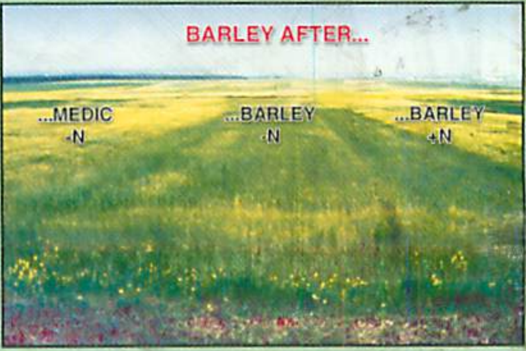
The Challenge of Production System Sustainability

Long-Term Studies in Agronomic Research in Dry Areas

M.J. Jones, Editor



International Center for Agricultural Research in the Dry Areas

About ICARDA and the CGIAR

Established in 1977, the International Center for Agricultural Research in the Dry Areas (ICARDA) is governed by an independent Board of Trustees. Based at Aleppo, Syria, it is one of 16 centers supported by the Consultative Group on International Agricultural Research (CGIAR).

ICARDA serves the entire developing world for the improvement of lentil, barley and faba bean; all dry-area developing countries for the improvement of on-farm water-use efficiency, rangeland and small-ruminant production; and the West and Central Asia and North Africa region for the improvement of bread and durum wheats, chick-pea, and farming systems. ICARDA's research provides global benefits of poverty alleviation through productivity improvements integrated with sustainable natural-resource management practices. ICARDA meets this challenge through research, training, and dissemination of information in partnership with the national agricultural research and development systems.

The results of research are transferred through ICARDA's cooperation with national and regional research institutions, with universities and ministries of agriculture, and through the technical assistance and training that the Center provides. A range of training programs is offered extending from residential courses for groups to advanced research opportunities for individuals. These efforts are supported by seminars, publications, and specialized information services.

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The World Bank, the Food and Agriculture Organization of the United Nations (FAO), the United Nations Development Programme (UNDP), and the United Nations Environment Programme (UNEP) are cosponsors of the CGIAR. The World Bank provides the CGIAR System with a Secretariat in Washington, DC. A Technical Advisory Committee, with its Secretariat at FAO in Rome, assists the System in the development of its research program.

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A workshop held at ICARDA, 8-11 December 1997

Abstracts of Presentations and Workshop Conclusions

M.J. Jones
Editor

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International Center for Agricultural Research in the Dry Areas

ICARDA, Aleppo, Syria

International Crops Research Institute for the Semi-Arid Tropics

ICRISAT, Patancheru, A.P. India

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Citation: Jones, M.J. (ed.). 1998. The Challenge of Production System Sustainability. Long-Term Studies in Agronomic Research in Dry Areas. Abstracts of Presentations and Workshop Conclusions. ICARDA, Aleppo, Syria. 55 pp.

ISBN: 92-9127-088-1

AGROVOC Descriptors: AGROVOC Descriptors: *Hordeum vulgare*; wheats; sorghum; millets; cowpeas; rice; feed legumes; grain legumes; feed cereals; on-farm research; rainfed farming; dry farming; farming systems; natural resources; resource management; pastures; tillage; crop residues; sustainability; crop yield; chemicophysical properties; soil cracking; soil structure; luvisols; nutrients; rotational cropping; cropping systems; watersheds; ley farming; fallow; land management; experimental design; fertilizer application; morbidity; research support; arid zones; international cooper ation; humid tropics; Middle East; North Africa; Pakistan; Sudan; Ethiopia.

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Notes:

- Name in **bold** made the presentation.
- Name **in square brackets** indicates that the presenter was different from the main author(s).
- SESSION VI: All the reports of this session were incorporated in the workshop conclusions reported on pages 41-53.

Foreword

This workshop arose from the fact that ICARDA and ICRISAT each had a series of long-term trials, all 10-20 years old, and might therefore hold a joint meeting to report the results and evaluate what had been achieved. However, as the two Centers began to develop the *Workshop Concept*, it became clear that other practitioners should also be involved to examine the future of this kind of work and, in particular, to identify practical methodologies to facilitate a wider incorporation of a long-term perspective into dry-area agronomic research.

General issues in third-world agricultural development include: intensification of production, sustainability of production increases, and sustainability of the agricultural resource base and associated environmental issues; and it was necessary to examine whether present modes of research are adequate to meet the challenge these issues pose. Annual trials, focused on yield maximization, still predominate in many programs of research. There is a need for new research modes, suited to a wider adoption and institutionalization by national research organizations, that integrate studies of production intensification and sustainability. While our present long-term trials offer one starting point for this, it must be recognized that the designs currently used tend to be costly in terms of human and financial resources. There are thus strong incentives both to find ways to extract more information from existing long-term trials and to develop new, more efficient and cost-effective research designs.

