Beyond the Gene Horizon

Sustaining agricultural productivity and enhancing livelihoods through optimization of crop and crop-associated biodiversity with emphasis on semi-arid tropical agroecosystems

Summary proceedings of a workshop

23–25 September 2002

Patancheru, India

Citation: Waliyar, F., Collette, L, and Kenmore, P.E. 2002. Beyond the Gene Horizon: sustaining agricultural productivity and enhancing livelihoods through optimization of crop and crop-associated biodiversity with emphasis on semi-arid tropical agroecosystems. Summary proceedings of a workshop, 23-25 September 2002, Patancheru, India. Patancheru 502 324, Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), and viale delle Terme di Caracalla, Rome 00100, Italy: Food and Agriculture Organization of the United Nations (FAO). ISBN 92-9066-451-7. Order code CPE 143.

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Acknowledgements

The Organizing Committee acknowledge the assistance of I Radha, Senior Administrative Associate in the preparation and conduct of the workshop, and Sue Hainsworth for help in preparing these proceedings.

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Editors

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2002

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Introduction

Increasing international attention is being given to the role and productive value of biological diversity in agriculture. Recognizing the potential of agricultural biodiversity and the services it provides will be key to meeting future food needs while maintaining and enhancing the other goods and services provided by agricultural ecosystems such as clean air and clean water. The Food and Agriculture Organization of the United Nations (FAO) and the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) are joining forces to further the understanding of the contribution of crop and crop-associated biodiversity (C-CAB) in sustainable agriculture in the semi-arid tropics (SAT). In order to address some of the key components of C-CAB, FAO and ICRISAT organized a joint workshop in late September 2002.

The meeting was intended to generate animated exchanges between experts from different disciplines. Its outputs aim to provide a first step, not only in the further understanding of the role and value of main components of C-CAB for sustainable agriculture production intensification and livelihoods benefits, but also in identifying linkages and synergies between components of C-CAB in production systems for strategic interventions.

The specific **Objectives of the Meeting** were to:

- Share knowledge and further understanding of the value and contribution of the main components of C-CAB for sustainable production systems and agroecosystem health in the SAT
- Identify linkages and synergies between components of C-CAB in production systems
- Identify key limiting factors to better management of C-CAB to achieve sustainable agriculture and maintain agroecosystem health
- Present how different components of C-CAB and management practices can be combined to optimize agroecosystem and livelihoods benefits and support sustainable production
- Identify elements of frameworks for C-CAB with linkages between C-CAB components to facilitate strategic interventions
- Identify priorities for strategic intervention at policy, research, and farmer levels (in terms of assessment, adaptive management, capacity building, and mainstreaming).

The process designed for the workshop by the organizing committee was intended to be open, participatory, flexible, and conducive to the generation of contributions from experts from multiple disciplines.

Prior to the meeting, in addition to a draft background paper on possible elements for consideration in the development of frameworks for C-CAB, individual papers on components of C-CAB and on SAT environments were circulated to participants. Short summaries of these individual papers are included in these proceedings.

The workshop was attended by 40 delegates from 8 countries (Bangladesh, Brazil, Burkina Faso, The People's Republic of China, France, India, Indonesia, and Italy), representing a range of development agencies and national and international research institutions.

On the first day, following a welcome by ICRISAT's Director General, in which he stressed the importance of the topic and of working in partnership to achieve impacts, plenary presentations on the role and linkages of components of C-CAB and on SAT environments were made by participants. On the second day, participants were divided into two working groups representing the interests of Asia and Africa. Experiences were shared collectively and captured in a matrix that guided the discussions (see Appendix). The main aims were to identify cross linkages and synergies of the potential contributions of C-CAB to sustainable agricultural intensification, and to propose frameworks for strategic C-CAB interventions. The groups then also suggested research priorities that took into account six key criteria, i.e., *partnership, demand-driven, scale of analysis, participatory, communication,* and *conservation* (sustainable use/preservation). Results were presented in plenary, and the workshop ended by participants endorsing a final statement.

These summary proceedings present an overview of the context within which the workshop was held, a discussion on C-CAB, the major outcomes of the workshop, together with the final statement, and short summaries of the presented papers. The full supporting papers will be included in the proceedings that will be published in the near future.

Context

Increasing productivity and food security to satisfy human needs while protecting and enhancing environmental quality and conserving natural resources for future generations is a major challenge. As populations grow and demand for food mounts, achieving sustainable agriculture is critical to food security and poverty alleviation. For this sustainability to be real the use of agricultural biodiversity and particularly that of C-CAB must be optimized.

In their very first (1992) meeting the countries that adopted the Convention on Biological Diversity (CBD) defined 'ecosystem' as: 'a *dynamic complex of plant, animal and micro-organism communities and their non-living environment acting as a functional unit.* In the decade since then these countries have worked actively to promote and apply the 'Ecosystem Approach' so that the three objectives set out in the Convention are more balanced. While *conservation* of biodiversity still receives the lion's share of resources, the other two objectives, *sustainable use* of biodiversity and the fair and *equitable sharing of the benefits* arising out of the utilization of genetic resources, are now receiving more attention. The members of the CBD, meeting in Nairobi in 2000, formally adopted a decision elaborating and promoting the Ecosystem Approach and called on all CBD member governments to support this approach in their programs and policies.

The Ecosystem Approach is a strategy for the integrated management of land, water, and living resources that promotes conservation and especially sustainable use of resources, including agricultural biodiversity, in an equitable way. The approach is based on the application of appropriate scientific methodologies focused on levels of biological organization including (but going beyond) genes to encompass the essential processes, functions, and interactions among organisms and their environments, all of which include human beings. It recognizes that humans, with their cultural, political, and social diversity, are integral components of ecosystems. Crop and crop-associated biodiversity is an intrinsic and important part of agricultural ecosystems and includes such components as predators, herbivores (including pests, pathogens and weeds) together with soil biodiversity and pollinators.

The application of the Ecosystem Approach implies intersectoral cooperation, decentralization of management at the lowest appropriate level, equitable distribution of benefits, and the use of adaptive management practices that can deal with uncertainties by being modified in the light of experience and changing conditions. The implementation of the approach will also build upon the knowledge, innovations, and practices of local communities.

FAO is committed to assisting countries in the realization of their obligations under the CBD and collaborates closely with the CBD in the implementation of the thematic and sectoral programs of work adopted by the Conference of the Parties to the CBD. It is particularly involved in the Programme of Work on Agricultural Biodiversity that includes the International Initiatives on Pollinators and on Soil Biodiversity. This Programme makes provision for the further understanding of agricultural biodiversity in order to promote management practices, technologies, and policies that promote the positive, and reduce and mitigate the negative impacts of agriculture on biodiversity, while enhancing productivity and the capacity to sustain livelihoods.

The Programme of Work also recognizes the importance of such existing instruments as the Global Strategy for Farm Animal Genetic Resources and the International Treaty on Plant Genetic Resources for Food and Agriculture, as well as the Global Plan of Action for the Conservation and Sustainable Utilization of Plant Genetic Resources for Food and Agriculture. The latter promotes the conservation and sustainable use of genetic resources of actual and potential value for food and agriculture. One of its specific activities promotes sustainable agriculture through diversification of crop production and broader diversity in crops. Although targeted at crops, the requirement for diversification will, of necessity, impact on the biodiversity of agroecosystems including crop-associated biodiversity.

The goal of the recently adopted International Treaty on Plant Genetic Resources for Food and Agriculture is the achievement of sustainable agriculture and food security. The Treaty includes articles promoting an integrated approach to the conservation and sustainable use of plant genetic resources and the application of ecological principles.

The FAO-CBD Programme of Work on Agricultural Biodiversity highlights the lack of sufficient methods to assess and understand the larger role of biodiversity in agroecosystems, stressing that '.... *Understanding of the underlying causes of the loss of agricultural biodiversity is limited, as is understanding of the consequences of such loss for the functioning of agricultural ecosystems. Moreover, the assessments of the various components are conducted separately; there is no integrated assessment of agricultural biodiversity as a whole. There is also a lack of widely accepted indicators of agricultural biodiversity The further development and application of such indicators, as well as assessment methodologies, are necessary to allow an analysis of the status and trends of agricultural biodiversity and its various components and to facilitate the identification of biodiversity-friendly agricultural practices...'.*

In its first biennial review of the implementation of the Programme of Work on Agricultural Biodiversity in April 2002 CBD members emphasized further action on the wider understanding of the functions of biodiversity in agroecosystems, and the interactions between its various components, at different spatial scales.

What is 'crop and crop-associated biodiversity'?

Vandermeer and Perfecto first suggested two basic categories of agrobiodiversity in 1995 (Figure 1). *Planned biodiversity* includes the crops and livestock purposefully introduced and maintained in the agroecosytem by the farmer. *Unplanned, or associated biodiversity* includes all soil flora and fauna, herbivores, carnivores, decomposers, and any other species that exist in, or colonize the agroecosystem. What seems to be missing here is the C-CAB that is planned—for example, leguminous cover crops used solely to improve the soil and to attract and support beneficial fauna, or hedgerow perennial plants used as windbreaks.

