measures including the use of soil amendments, leaching and salt-tolerant crops and varieties.
	• Use of poor quality waters for irrigation	Increasing the water use efficiency and promoting conjunctive use of rainfall, surface water and groundwater to maintain hydrological balance and avoid overexploitation of groundwater.
		Promoting integrated nutrient and pest management schemes, application of fertilizers based on proper soil testing results and scheduling of irrigation based on water requirements of different crops.
		Discouraging cultivation of high water requiring crops like sugarcane and paddy in areas using brackish water for irrigation.
		Promoting the best suited cropping schemes and crop rotations to prevent heavy withdrawal of nutrients due to exhausting cropping schemes and inadequate replenishment of nutrients, particularly micro nutrients.
Hilly and Mountainous Agro-ecosystems	• Natural instability and ecological fragility	More investment in research and appropriate technology development with a focus on proper watershed management.
	• Increasing population and tourists pressure	Developing location/area-specific technologies and adopting soil and water conservation techniques like contour bunding and bench terracing combined with improved agronomic practices.
	• Inaccessibility, poor infrastructure and undeveloped market links	Promoting diversified and integrated farming systems incorporating food crops, vegetables, horticulture, commercial crops, floriculture, plantation crops, agro-forestry, livestock, farming and silvi-pastoral system.
	• Cultivation on sloping land with high risk of soil erosion and water loss	Promoting cultivation of high value and low volume crops like fruits, medicinal plants, spices, ornamentals and plantation crops.
	• Unplanned shifting cultivation practices	Supporting minor irrigation and water saving techniques like sprinklers and drip system.

Category of Agro ecosystems	Pressures/Threats	Policy Responses
	• Decreasing diversity in farming systems	Developing post-harvest technology including processing and product-manufacturing units with adequate storage facilities for perishable produce like milk, cut-flowers and vegetables.
	• Land use conversion	Supporting development of suitable agricultural implements and machinery, like small-sized power tillers, with particular attention to the small operational holdings.
	• Inadequate forest management systems	Providing simplified credit support and crop insurance cover for stepping up the use of inputs and adoption of modern technology.
		Encouraging replacement of the "shifting cultivation' practice by promoting integrated horti-agricultural systems and providing additional income opportunities.
Coastal Agro-ecosystems associated	• Ecological fragility • Land use conversion	Developing and adopting eco-friendly technologies. Providing protection to mangroove vegetation and biodiversity.
		Regulating land use in coastal zones.
	• Poverty and illiteracy	Promoting off-farm additional income generation schemes for resource-poor farm families ensuring gender sensitivity.
	• Negative impact of anthropogenic pressure	Focusing on improving literacy, healthcare and developing additional skills.
	• Climate change	Promoting livestock and aquaculture-based diversified agricultural systems.
	• Uncertainty to the lives and properties, particularly those in lowlands, due to high tidal floods and cyclones	Developing Village Knowledge Centres Network, with the help of Self-Help Groups, linked to weather forecasting and early warning systems.
		Aiding the construction of protective embankments with wind-breaks and shelter belts.
	• Rapidly increasing municipal wastes, industrial effluents and domestic residues	Improving drainage not only assist flood control but also to meet agricultural requirements through internal field drainage.
		Supporting on-farm reservoir for rainwater storage.
		Promoting integrated agri-horticultural systems including vegetables, plantation crops and aquaculture while managing salinity and growing salt-resistant varieties.

Sustainable Agriculture with Sustainable Development: The Way Forward

Intensive irrigated agriculture, with high chemical input use and unsustainable crop rotations, has thrown up problems in some areas in the form of soil degradation, water logging, salinity, disturbed hydrological cycle, pollution, nutrient imbalances, biodiversity loss and high vulnerability to new diseases and pests. Agriculture has received more attention in recent years not only for its contributions to global food and nutrition security and providing sustenance and employment to nearly half of the human population but also for its important role in international trade and because of its adverse impact on environment (Pillai, 1999).

Several organizations have commissioned comprehensive studies on assessment of the status and sustainability of ecosystems, including agro-ecosystems, on a global scale. Their approach and methodologies differ but their results show alarming deterioration. The World Resources report, using findings of a Pilot Analysis of Global Ecosystems, presented a scenario showing clearly declining trends in five major ecosystems

but also pointed to striking regional differences. A more comprehensive Millennium Ecosystem Assessment by UNEP is underway (WRI, 2000).