Thus the workshop became a 'state-of-the-art' review of sustainability studies in dry-area production systems, with a particular emphasis on the contributory role, current and potential, of existing long-term trials, and a quest for new, more efficient methodologies. The broader aim was to formulate a new philosophy for cropping systems research in dry areas. The program opened (Session I) with appraisals of the current situation in the semi-arid tropics (SAT) and West Asia and North Africa (WANA) and reports of findings from ongoing experiments, mainly long-term research-station plot trials. The objective was to seek patterns in the data and interpret their implications for production sustainability and the planning of future research (Session II). New programs will need to incorporate the long-term approach more generally into agricultural research and development and, not least, into the farm-level environment. Session III moved the focus to farmers' fields and the lessons learned there so far.

Session IV examined the opportunities for greater efficiency in research designs and in the collection, analysis and interpretation of data from them. How can we use ongoing trials and their historical data sets to identify the effects of management practices on long-term yield trends? Are there more efficient trial designs? To what extent can modeling help us to generalize our information and apply it validly to a wider range of situations in time and space? And how can the results from controlled research trials be relevantly related and applied to on-farm realities?

Although the workshop was focused on the developing-country 'dry areas,' sustainability is a high-profile issue on a global scale. Session V sought the research view from other environments, from the agricultural systems of the humid tropics and of western Europe, and, not least, from the donor community. How best can researchers seeking to reconcile intensification and sustainability of production give their financial supporters, national and international, value for their money? And how can it best attract that support in the first place? All these issues were brought together and thoroughly examined by means of rapporteurs' summaries and two panel discussions, which together comprised Session VI.

Early in the planning process, it was agreed that this workshop would not seek to design a new 'project' to support long-term research. Nor would it pass a long list of worthy resolutions, to subsequently gather dust on the shelf. We rather hoped that the meeting would catalyze individuals, institutions and groups of institutions to follow up on the issues raised, through new research initiatives and appraisals of existing activities, and the development of practical and feasible proposals for new linkages, networks and/or research projects to promote sustainable agricultural production systems in dry areas. The aim was to sow seeds.

As a first step and brief record of the workshop deliberations, and to stimulate a greater awareness of the issues, we publish here abstracts of all the presentations made. At the end of the workshop, it was agreed that a draft 'conclusions' paper, based on presentations and subsequent discussions, would be prepared and circulated for comments to all those who had been present. A final version of that paper, amended according to the feedback received, is included here.

Adel El-Beltagy
Director General
ICARDA

Workshop Concept

Stimulated by the Brundtland Commission report and the Rio Conference on Environment and Development, the agricultural research community identified sustainability as the ultimate goal of its research and development efforts. This is reflected in the following goal statement of the Consultative Group on International Agricultural Research (CGIAR):

> *"Through international research and related activities, and in partnership with national research systems, the CGIAR aims to contribute to sustainable improvements in the productivity of agriculture, forestry and fisheries in developing countries, in ways that enhance nutrition and well-being especially among low-income people."*

In order to implement this statement, the Technical Advisory Committee (TAC) of the CGIAR has identified a number of priority research areas, including:

* effective management and conservation of soil, water, forests and other natural resources for sustainable production,
* improved productivity of important land use systems and integration into a sustainable development framework,
* linking improved productivity to sustainable use of natural resources via an appropriate policy frame, and
* strengthening of institutions and human resources in national research systems to accelerate the process of identification, generation, adaptation, and utilization of technical innovations.

To factor these priorities into the agenda, a redefinition of the agricultural research strategy is needed, particularly for dry and often fragile ecosystems.

Strategy for Sustainable Agriculture in Fragile Ecosystems

A number of institutions in developing countries have a history of research on farming systems and resource management. However, relatively few studies have been undertaken to design strategies for sustainable agricultural production that integrate concerns for efficiency, diversified land-use systems, and environmental security. The basic question to be answered everywhere is: how, and for how long, can the agricultural production from fragile ecosystems meet expanding food requirements without threatening the resource base and the inter-generational equity in respect of its use? To answer this question adequately, research must be holistic and interdisciplinary, combining long-term perspectives of soil and water conservation and fertility maintenance with innovations that enhance yield performance. It must seek to develop high-performance production systems that both mitigate climatic risk and provide the much needed long-term environmental security.