Figure 1. Planned and associated biodiversity as described by Vandermeer and Perfecto (1995)

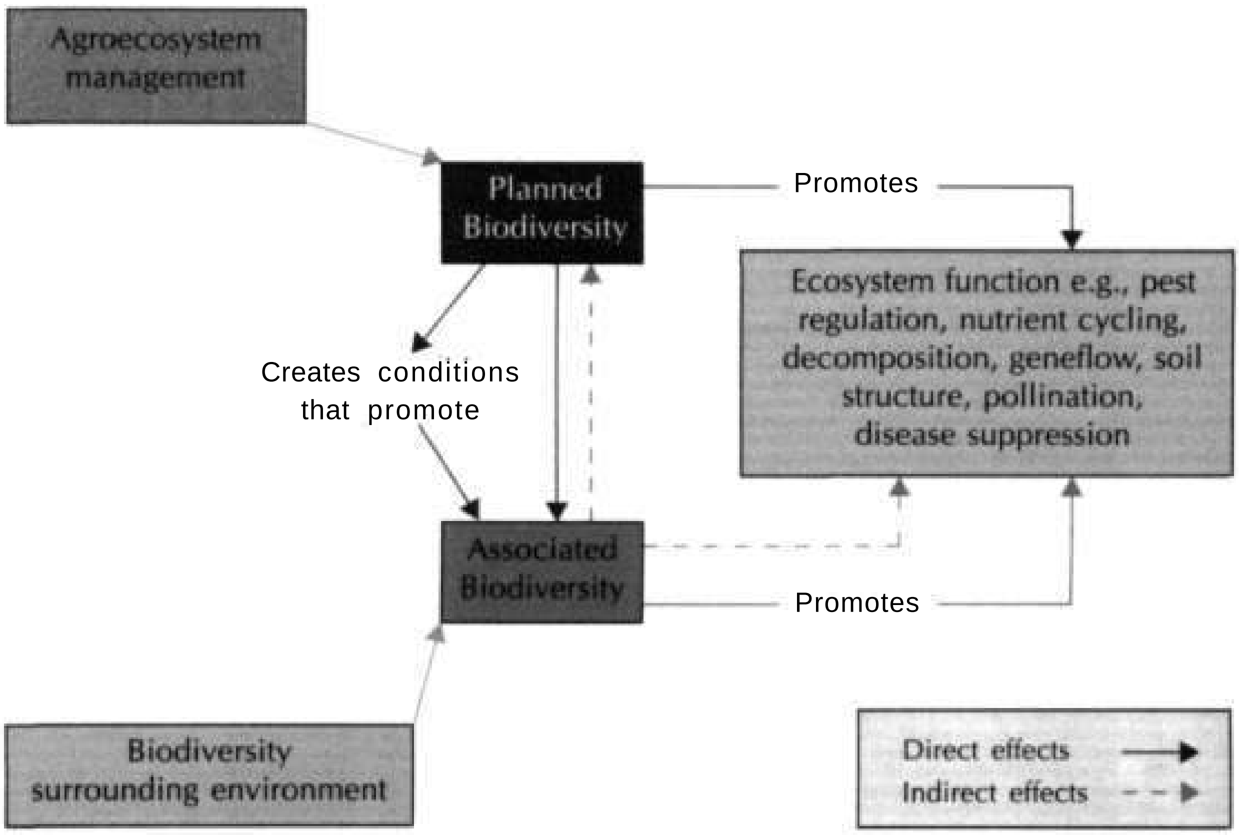
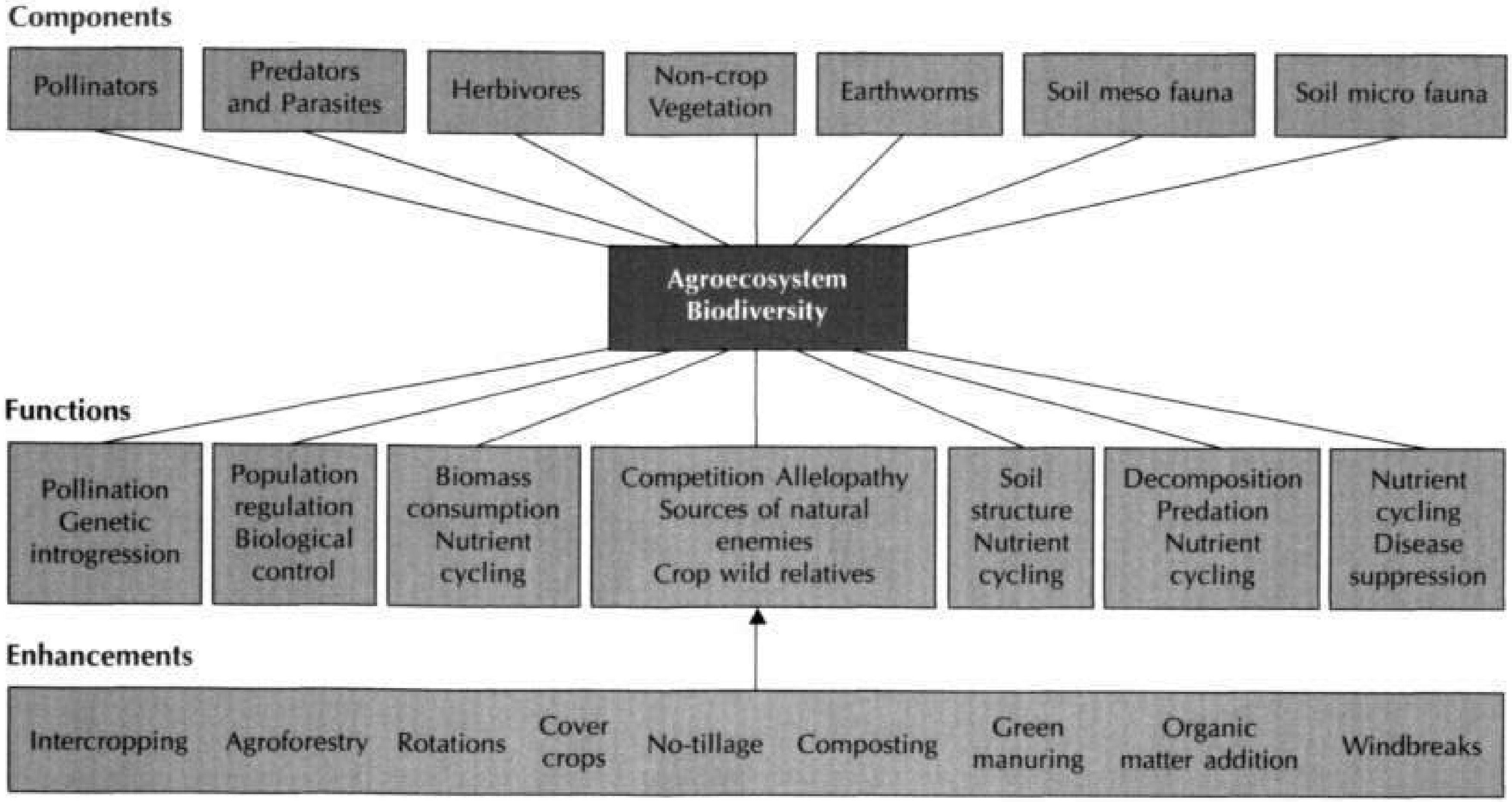


Figure 2. Overall relationship between CAB and management practices as described by Altieri[1]



1. *Biodiversity and Pest Management in Agroecosystems* New York: Haworth Press 1994

Earlier, Swift and Anderson had conceived C-CAB as divided into three types: *productive, beneficial,* and *destructive. Productive* biota includes crop plants and livestock, producing food, fiber, or other products for consumption. *Beneficial* biota contribute positively to the productivity of the system as pollinators, plants of fallows, soil biota controlling nutrient cycling, arthropod predators and parasitoids, and more. *Destructive* biota includes only weeds, pests, and pathogens.

Altierti suggested an even more elaborate, but quite useful organizational chart in 1994 to display the relationships between the components of the cropping ecosystem, their related ecosystem functions, and the 'enhancements', or agricultural practices that promote the improvement of the components (Figure 2).

Each perspective has something to offer. What is clear is that in contrast to the long history of formal research and historical knowledge related directly to crops, the understanding of the mechanisms and importance related to C-CAB is only now being thought of in any systematic fashion. The research literature on terrestrial agroecological relationships goes back many decades, but some topics, such as the role of vegetative diversity in the promotion of improved pest suppression, and the related question of how diversity relates to stability, remain controversial due to a lack of understanding of general mechanisms. Soil ecology is a relatively new discipline, hindered by the size and vast numbers of the organisms involved. Advances in understanding the importance and role of C-CAB, overali, seems hindered by the general problem of understanding and representing highly complex systems.

According to the original idea of Vandermeer and Perfecto, *planned biodiversity* has a direct effect on ecosystem function—for example, overstory trees in an agroecosystem provide the opportunity to grow crops that do not do well in direct sunlight (direct promotion of ecosystem function), and also promote an environment that allows for the attraction of beneficial arthropods that help control pests (indirect effect, represented by the dotted line).

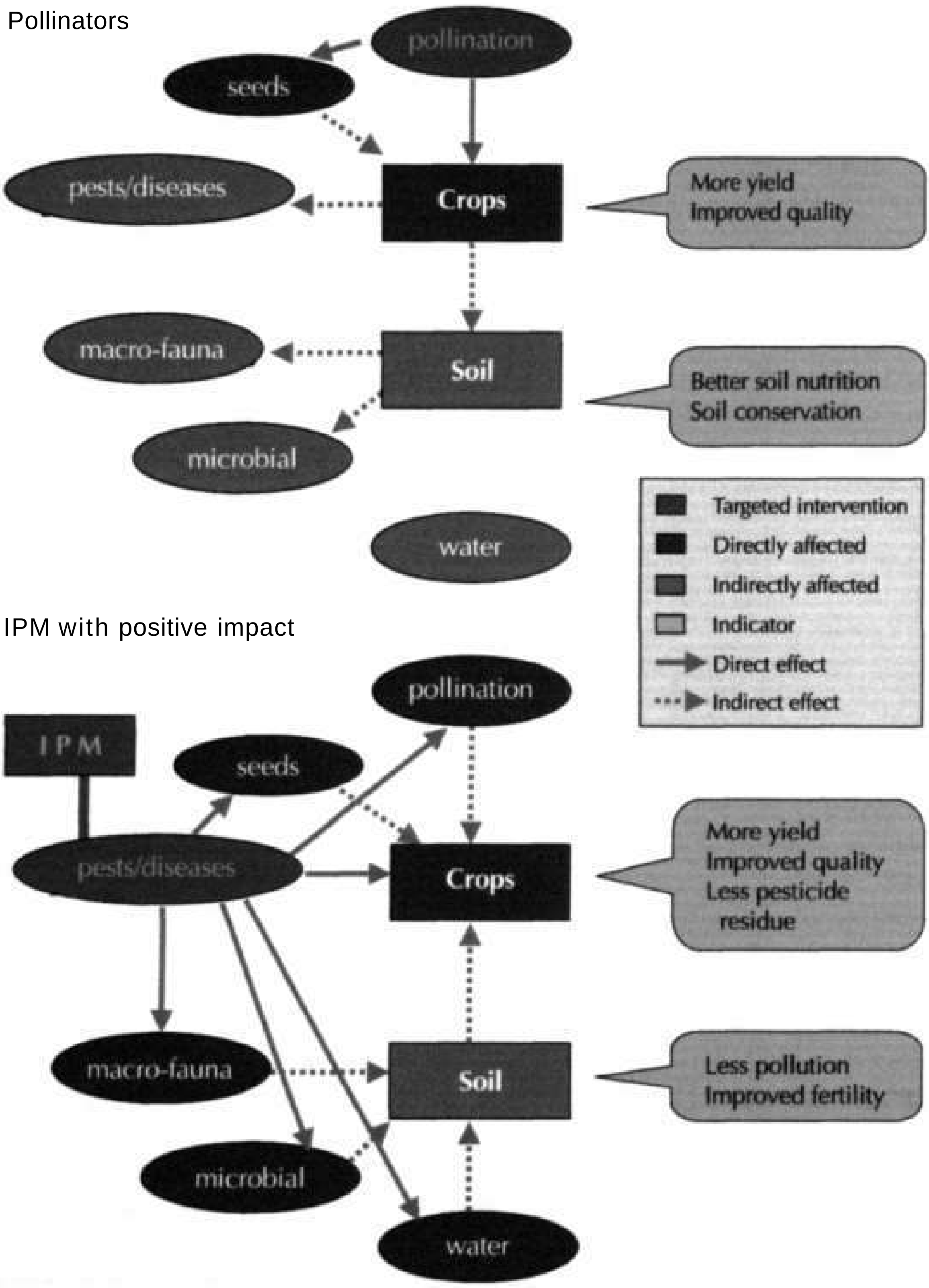
Altieri shows the overall relationship between CAB and management practices (enhancements) that have some relationship with components and functions in the agroecosystem. The task remains, however, to determine the actual mechanisms that would lead to a predictive strategy for managing associated biodiversity.