Another kind of attempt is being made by WWF in collaboration with United Nations Environment Programme (UNEP) and World Conservation Monitoring Centre (WCMC) by bringing out Living Planet Reports measuring the world's natural wealth in forests, freshwaters and coastal and marine areas based on changes in populations of selected indicator species for computing Living Planet Index (WWF, 2000). This report for 2000 has an additional feature in the form of the "Ecological Footprint" that measures a population's consumption of food, other materials and energy in terms of the area of the biologically active land or sea required to produce those resources and to absorb the corresponding waste. Interestingly, it shows among other things that the "Cropland Footprint" (a measure of the area required for an individual to produce all the quantities of crops which that individual consumes) of a person living in North America or Western Europe is more than twice of that of an individual residing in Latin America, Asia/Pacific or Africa from where most of the world's hungry and undernourished people have been reported (UNEP, 2000).

Leaders from 185 countries pledged during the World Food summit, held in Rome in 1996, to work towards eradicating hunger (FAO, 1996). Follow up meeting, World Food Summit: Five Years Later, was held in Rome in November 2001 to review the progress made towards the goal of reducing the number of hungry people by half by 2015 and consider ways to accelerate the process. Unfortunately, current data indicate that the number of under-nourished is falling at a rate of 8 million each year, far below the average rate of 20 millions per year required to reach the target. Although a headway has been made yet much remains to be done. The message is clear that ways and means need to be found for raising the productivity of agro-ecosystems substantially and faster, in an ecologically sustainable manner, and economic access to food of the hungry people will have to be increased. This calls for developing strategies and action plans for promoting sustainable agriculture with sustainable development in developing countries with agriculture-based economies.

Win-Win Options

Lack of adequate and sustained funding has slowed down agricultural development in many developing countries whose national economies largely depend upon agricultural production. Financial institutions tend to invest in areas with assured environment (like irrigated agriculture) expecting that it will generate more agricultural output and higher economic growth at lower cost than in areas under stress and uncertain environments (like rainfed and arid agriculture). Such investment is also seen to help in poverty alleviation since a faster economic growth may provide more employment opportunities with higher wages while more agricultural production may lower food prices, both the outcomes being beneficial to the poor. People living in areas under stress environments should also benefit from these developments that seem to assist in availability of cheaper food, offering increased market opportunities for growth, and also opening new options to underemployed agricultural workers to migrate to more remunerative jobs in intensive agricultural areas. Arguably, this migration may also decrease environmental degradation because of reduced population pressure in stressed areas that are likely to benefit additionally from the migrants sending remittances back home.

This model for economic development has received a setback from recent experiences in India (and also China) showing that the right kind of investments in semi-arid rainfed areas can increase agricultural productivity in diversified farming systems to much higher levels than previously expected and may compare well in gains from comparable investments in irrigated areas that have reached the point of diminishing returns. There are numerous such situations under the wide spectrum of rainfed agro-ecosystems that offer 'win-win-win' options, that is, higher growth ensuring economic security, greater poverty alleviation and lower environmental degradation meaning higher aggregate social returns. When resource-poor farmers in developing countries are being motivated to go for new technologies and adopt high-cost (purchased inputs) and high-risk crop production packages, it is time for the international financial institutions to reconsider their priorities and eligibilities for investments in agricultural development, particularly with the objective of poverty alleviation and supporting ecosystems and integrated management systems of natural resources (Swaminathan, 1998).

It is now widely recognized that countries and regions that are currently exporting food and other agricultural produce need to assess sustainability of their production levels and identified "Hotspot Areas" that require priority attention. Suitable criteria/indicators for the desired

assessment need to be developed to begin with and the analysis must lead to the development of a budgeted action plan along with supportive recommendations on policy, administrative and other regulatory measures. It is not intended to suggest a universal model or some ready-made solutions for adoption. Developing suitable options and sharing the lessons learned from such process may be more helpful. A study conducted recently on food insecurity in rural India, for example, inferred that every state had its own strengths and weaknesses in relation to achieving the goal of sustainable food security and, hence, required different action plans for this purpose (WFP and MSSRF, 2001).

Policy Recommendations

While recognizing the limitations in making general policy recommendations regarding agro-ecosystems due primarily to their highly diverse nature, some strategies are being suggested with a view to providing some options for the policy makers and managers working in agriculture-based developing economies. It is obvious that the priorities and follow up action plans will depend upon national policies and planning processes that respond to specific development (and also environment) needs and people's aspirations.