Plan Suggested by the TAC Sustainability Committee

TAC has suggested that CG Centers together with NARS should initiate long-term research trials that quantify sustainability parameters within production systems and establish comprehensive, long-term studies targeted to specific agroecologies. This is in line with a renewed interest worldwide in long-term studies arising from a new awareness that sustainable increases in food production depend upon the implementation of programs that encourage the judicious, non-destructive use of natural resources. In 1992, the Rockefeller Foundation took the initiative to compile a directory of long-term agronomic experiments. Their analysis of over 100 experiments showed that very few reliable interdisciplinary studies have been conducted on food crops, particularly in the developing world. Most experiments were designed to evaluate crop performance or the effects of soil amendments or crop management techniques. Further, many such experiments suffer from serious limitations, in such factors as site selection, treatment relevance, adequacy and accuracy of data collection, and statistical design. These findings point to a clear need to open up new discussion on long-term agricultural research, its purposes, methodologies, and how to promote its practical application in the quest for farm-level sustainability.

Current Status of Long-Term Research by ICARDA and ICRISAT

ICARDA and ICRISAT have both, over many years, undertaken broad programs of multidisciplinary research to identify management strategies to enhance the productivity of rainfed agriculture in dry areas. Thrusts have included: the characterization of natural resources and farming systems; soil and water conservation; crop management under low and variable moisture conditions; nutrient application strategies; and quantification of production risks. These have been variously complemented by longer-term studies, which in recent years have carried an increasing emphasis on production and resource sustainability.

In particular, ICRISAT has conducted long-term watershed-based soil and water management studies on vertisols at its Asia Center at Patancheru, India, and, in cooperation with the International Livestock Research Institute and the Ethiopian Institute of Agricultural Research, at Ginchi, Ethiopia. It now has a considerable volume of long-term soil, crop and climate data from several of these activities. Meanwhile, in Syria, ICARDA has studied long-term winter cereal-based rainfed crop rotations, with livestock integration, focussing first on productivity, later on system sustainability; and parallel collaborative work has been set up with NARS partners in Algeria, Jordan, Iran and Syria. New statistical techniques have been developed to identify trends in yield from long-term rotations grown under highly variable rainfall conditions. Long-term studies have recently been expanded to

Egypt, with new sustainability trials established at five locations (four irrigated, one rainfed). Each case was complemented by a long-term program of monitoring of local farmers and farmers' fields.

Given the global interest in sustainability research, now seems to be a good time to appraise the results and the lessons learned from these activities and, further, to enhance our dry-area perspectives with experience and insights from practitioners in other parts of the world. From a full exchange of ideas, we look to identify strategies and methodologies by which longer-term sustainability-oriented approaches may be established more widely within national and international research programs for dry-area agriculture. This leads us to the following concept for an expert workshop:

STRATEGIC OBJECTIVE: The wider adoption of a more far-sighted, interdisciplinary framework for agricultural research in developing countries, linking improved productivity to the sustainable use of the natural resources.

WORKSHOP AIM: A state-of-the-art appraisal of the past, present and future of long-term agronomic research—methodologies and practicalities—to promote the sustainability of dry-area agricultural production systems.

Session I

State of the Art

1. Long-term experiments in semi-arid rainfed agriculture: ICRISAT's experience in natural resource management research

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Despite technological advances in secured irrigated regions, sustained crop production in the rainfed agriculture of the semi-arid tropics continues to be beset with problems. Food and nutritional security are central to all the agricultural research and development efforts, particularly of the marginal rainfed agriculture sector of the population-rich developing countries in the tropics. Optimized management of natural resources is a major factor in semi-arid agricultural productivity. Inadequate water-holding or intake capacity of the tropical soils and poor temporal distribution of rainfall seriously reduce the effectiveness of rain-water for crop production. Year to year variability in amount and distribution of rainfall produces uncertain crop yields and leads to insecurity in food and finance. Low-rainfall years end up in a complete denudation of vegetation cover due to high grazing pressures on the land, and when such years are followed by high seasonal rainfall, soil erosion is particularly serious. Thus a vicious cycle of low yields, poverty, rural labor migration, poor application of soil and water development practices, and soil degradation has gripped rainfed agriculture in the semi-arid tropics. These problems are likely to become more acute if changes to the global climate occur as projected by the world's leading atmospheric and oceanic scientists. El Nino of 1997 is an example. South and Southeast Asian countries have suffered from longer than usual drought periods, higher temperatures and unusual rainfall anomalies which have devastated rural economies in rainfed areas.

* * *

2. Long-term experimentation: West Asia/North Africa perspectives and ICARDA experience

M.J. Jones
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In most WANA countries, rapidly increasing populations depend agriculturally on a limited and partly degraded resource base. Constraints of climate, terrain, and

water resources preclude any major expansion of agricultural area or irrigation development. On a per-capita basis, the region's annually renewable water supply is already the lowest in the world. Nowhere is the quest for sustainable high-output systems more urgent than in the WANA region.