The question is worth posing then. . . . *To what extent do the concepts and theories of ecosystems and ecosystem management really have utility in addressing agricultural systems?*

This workshop on C-CAB is one early doorway into this larger domain of questioning.

Figure 3. Asia Working Group output

Linkage among components of C-CAB and effect of interventions on other components



Outcomes

The workshop resulted in the production of frameworks that were specific for each region, and complementary. Both working groups identified common measures (technical, political, instutional, etc), that would have positive impacts on C-CAB.

The Asia Group illustrated linkages between components *oi* C-CAB and particularly explored how targeted interventions focusing on one component of planned C-CAB can have direct or indirect effects on other components of non-planned C-CAB. The examples illustrated in Figure 3 relate to pollinators and IPM.

The Africa Group produced a diagram (Figure 4) illustrating a timeframe of interventions and bioindicators of non-planned C-CAB. The nature of the interventions determine when their impact could occur. Early bioindicators that monitor the impact of the interaction were identified. For instance, the effect an IPM intervention could be seen in the field within the first year and could be monitored by predator density indicators, while tillage and organic matter interventions would have impacts two years after their initiation, and their impact could be monitored by measuring infiltration rates and/or populations of termites, ants, and earthworms (Figure 4).

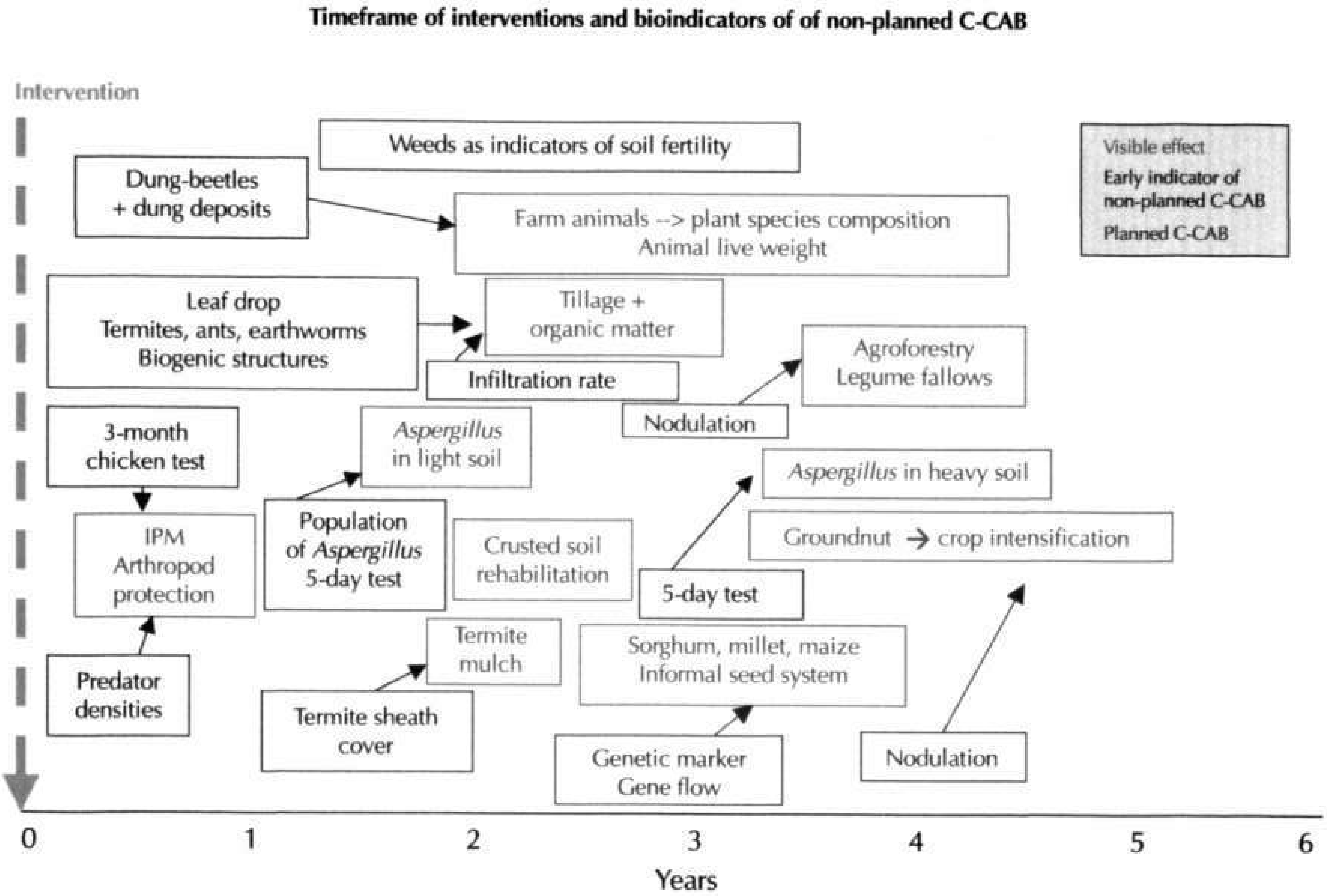
The frameworks developed in both groups, considered in terms of the six key criteria defined earlier (see page 2), were used by the groups to identify priority areas for research. These priority areas have been clustered and are presented in the final statement.

Final Statement

The workshop was designed to ensure that the agreed objectives were fully addressed in an iterative manner. Following the plenary presentations on specific topics, nine components of C-CAB were identified. These were combined with seven elements of a generic process for operationalizing C-CAB in SAT ecosystems to form a matrix.

Two working groups representing the interests of Asia and Africa shared their collective experience across the resulting matrix. This culminated in the identification of cross linkages, synergies, and indicators of the potential contributions of C-CAB to sustainable agricultural intensification. During the discussions it was noteworthy that key processes leading to those contributions emerged, along with practical biological indicators. Those indicators could be used by farmers to manage their agroecosystems more adaptively quite soon after they initiate interventions.

Figure 4. Africa working group output



From the group discussions evolved frameworks for strategic C-CAB interventions that were remarkably complementary across continents. These frameworks were sufficiently robust to be drawn upon by communities of farmers, researchers, and policymakers when considering potential C-CAB interventions. The groups then used the frameworks to suggest research priorities that took six key criteria into account. These research priorities were regrouped into clusters (12 for Asia and 8 for Africa) and are shown in following table. They correspond well to the elements of FAO's Global Programme on Biological Diversity for Food and Agriculture.

Elements of FAO's Programme	Working group research area priorities: Asia	Working group research area priorities: Africa
Assessment	• Agroecosystem biodiversity • Marketing intelligence for under-utilized crops	• Agroecosystem biodiversity • Potential interventions
Adaptive management	• Dual-purpose crop varieties • Improvement and value addition of crops including under-utilized crops • Improved breed of animals • Seed production and processing technologies • Sustainable eco-friendly agricultural practices	• Trade-off analysis: preservation or conservation (sustainable use) • Case studies of C-CAB costs and benefits • Creating demand for products through marketing
Local capacity building	• Knowledge sharing • Farmer-friendly media • Farmers' field schools	• Participatory needs assessment[1] • Knowledge transfer pathway to make it demand-driven[1]
Mainstreaming (especially policy)	• Policy reforms • Incentives for ecofriendly agriculture	• Policy reform, market failure, and public-private partnerships

1. All proposed research under this cluster will strengthen the local capacity to intervene in any activities **related to assessment, adaptive management, and** mainstreaming

Summaries of presentations on SAT environments and C-CAB components

Strategic assessments of agriculture in the semi-arid tropics: understanding change

M C S Bantilan and R Padmaja

Despite the remarkable advances made by agricultural research in recent decades, poverty, food insecurity, and malnutrition still remain as the most critical challenges facing the semi-arid tropics (SAT). The SAT is a harsh, risk-prone, fragile environment. Drought is a constant threat; water scarcity is a growing problem; soils are poor; and land degradation is increasing. Risks are pervasive and greater than in any other important food-production system. Poor infrastructure and inadequate policy contribute to the lag in transforming research results into vibrant diversification and commercialization.

Agriculture remains the backbone of SAT economies. Research should therefore be directed at developing appropriate technologies for sustainable intensification of agriculture in risk-prone SAT areas for the benefit of hundreds of millions of poor people. In particular, improved integrated genetic, soil, and water management strategies are increasingly needed to maintain/enhance productivity and reverse degradation in these regions.

There is a growing recognition of the special challenges and opportunities presented by the SAT. First of all, it offers the hope of redressing the imbalance that has been evident in past R&D investments. Environmental considerations are being increasingly integrated into international development policy. Moreover, publicly funded agricultural research which has declined by over 50% during the past 15 years, is increasingly augmented with a growing share of agricultural research and ownership of new technologies by the private sector. New institutional innovations including NGOs and networks are increasingly recognized.

The SAT is continually changing. Trends and major changes must be constantly monitored, and the research agenda accordingly reviewed and modified as needed. Some of the factors yet to be explained are: the dynamics and determinants of poverty, causal relationships underlying the development of SAT agriculture, and continuing lags in technology adoption.