Strategy 1- Promoting High Productivity and Sustainability of Production Systems

- Defending the location-specific gains already achieved under different categories of agro-ecosystems by paying more attention to conservation and enhancement of soil and water resources, forests, biodiversity and other basic life-support systems.
- Extending the gains made under irrigated agriculture to rainfed, semi-arid, hilly and coastal areas by adopting new yield enhancement and stabilization technologies and opting for low water requiring but high value crops.
- Making new gains through farming systems' intensification, diversification and value addition by making full use of the results obtained from molecular biology and innovative bio-technologies by forging new partnership with industry.
- Providing users-driven institutional support and centralized services to small and marginal farm families for adopting eco-farming based on integrated pest management, efficient water management, integrated nutrient supply, post-harvest technology and marketing access.
- Strengthening research on farming systems and diversified cropping schemes (Crops, horticulture, livestock, aquaculture and agro-forestry).
- Bridging the gap between the actual and potential yield levels (already achieved on research farms and demonstration plots) under major farming systems.
- Promoting the use of safer chemicals, in particular the pesticides, by regulating the production, import, export, disposal and use of Persistent Organic Pollutants, as recommended by The Stockholm Convention on POPs signed by 91 countries on 22-23 May 2001).

Strategy 2 - Assigning Top Priority to Land Care and Management Systems

- Conserving prime farmland for agriculture by protecting them from conversion to other uses, often for short-term gains.
- Preventing the loss of the biological potential of the soil (desertification) by taking effective measures to check different kinds of soil erosion.
- Restoring the degraded land by providing incentives, based on agroforestry and other arable practices.
- Implementing land reforms to overcome land-tenure insecurity.

Strategy 3 - Treating Water as a Social/Public Resource

- Developing strong public policy for regulation of water use (The model adopted by Israel may serve as a model for promoting irrigation with mixed sewage waters).
- Improving traditional rainwater harvest and underground storage methods.
- Promoting ecologically sound cropping patterns based on eco-zoning of crops.
- Supporting sprinkler and drip irrigation to improve water use efficiency.
- Adopting conjunctive use of surface and ground waters for irrigation (ensuring thereby more crop for every drop).
- Providing incentives for recycling of rainwater and home-used (waste) waters by developing and enforcing building bylaws for compulsory provision for this purpose.

Strategy 5- Strengthening Conservation of Living Aquatic Resources

- Regulating the land use in coastal areas by enforcing suitable policy, administrative & legislative measures.

- Promoting aquaculture-based diversified farming systems.
- Providing off-farm additional income opportunities to farm families with attention to gender sensitivity.

Strategy 6 - Supporting On-Farm Conservation of Agro-biodiversity

- Providing effective incentives to farming communities to support the *in situ* on-farm conservation of agro-biodiversity.
- Providing legal recognition to Farmers' Rights including their livelihoods security under WTO's Agreements on Agriculture and TRIPs (See Box 3 & 4).

Strategy 7 - Developing the Protocol on Agro-Biodiversity under CBD

- Negotiating the Multi-lateral System of Exchange of Food Security Crops under the International Treaty on Plant Genetic Resources for Food and Agriculture.
- Enacting legislation (to be done by both the developed and the developing countries) supportive of access to genetic resources linked to equitable benefit-sharing and bring the private sector and industry under its purview.

Strategy 8 - Supporting Anticipatory Research to Face Consequences of Climate Change

- Assisting on-farm *in situ* conservation of agro-biodiversity and long-term preservation of ex situ collections kept in Gene Banks for possible tapping of this reservoir of genes for enhancing plant adaptation to future climatic changes.
- Funding systematic world-wide research on avoidance and mitigation measures to face consequences of projected climatic changes.
- Expediting the pace of implementation of the Kyoto and Montreal Protocols through inter-governmental negotiations.

To sum up, the policies for management and use of land, water and biological resources are required to be based on ecological considerations, meteorological data and marketability criteria (McNealy and Scherr, 2001). Basic principles underlying these policies should be based on ethics and equity in the use of natural resources. Future research efforts should aim at developing eco-technologies that blend traditional and frontier technologies. Participatory multi-stakeholder management of natural resources should provide a "win-win" situation for all while offering all-inclusive (not exclusive) use and equitable sharing of benefits. Under protection of intellectual property, there should be a provision for compulsory licensing of rights (with justified reasoning) in case of discoveries that are of importance to human food, health security and ecological security (for example, discoveries that may help in combating the alien invasive species). The developing countries, whose national economies are primarily based on agriculture, are vigorously lobbying for a level playing field for negotiations under the WTO's Agreement on Agriculture while asking for the protection of food security and also addressing the farmers' livelihood concerns (Dutfield, 2000; Crucible Group II, 2000).

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