Changes in the SAT environment will impact on the research agenda. Coupled with increasing market access, the liberalization of macroeconomic and trade policies has increased the relative importance of tradables in the commodity mix. The expansion of markets for both inputs and products has broadened the range of livelihood strategies. New opportunities are arising from broadening institutional partnerships. The direction for future work is to look at agricultural and economic growth including trends and opportunities in the SAT with a vision to stimulate/enhance:

- The breadth and evolution of investment patterns in SAT farming systems,
- Diverse rural investment options/or livelihood strategies in on-farm and off-farm enterprises,
- The implication of changing investment patterns for policy and agricultural research priorities

Key issues that need thorough understanding include: coping mechanisms and risk-management strategies of farmers in a risky environment with changing employment and market opportunities, farmer investment strategies and priorities, and impacts of new agricultural technologies. The ultimate question is.....*How can agricultural research improve the payoffs to the diverse and changing investment opportunities in the SAT?*

The ultimate objective of sustaining agricultural productivity and enhancing livelihoods through crop and crop-associated biodiversity should take us beyond genes, species, ecosystems, biomes, etc., to include the people and their social and economic environment. The role of the poor and marginalized communities cannot be overemphasized.

Statistics reveal that the SAT of South Asia has three times the number of poor people than the SAT of sub-Saharan Africa. The evidence on the relationship between the numbers in poverty and the agroecological potential of the environments on which they depend is mixed. Some studies indicate there are more poor in lower-potential areas than in higher-potential or irrigated areas, while others show a reverse trend. It has been indicated that about one-half of the land degradation in Africa is caused by overgrazing, and about one-quarter by agricultural activities. Deforestation and over-exploitation account equally for the balance. In contrast 40% of Asia's degradation is attributed to deforestation, with overgrazing and agricultural activities contributing about one-quarter each.

The differences in the nature of poor in the SAT of South Asia and sub-Saharan Africa, and regional differences in resource endowments, infrastructure, the roles of livestock in production and consumption, and the nature and extent of land degradation clearly imply the need for different R&D strategies in the two regions.

If future agricultural growth is to benefit the poor and contribute towards equitable economic growth, it is important to recognize the overlooked potentials of the less-favored lands, and to design suitable strategies and policies for stimulating sustainable productivity growth in these regions. The adverse biophysical conditions and the scarcity of water, that characterize much of the SAT, and the wide diversity and fragility of ecosystems in these regions, are likely to require approaches that should go beyond the Green Revolution strategy.

With the dynamics of the external environment surrounding the SAT, ICRISAT will need to have a continuing brief to monitor and use the accumulated information, knowledge, and understanding to refine R&D strategies, and assess priorities and impacts. It will be especially important to build up a better understanding of the dynamics and determinants of poverty and how ICRISAT can intervene to help alleviate it. Greater and continuing attention to problem diagnosis against this background would seem appropriate.

Soil and water: the flesh and blood of semi-arid agriculture in Africa

S Twomlow

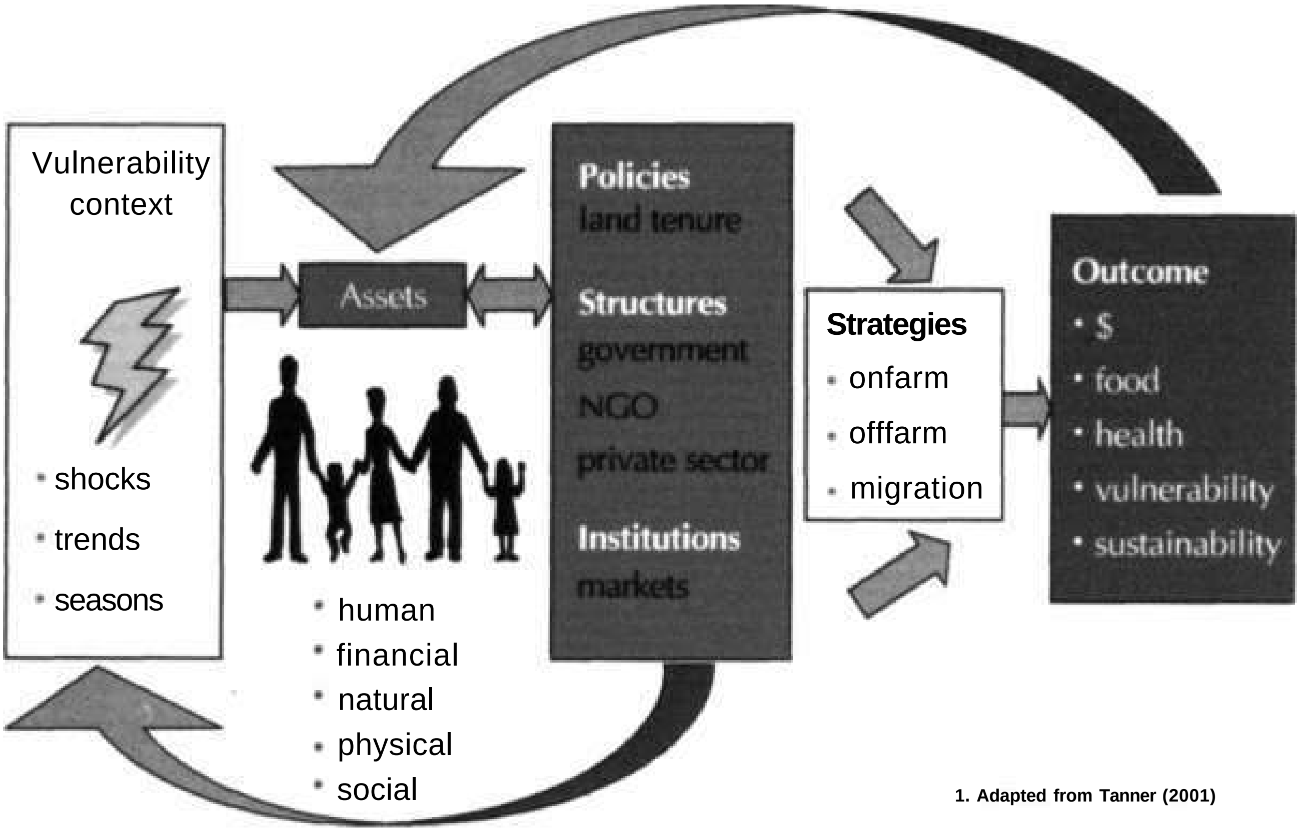
The agroecosystems of semi-arid sub-Saharan Africa have developed in response to the needs of both rural and urban populations of the region. The traditional production systems of the rural households are thought to be generally sustainable under conditions of low population pressure and lack of market integration, with system productivity geared towards subsistence. These systems remain in a sustainable equilibrium until such changes as population growth or external economic pressures occur at too fast a rate. These increases in internal and external forces can bring about an intensification of agriculture, or an extensification into marginal lands, where the risks of crop failure, environmental degradation, and loss of biodiversity increase due to inappropriate management practices that mine the soils of nutrients and organic matter.

Marginal lands once used for grazing are being cultivated, remaining grazing areas and woodlands are over-exploited, and this results in the degradation of the natural resource base and a loss of biodiversity. Although most rural households are conscious of the quality and limitations of their natural resource base, household subsistence needs and the lack of rural markets pose major obstacles to the uptake of technological interventions. Consequently, smallholder farmers, appear unable or unwilling to implement any technological intervention, or to respond to the external demands of society at large, that impact upon productivity and agroecosystem health.

To date, agricultural research has been successful in boosting productivity and has gone some way to alleviating poverty. However, it is now recognized, on the broader agroecosystems scale that many development projects have failed because they focused on a particular natural resource sector (crops, forestry, livestock, water etc.), while neglecting other users that also compete for the same natural resources to achieve their livelihood strategies. Such mismanagement has been termed the 'Achilles heel' of long-term sustainable development. The major lesson learned is that the lack of participation by the direct and indirect beneficiaries at the project design stage contributed to project failure. Suggesting that the researcher, extension, and development communities be aware of inter-sectoral linkages is nothing new. What has been missing is an effective framework that allows research to better accommodate these broader ranges of factors and players, and to be aware of the nature, causes, and potential results of conflicts and constraints within agroecosystems.

The framework currently being discussed among the Consultative Group on International Agricultural Research (CGIAR) centers is Integrated Natural Resource Management (INRM), a conscious process of incorporating multiple aspects of natural resource use into a system of sustainable management to meet explicit production goals of farmers and other users (e.g., profitability or risk reduction) as well as the goals of the wider community (sustainability). Given this definition, and considering the elements of the sustainable livelihoods approach shown in Figure 1, the issue of 'scale' becomes a critical element in the success of development projects. As the scale of interest changes, the nature of the biophysical and socioeconomic determinants of a system's productivity also change; since a phenomenon at a plot scale may be less important at the farm, community, or regional scale, and vice versa. Consequently, spatially robust INRM approaches and methods need to be developed and applied at varying levels of scale that will contribute to the globally significant issues of poverty alleviation, environmental degradation (biodiversity, desertification, etc.), and climate change.

Figure 1. The sustainable livelihoods approach



1. Adapted from Tanner (2001)

If the CGIAR system-wide aim of improving INRM is to contribute more broadly to sustainable rural livelihoods, there are various pathways that can be followed. These include: direct interventions to improve the status of the natural resource base, strengthening farmer knowledge and skills, improving organizational linkages that promote better learning and sharing of ideas between the R&D community and the end-user/beneficiaries, support to micro-finance and formal credit schemes, and improving access to input and output markets. Given the multidisciplinarity and complexity of such an initiative, it will be necessary to pursue a strategy at a macro-level aimed at supporting the evolution of policies that bring greater benefits to the rural communities (the custodians of the natural resource base) while at the same time providing support to networking between various organizations working on INRM issues at a micro-level. For an INRM approach to work it should have an in-built flexibility that gives due cognizance to the needs and aspirations of the rural community. Such an approach means that technologies/interventions should not be imposed on the households, but that such households be exposed to a basket of options, and be allowed to develop and modify as they wish, so as to determine.... *Under what conditions will rural households be encouraged to reinvest in their agroecosystems?*

Pest and disease biodiversity and their integrated management

F Waliyar and H C Sharma

Recently, agrobiodiversity is gaining importance worldwide as understanding of the elements that play a key role in agroecosystems develops. Many microorganisms exist in nature. Fungi, bacteria, viruses, insects, nematodes, and phytoplasmas are integral parts of the agrobiodiversity of all natural ecosystems. Their diversity is wide, some of them are beneficial organisms, whilst others are pathogens that at certain levels can cause serious damage. Although pathogens represent a relatively minor proportion of total microorganism biodiversity, they have received considerable research attention.

Unless pathogens are well-managed, they can reduce crop yields significantly. Within functional agrobiodiversity it is important to optimize the diversity of each ecosystem. Very often pathogens are host-specific and therefore can only damage a single crop. But variability within pathogens is also wide. Some, e.g., *Fusarium oxysporum* can even develop special forms that are adapted to other crops. Others have a wide range of hosts, e.g., peanut clump virus (PCV) that is found in many cereals as well as in groundnut. PCV may cause damage to its alternate hosts, or simply use them as a reservoir for survival.

Pathogens can adapt to a wide range of climates and production systems, but some are region-specific, as is groundnut rosette virus (GRV) that is transmitted by *Aphis craccivora.* Although the aphids can be found on all continents, GRV is found only in Africa.

Because of the long-term co-existence of pathogens and plants, disease incidence and severity can vary from minor to epidemic. Epidemics are mainly due to long-term co-evolution of pathogens in plants, or pathogen adaptation to such new hosts as breeding lines susceptible to disease. Epidemic survivors that contain vital resistance genes can form the nucleus of new populations. They are recognized by farmers and researchers, both of whom use them in selection. Epidemics are also influenced by climate and cropping-system changes.

In agroecosystems pathogen-diversity is considered harmful, and some drastic management practices have led to reduced biodiversity. While there is a need to develop cost-effective and efficient management practices that reduce crop damage, it is important to maintain biodiversity.

There are many components of pest management that need to be considered. These include the limited use of pesticides, host-plant resistance, natural plant products, bio-pesticides, natural enemies, and agronomic practices.

For the past few decades there has been heavy reliance on pesticides to control pests and diseases, but time has shown that these pesticide applications are reducing biodiversity, influencing the environment, causing the health of human and animals to deteriorate, and adversely affecting the quality of groundwater. Some alternatives to the use of fungicides have been developed and are in use in some countries. But these biopesticides and natural products are yet to prove their efficiency in large-scale farming systems. Host-plant resistance is still the most economical way of reducing crop losses due to diseases and pests.

Agronomic practices such as manipulating sowing dates, using bio-fertilizers, altering crop density, etc., have significantly reduced pest and disease incidences on some crops. Examples of this are the management of groundnut foliar diseases and GRV, where high crop densities are conducive to foliar disease development while low densities leave the plants vulnerable to high GRV incidence. Just by manipulating densities farmers can mitigate damage from either pathogen.

In view of the importance of diseases and pests and their continued pressure on some of the major crops in the SAT, it is essential that ecofriendly integrated pest management (IPM) practices that are acceptable to the farming community are developed. In order to increase crop yields, maintain pathogen biodiversity, and ensure a safe environment, these practices will need to be adapted to different production systems.

For this to be achieved there is a need to better understand the type of approaches that need to be considered for the development and implementation of such technologies. IPM is a way to optimize pest control measures in an economically and ecologically sound manner. This can be accomplished by the coordinated use of multiple tactics to ensure stable crop production and to maintain pest damage below the economic injury level, whilst minimizing hazards to humans, animals, plants, and the environment.

Vegetational diversity, arthropod response, and pest management

H C Sharma and F Waliyar

Vegetational diversity influences the relative abundance *of* herbivore arthropods and their natural enemies. The ecological interaction between plants, arthropods, and natural enemies, and the evolutionary responses of each component lead to complex interactions amongst them. Vegetational diversity may involve two or more crops (mixed or intercropped), or a crop and weeds. In some places, different varieties of the same crop that flower at different times can also be sown as a mixed crop (e.g., early and late-flowering pearl millet in West Africa). Agronomically similar genotypes that possess different genes for insect resistance can also be sown as multi-lines or synthetics. The variation in species diversity over space and time can be exploited to minimize losses caused by insect pests, to encourage the activity of natural enemies, and to increase the productivity potential of land per unit of time. The resource-concentration hypothesis suggests that under monoculture where the same plant species is cultivated over large areas, herbivores find a concentrated source of food in one place, which supports uninterrupted increase in their populations.

The need to realize the highest possible crop productivity per unit of time coupled with increasing farm mechanization has led to the adoption of modern farming technologies that place heavy reliance on irrigation, high-yielding (but insect-susceptible) varieties, chemical fertilizers, and pesticides. As a result, the diverse and sustainable traditional production systems of the past have given way to the highly productive monoculture systems of today. But these monocultures often result in frequent outbreaks of insect pests and diseases. The best example to illustrate this scenario is cotton, a major crop in many parts of the world, that is subjected to the depredations of a large number of insects and diseases.

Polycultures are still prevalent in many regions, and it is therefore important to understand the arthropod responses to polycultures to improve pest management in these systems. Arthropod responses to their crop hosts are quite complex, e.g., a two-crop mixture with 6 herbivores and 6 natural enemies can lead to 364 ecological interactions, and possibly an equal number of evolutionary responses. As a result, taxonomically diverse plant communities suffer fewer herbivore attacks than single-species plant stands.

The wider the biological diversity in a community, the greater its stability should be. However, such a contention is not supported by empirical data. The goal of pest control is not based on stabilizing the pest populations, but on suppressing them. If large population densities of a pest can be tolerated, then our aim should be to reduce the magnitude of fluctuations in pest populations. But, large pest populations are not often tolerated, and the goal of pest control is always to reduce the pest population to below economic injury levels.

The effect of herbivore anthropods on crop plants in polycultures and monocultures can be measured by removing the herbivores from both systems using insecticides. Comparison of plant damage and yield loss in both the systems can also be used to determine the effect of vegetational diversity on insect abundance, yield loss, and the sustainability of crop production. Yield losses are often lower in polycultures where the response of herbivore arthropods is influenced by resource concentration and the influence of natural enemies, coupled with associational resistance.

Development of strategies that help conserve natural enemies, minimize the risk of insect pest outbreaks, and slow down the rate of development of resistance to insecticides will be crucial for sustainable crop production in future. The nature of interaction between insect pests, crops, non-host plants, and their physical environment determines the effectiveness of biological control processes. For biological control to be successful, it is important to ensure that essential parasitoid resources and hosts coincide in time and space. Cropping systems have been successfully altered in many cases to augment and enhance the effectiveness of natural enemies.

The effects of resource concentration and natural enemies on herbivore arthropods are complementary, but they influence monophagous and polyphagous species differently. A monophagous species is likely to be less abundant in polycultures than in monocultures. Some arthropod species respond differently to polycultures, depending on the number of host plants in the polyculture, and the relative preference of the herbivore for different host plants. In general, resource concentration has a greater effect on herbivore response to polycultures than do natural enemies, but the natural enemies also act concurrently.

Some of these interactions are related to the evolutionary history of a particular plant and the arthropod, and the ecological interactions involved in the process may unravel the effects of vegetational diversity on herbivore arthropods and their natural enemies.

Effect of organic resources management on soil biodiversity and crop performance under semi-arid conditions in West Africa

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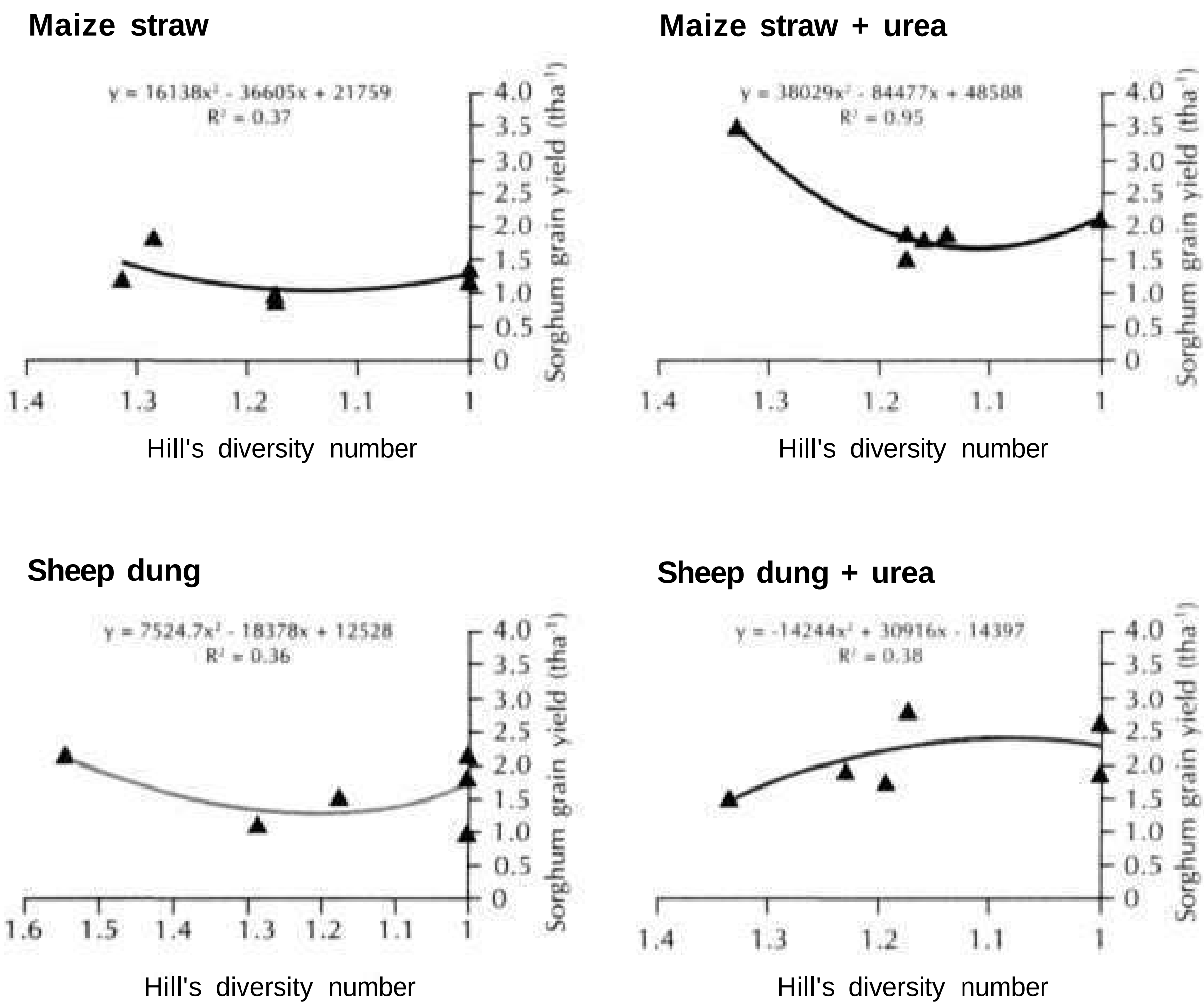
Soils in many areas of the semi-arid tropics (SAT) face reduced productivity. Because of organic matter and nutrient depletion that induce losses in soil biodiversity, they cannot function well within their ecosystems. In the prevalent low-input agricultural systems of the SAT, organic resources management and the maintenance of soil biological qualities are key elements in the sustainability of agriculture. However, little is yet known about the organisms in SAT soils, particularly of those in West Africa. The impact of different types of organic resources management on soil biodiversity, with special attention to soil fauna and their interaction impacts on crop performance, are under investigation. These organisms play a key role in controlling soil functions and have high importance in ecosystem studies. Judicious management of organic resources could improve crop performance and help to maintain the beneficial contribution of soil biodiversity to the agriculture of SAT West Africa.

Strengthening research on the role and contribution of soil organisms is essential for the adapted establishment of technologies for soil functions maintenance that would result in improved crop performance. The maintenance of soil functions in the SAT is related to the sustainability and conservation of beneficial soil fauna that contribute to ecosystem functioning. The soil ecosystem is complex and has features that may transcend time-scale consideration. A network for soil diversity studies could be a way to compensate for the lack of data on West African soils.

Organic resources management is one of the important factors for both improvement *of* crop performance and conservation of soil biodiversity in the SAT. Soil quality and hence crop performance improvement result from the interaction of different groups of soil fauna and abiotic soil conditions. Soil fauna population size is closely related to soil organic matter content under West African SAT conditions. In a study on the impact of organic resources management on soil-fauna dynamics and crop performance in Burkina Faso, it was shown that adding nitrogen in the form of fertilizer urea to soil amendments with organic matter, either as maize straw, or sheep dung had positive effects on sorghum yield. Soil-fauna diversity was related directly to organic resources quality and indirectly to the type of soil fauna attracted by a given quality of organic material (Figure 1). In this experiment the use of organic resources or fertilizer alone did not promote beneficial soil-fauna diversity or improve crop performance.

Figure 1. Correlation between soil fauna (measured by Hill's diversity number), quality of organic resource, and sorghum grain yield in Burkina Faso



Organic material and fertilizer contributions should be promoted, since they are warranted by the resulting beneficial soil-fauna diversity and enhanced crop production improvement. It will be important to strengthen network studies on how soil organisms can lead to better soil function maintenance and crop performance improvement. The maintenance of above- and below-ground resource diversity will certainly lead to improved rural livelihoods.

Managing and harnessing soil flora/fauna biodiversity for sustainable crop production in the semi-arid tropics

O P Rupela, S P Wani, and T J Rego

The Green Revolution initially resulted in high-yielding cereal varieties responsive to increased inputs that addressed the food needs of several countries, particularly those in Asia. However, after three decades, farmers have started experiencing difficulty in maintaining such high yields, even with increasing levels of inputs. Second-generation issues, fall-outs of the Green Revolution, have now surfaced. These issues include problems associated with soil quality, sustainability, and environmental degradation. Prior to the Green Revolution sustenance agriculture was relatively free from such problems, but it operated at a low level of productivity, that could not sustain the food needs of Asia's ever-growing population.

Several long-term experiments, with such treatments as sole organic inputs in the form of large quantities of farmyard manure (FYM), only occasionally produced higher yields than treatments with chemical fertilizers. Farmers who depend mainly on biological inputs and have a high level of biodiversity on their farms generally claim to produce equal or higher yields than those of farmers in mainstream agriculture. It seems possible to achieve high yields by applying large quantities of FYM/biomass, but except for a few niches, such large quantities of organic materials are not available. At present, farmers in some areas of four Asian countries continue to burn large quantities of crop residues that could be used on their fields, but for other areas strategies for on-farm production of biomass such as growing multiple-use tree species on farm boundaries will need to be considered.

The potential of using environmentally friendly, traditional, and scientific knowledge on soil biology/biodiversity to sustain high crop yields using natural/recyclable resources produced on-farm has been assessed. A 3-year study at ICRISAT revealed that plots receiving large quantities (101 ha^{-1} crop residues and 1.7-2.0 t ha^{-1} compost/FYM annually) of biomass as a surface mulch without tillage yielded more in two out of three years than those receiving recommended tillage, chemical fertilizers, and pesticide applications. The high yields in the biomass-applied plots were largely due to their being least damaged by insect pests. These plots were protected by microbial pesticides developed at ICRISAT, and had high populations of the natural enemies of insect pests, such as spiders and coccinelids.

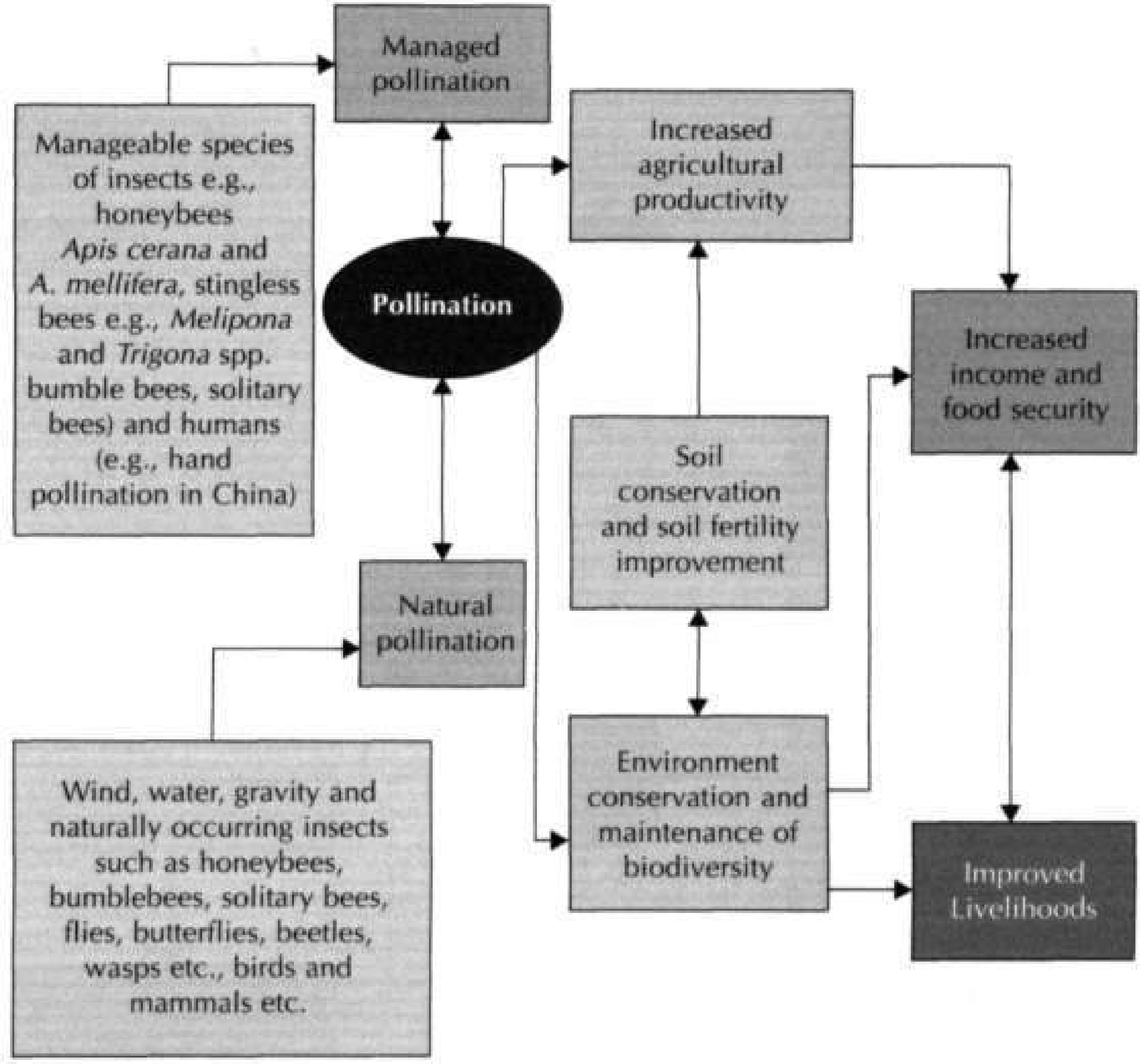
Although the overall yields were high in the plots receiving biomass, stover yields (above-ground total dry matter minus economic yield) were generally higher (particularly of non-legume crops) in the plots that received both chemical fertilizers and pesticides. Based on this experience and on the available knowledge on soil flora/fauna biodiversity, two protocols (one each for rainfed and irrigated areas) of crop production have been proposed for on-farm evaluation.

Improving agricultural productivity and livelihoods through pollination: some issues and challenges

Uma Partap

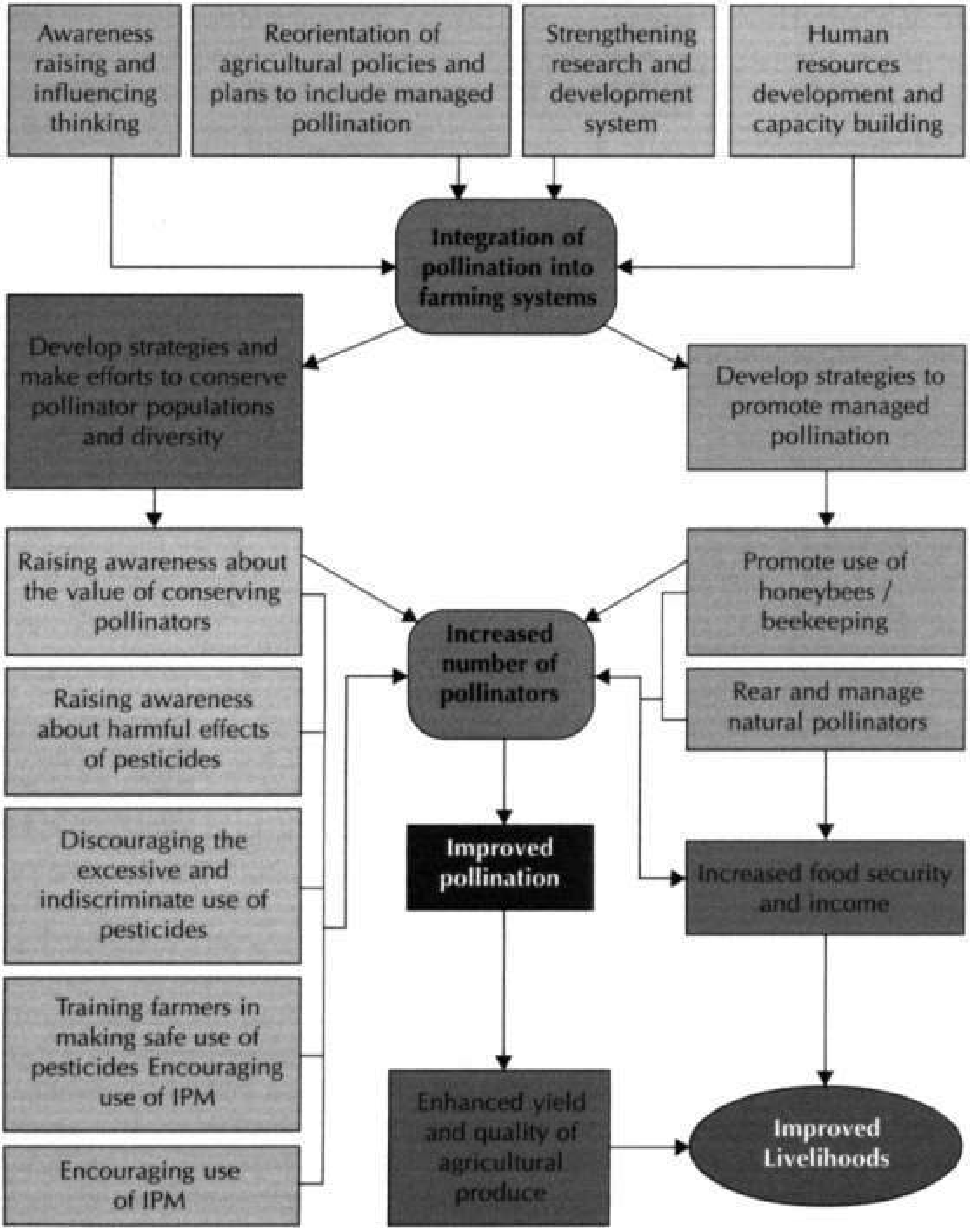
With the ongoing shift in the focus of agriculture from subsistence systems to commercial agriculture in many developing countries, new challenges for improving and maintaining productivity are emerging. Among these challenges are crop failures due to inadequate pollination. Like soil, water, and nutrients, pollination is also a limiting factor in crop productivity, in which it plays a crucial role. Figure 1 illustrates the contributions of pollination to enhancing agricultural productivity and improving rural livelihoods. Even if agronomic inputs including: better-quality seed and planting material, good irrigation, use of organic and inorganic fertilizers and biocides are provided, without pollination no fruit or seed will be formed. Pollination failure can be caused by several factors, the most important of which is the lack of adequate numbers of pollinators. In recent years pollinator populations and diversity have been declining, because wilderness and habitats are being lost, land uses are changing, monocultures increasingly dominate agriculture, and excessive and indiscriminate use of agricultural chemicals and pesticides are increasing. Consequently, the need to ensure pollination by conserving pollinators and managing crop pollination has increased and will increase further. Increasing the number of pollinators has become more urgent. This can be achieved by: conserving populations of natural insect pollinators, promoting ecofriendly integrated pest management, and by judicious use of chemical fertilizers and pesticides. But the most practical and preferred solution would be to promote manageable species of honeybees. Such promotion calls for a more intensive focus on the issue from the perspectives of policy, research, development, and extension.

Figure 1. Contribution of pollination to enhancing agricultural productivity and improving rural livelihoods



There is a need to formulate policies that include pollination as an integrated input to agricultural production technologies. Policy reorientation, improving institutional capabilities, and human resources development are the key areas needing attention. Figure 2 illustrates the challenges of integrating pollination into farming systems, and enhancing rural livelihoods through promoting managed pollination and conserving pollinator populations.

Figure 2. Awareness raising and reorientation of agricultural development policies to include pollination as an input[1]



1. Institutional strengthening R&D Institutions, human resources development, and capacity building are necessary to integrate pollination into farming systems, thus enhancing agricultural productivity and the livelihoods of rural people

Seed sense: strengthening crop biodiversity through targeted seed interventions

R B Jones

Seed has multiple functions. It is both an essential input for all crop-based farming systems, and is the primary harvested product of many but not all crops. The genetic information carried by the seed allows farmers to use plant genetic resources in a sustainable way and to conserve them over time. Seed is also used to deliver new varieties to farmers. Given the importance of seed, much attention has been devoted to developing new varieties, controlling seed quality, and setting up seed systems to serve the needs of farmers, but the impact of seed systems on crop and crop-associated biodiversity (C-CAB) is a strangely neglected subject.

Biodiversity has been neglected in agriculture, and seed systems have been neglected both by biologists and many public-sector plant breeders. This is not the case with private-sector breeders who depend on functioning seed systems for their livelihoods. Smallholder agriculture in marginal areas — especially in sub-Saharan Africa — is in crisis, and conventional approaches to agricultural research and development are being challenged. This is particularly noticeable for publicly funded crop improvement programs.targeted towards crops that are important to the needs of the rural poor, but are perceived to have had limited impact. The question is. . . . .*What alternatives exist?*

Several trends are evident in the area of plant genetic resources; enhancing the role of C-CAB in agriculture and the use of more participatory approaches in plant breeding, the application of biotechnology for crop improvement, and addressing seed-system constraints largely through policy change. All of this is taking place in an increasingly globalized economy with the private seclor being the engine of growth, and governments withdrawing from service provision — especially in agriculture — and concentrating on providing an enabling environment in which the private sector can operate.

An understanding of C-CAB and its management is seen as one avenue to a more sustainable agriculture that will maintain agroecosystem health, and provide livelihood benefits to the rural poor of the semi-arid tropics (SAT). However, sustainable agriculture and agroecosystem health are difficult concepts to define and measure, and are still subject to scientific discussion. Biophysical scientists in promoting more environmentally sustainable practices tend to ignore the incentives for farmers to adopt such practices. This is particularly the case for natural resource management technologies where the incentives are commonly lower than incentives to simply extract natural resources. The value of an additional dollar of output today is worth far more to most small-scale farmers than the value of much larger production levels in the distant future.

If sustainability is to be pursued through promoting the adoption of new technologies, these investments must offer higher near-term payoffs than alternative demands on scarce land, labor, and capital. How often are relative returns to investments in agriculture evaluated with alternative farm investments or investments off-farm? The challenge for agricultural researchers interested in C-CAB is to learn from the mistakes of the past, and to approach C-CAB in a more holistic way.

Formal seed systems are increasingly dominated by the private sector, which necessitates that they operate along commercial lines. Commercial seed companies have tended to focus their efforts on marketing hybrids, and seeds of other crops where there is a consistent demand for seed that is not easy for farmers to meet through their own efforts. By understanding the decision-making process that drives the commercial sector, there are opportunities to redirect crop improvement efforts to produce products that provide both real benefits to farmers, and commercial incentives to private-sector seed companies. As globalization proceeds, farmers will increasingly have to respond to the needs of end-users. Although farmers in marginal areas might not themselves be involved in these vertically integrated supply chains, they will be affected indirectly as agricultural produce moves more freely in response to consumer demand. The desire amongst consumers for greater variety in the range o\ foodstuffs consumed can potentially provide markets for crops that have largely been neglected, but to exploit these opportunities will require efficient and dynamic seed-supply systems to support farmers, otherwise they risk becoming marginalized in the global economy.

There are new insights into crop improvement that necessitate a shift away from centralized breeding to localized efforts that are targeted towards specific agroecozones. This new breeding paradigm will require a different approach to seed supply that builds upon the strengths of informal seed exchange mechanisms whilst overcoming some of their deficiencies. The present regulations surrounding release of new varieties and certification of seed that exist in many countries can block farmers' access to new varieties. While some controls are vital for plant sanitation, the current situation in which farmers are told which germplasm to grow and where, needs to change to one in which farmers evaluate and multiply promising materials themselves.

Free seed distribution through relief schemes has not been particularly useful except in the rare cases where there is an absolute lack of available seed. Procurement of relief seed from the formal sector fails to strengthen existing seed systems because the seeds supplied are often inappropriate and hence rejected by farmers. An alternative approach is to first understand what problem exists, and then to address the identified problem. If the problem is one of households not having sufficient resources to access available seed, it is better to provide resources to farmers so that they can make their own choices about which crops and varieties to grow.

No one strategy is right. Rather we need to further the development of a dualistic seed-supply system that can address the diverse requirements of farmers in the SAT. Commercial seed companies have a role to play, but are not the sole solution. The public sector must be strengthened to address seed supply of crops that are of little interest to the commercial sector, but are critical to agriculture in marginal areas.

Much can be done to enhance C-CAB through seed-supply interventions. There are now well-documented experiences on the range of seed interventions described, and the time is right to develop a coordinated and focused plan of action involving multiple stakeholders to improve the livelihoods of smallholder farmers in marginal areas.

Enhancing the livelihoods of rural communities through promotion of neglected crops and their associated biodiversity in semi-arid agroecosystems

S Appa Rao, N Kameswara Rao, S Padulosi, G D Sharma, B S Phogat, and S Padmaja Rao

Global food security and rural incomes are at risk due to excessive dependence on a declining number of plant species. To conserve and use the world's plant genetic resources (PGR) for the development and welfare of present and future generations, there is need to enhance the use of PGR and to promote greater awareness of the important role that neglected and under-utilized species (NUS) play in securing the livelihoods of people around the world. Hundreds of such species are still to be found in many countries, representing an enormous wealth of agrobiodiversity that has the potential to contribute to improved incomes, food, and nutritional security. The primary challenge in conserving and using the PGR *oi* NUS is to secure their survival and environmental adaptation while at the same time providing increased incomes for rural poor.

Of the 850 million undernourished poor in the world today, the majority still live in rural areas, and in adverse environments. Many NUS are nutritionally rich and are adapted to low-input cultivation. Their use could contribute to food security and the well being of the poor. The contribution of NUS in combating vitamin and micronutrient deficiencies is seen as essential, particularly in marginal rural areas where these species are sometimes better adapted than major crops. Designer foods with balanced amino acid and micronutrient profiles can be developed using appropriate blends of major cereals and NUS. Marketing opportunities, processing and adding value to NUS would create demand and encourage farmers to grow and consume these crops. Growing demand from consumers for diversity and novelty in foods is creating new market niches for which NUS could provide products that would generate additional income.

Climate change and degradation of land and water resources have led to a growing interest in crops and species that are adapted to such difficult environments as those with poor soils or degraded vegetation, drought-prone areas, and desert margins. In these areas NUS could promote sustainable agricultural development based on environmentally sound management of natural resources and conservation of agrobiodiversity.

The use of plants has long been an intimate part of local cultures and traditions and many of the NUS play a major role in keeping cultural diversity alive. Their unique array of diversity in taste, color, texture, modes of preparation, and ritual uses represents a rich component of the cultural, food-based social language that make our lives more interesting and enjoyable. People should be encouraged to rediscover the cultural values of raising their traditional crops, by according social prestige to such traditions.

The promotion of NUS requires the combined understanding, inventiveness, and interaction of farmers, industrialists, agricultural scientists, educators, environmentalists, and health-care workers. The food security base could be broadened by including NUS in farming systems research programs. Such sustainable food production practices as integrated farming systems, ecotechnology, organic farming, and integrated nutrient, water and pest management are ways to enhance NUS productivity. Efforts to improve NUS production through yield improvement, higher-factor productivity, and better postharvest management should be accelerated.

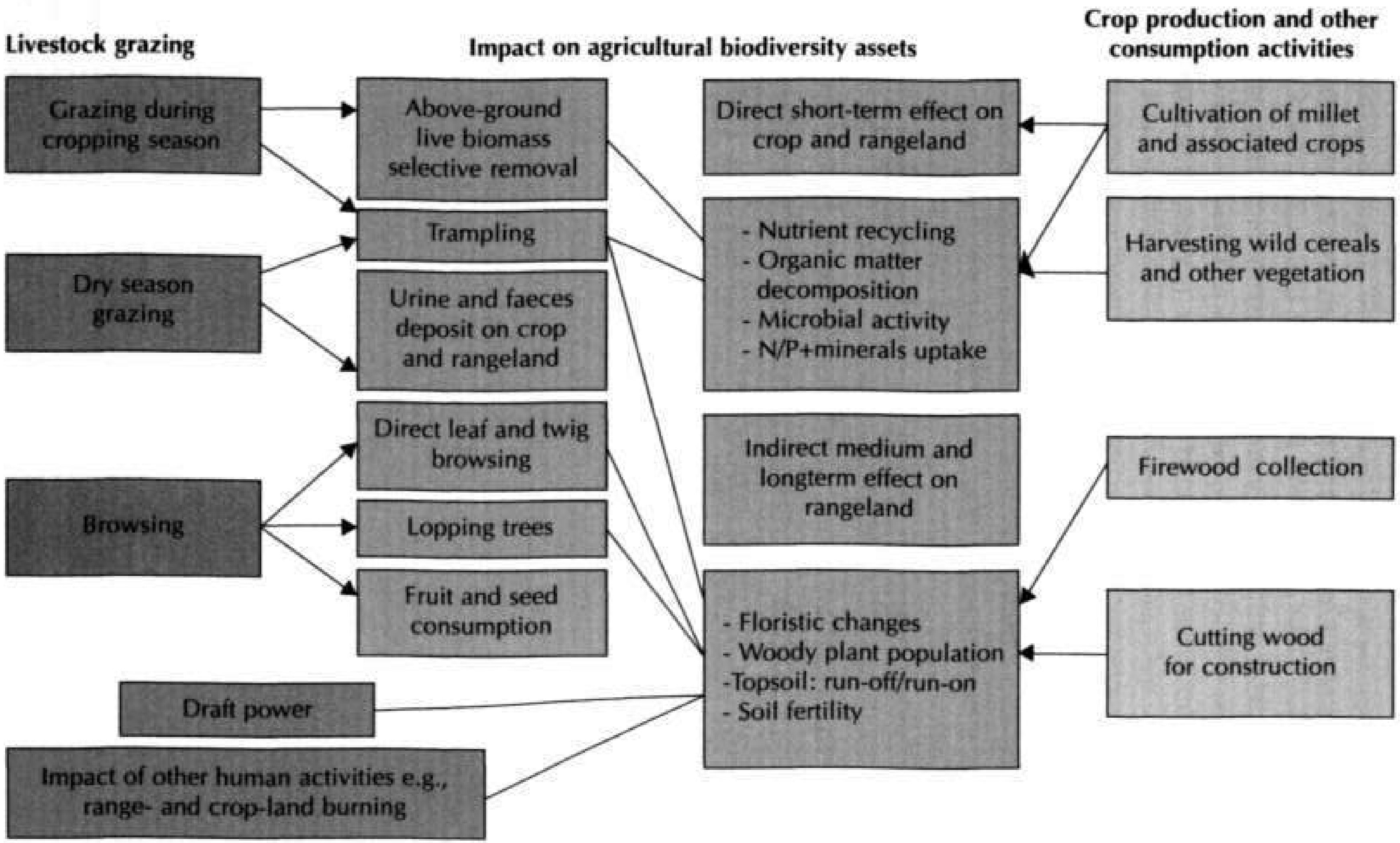
Forage crops are often given low priority and are grown in degraded, low-productive wastelands, on poor and problem soils that are not suitable for food crops production. Their productivity depends on the availability of good-quality seed of improved varieties. As they are shy seeders with low Harvest Indexes and are subjected to frequent cutting, opportunities to produce large quantities of quality seed are limited. Concerted efforts are needed to augment the seed production of cultivated fodders, range grasses, and pasture species to sustainably improve forage production. There is need to address various aspects of forage seed production and to overcome other constraints to forage production. Genetic improvement and organized seed supply systems need to be implemented based on the specific requirements and available infrastructure for future improvement in forage resources in the SAT.

Improving productivity and livelihood benefits of crop-livestock systems through sustainable management of agricultural biodiversity in the semi-arid tropics

T O Williams, P Partharsarathy Rao, P Hiernaux, M Blummel, and B Gerard

There is a growing worldwide acknowledgment of the multiple values of agricultural biodiversity for sustainable agricultural production, livelihoods, and ecosystem health. Poor people, particularly those living in areas of low agricultural productivity like the semi-arid tropics (SAT), depend heavily on genetic, species, and ecosystem biodiversity to support their livelihoods. This support takes the form of contributions to crop-livestock development, human nutrition and health, and reduced vulnerability to agricultural production risks. Nonetheless, agricultural production often impacts on land, vegetation, water, and soil organisms, eroding biodiversity in ecosystems and thus jeopardizing productivity and livelihoods. How can agricultural biodiversity be managed and sustainably used to increase crop-livestock productivity and livelihood benefits, while maintaining ecosystem health? How can crop-livestock systems management be improved to promote sustainable conservation and use of biodiversity? These are the challenges we face. Figure 1 shows the impacts of crop and livestock production on agricultural biodiversity, and also clearly indicates the direct effects and

Figure 1. Impacts of crop and livestock production on agricultural biodiversity in a West African semi-arid ecosystem[1]



1. Adapted from Hiernaux (1996)

feedback loops that need to be taken into consideration in the sustainable utilization of agricultural biodiversity to enhance crop-livestock systems' productivity, and thus livelihoods in the SAT.

Over the next two decades, the demand for meat and milk in developing countries, including those situated in the SAT, is expected to more than double as a result of growth in urbanization and incomes. This expected growth in demand raises a number of opportunities and challenges for optimal utilization of agricultural biodiversity to improve crop-livestock systems' productivity and thereby the livelihoods of the smallholders who derive sustenance from these systems without jeopardizing ecosystem health. These opportunities and challenges can be considered at three levels — farmers, policy, and research.

There is evidence to suggest that due to the considerable agricultural production risks faced by smallholder farmers in the SAT, they tend to actively manage agricultural biodiversity in order to improve the productivity of their farms and thus their household food security. They practice a system of mixed farming in which a large number of species are raised, with considerable genetic diversity within species. Good use is also made of wild plant diversity and non-plant agricultural biodiversity to minimize risk and enhance livelihoods and ecosystem health. For the future, a key requirement is to empower such farmers to continue to do this through access to new technologies, education, and training.

Policy and institutional changes are needed to create the conditions that would permit smallholders to benefit from the multiple values of agricultural biodiversity. This will involve eliminating such perverse incentives as subsidies, tax relief, below-cost resource pricing in the agricultural, energy and transport sectors, and marketing and distribution restrictions that encourage a narrower range of crop and animal species, varieties, and breeds. It will also involve addressing issues surrounding access and use rights. Well-defined and secure property rights (common, private, state) provide good incentives for sustainable use of natural resources as they give greater security over future use and allow for long-term planning. At present, biodiversity issues are rarely seen to bear any relevance to mainstream policy and decision-making. There is a need to develop and experiment with approaches and mechanisms that can help mainstream biodiversity issues into sectoral policies and integrate livelihoods perspectives into biodiversity policies.

At the research level, surveys and assessments of agricultural biodiversity and its importance to crop-livestock production systems and local communities should be conducted. These can bring to light specific opportunities for using agricultural biodiversity to improve livelihoods and reduce poverty. Research is needed to develop indicators to measure the status and changes in agricultural biodiversity, including the impact of crop-livestock systems on biodiversity, and the role of biodiversity in agricultural production and ecosystem processes. The emphasis should be on indicators that are practical and relevant to management and decision-making.

Appendix

Generic process for operationalizing C-CAB

Matrix for analyzing components of C-CAB	A Demon-strated benefits delivered by this component	B Demonstrated distruption caused by removing or compromising component	C Interventions to enhance effect of component a. Planned C-CAB b. Associated C-CAB	D Results: Production; Associated changes; Risks	E How to strengthen local communities' capacities to capture benefits; Building understanding and adapting tools	F Policy reforms to enhance ABD[1] in agriculture; Political economy of ABD	G Research priorities; Partnerships
C-CAB components							
1. Soil ecology: Macro-fauna							
2. Soil microbial ecology							
3. Pollination							
4. Crop–livestock systems							
5. Seed sense and public/private sectors							
6. Neglected/ under-utilized crops							
7. IPM: Pathogen suppression							
8. IPM: Arthropod predation							
9. Abiotic factors: Land and water							

1. ABD = agrobiodiversity

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690-2002