Across the three broad production environments—rainfed arable, irrigated arable and rangeland grazing—threats to sustainable output involve both the deterioration of resource-base condition (processes like fertility decline that are potentially reversible) and the permanent loss of resource capacity (processes like soil erosion and aquifer exhaustion). Yet agricultural research strategies are still strongly orientated to the short-term maximization of production, with insufficient regard for effects on the resource base and insufficient linkage to institutions concerned with natural resource conservation.

The importance of socioeconomic factors and farmer participation in agricultural research is at last quite widely accepted by agricultural scientists and planners in the developing world. Now, a similar revolution in thinking is needed to bring about the development of a more holistic pattern of research, one that takes appropriate account of the two-way nature of the interaction between production and resource base and of the inevitable increase in intensity and continuity of resource-base utilization in future. Long-term agronomy trials and the information they are beginning to provide on time-trends in soil properties and crop-yield parameters comprise a small step in this direction. The questions now are: how to improve that approach and apply it more widely, given the institutional and budgetary constraints; and how to build a long-term perspective more generally into agricultural research? In all this, it is important not to lose sight of the 'user' dimension. The battle for sustainable resource-base management will ultimately be won or lost on the producers' fields and rangelands. The biggest challenge, therefore, is to develop methodologies by which issues of land, soil and water management for sustainable production may be researched effectively for (and in) farm-level environments.

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Session II

Long-term On-station Experiments

3. Tillage systems and stubble management in a Mediterranean-type environment

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Sustainable agriculture has become an important way of looking at production systems all over the world. As tillage, crop residue management and crop rotations are major components of sustainable agricultural systems, long-term work in relation to these factors needs to be addressed. ICARDA is developing improved cultivars and management practices, so it needs to critically examine several systems in terms of efficiency, costs and sustainability. Therefore, two long-term trials were established in the 1978/79 and 1985/86 at ICARDA's main research station at Tel Hadya, near Aleppo in northern Syria, to evaluate the time of tillage in durum wheat (*Triticum turgidum* var. durum) – lentil (*Lens culinaris* Medik.) rotation, and tillage systems in bread wheat (*T. aestivum* L.) – chickpea (*Cicer arietinum* L.) – watermelon (*Citrullus vulgaris* L.) and durum wheat–lentil–water-melon rotation systems, respectively.

In the first trial, the two tillage systems compared were: 'conventional tillage,' which involves deep discing (25 cm) followed by appropriate secondary tillage to prepare the seed bed; and zero-till. Conventional tillage represents practices widely used by farmers on similar soils in the wetter zones (> 300 mm) of most of the WANA region. It is compared at three different times of application: early—all operations and sowing before the first rain; intermediate—discing before rain, secondary tillage and sowing after the first rain; and late—all operations and sowing after the first rains. Zero-till early and intermediate are direct-drilled at the same time as the corresponding conventional tillage treatments. The first stage of this trial was designed for weed control with a single-phase entry; the second stage started on the same plots in 1986/87 season, to concentrate only on time of tillage; it has two-phase entry (that is, both crop phases of the rotation are grown each year).

The second, 'tillage systems comparison,' trial was established to test the hypothesis that on swelling clay soils, tillage, production costs and energy use can be reduced without causing a yield reduction in crops grown in a three-course rotation. Tillage systems compared are two alternative deep tillages (disc and chisel at 25 cm) applied to dry soil, and a shallow, minimum tillage (tyned cultivator; sweep at 10-12 cm) applied after rain, and zero-till. All deep and shallow tillage systems are followed after rain by appropriate secondary tillage for seedbed preparation. Zero-till plots are sprayed with a systemic herbicide for pre-sowing weed control. An auxiliary treatment of stubble burning has been imposed on one-fourth of the plots in the wheat phase to answer questions raised by farmers about easy seedbed preparation as well as to measure long-term effects on soil properties. Both the wheat and the alternate phases are grown each year.

Wheat and lentil yielded better under normal planting conditions where the probability of obtaining rain was higher in November for both conventional tillage and zero-till. Water use was greater in wheat than in lentil crops suggesting that more water was available for wheat that followed lentil. However, water-use totals were similar across tillage-time treatments, providing water-use efficiency values parallel to crop yield levels.

Deep tillage showed no advantage over minimum or zero-till systems either for soil moisture storage or yield increase of any crop grown in the three-course rotations. The zero-till system was good for legume crops, but gave lower productivity in wheat and was not suitable for watermelon. Minimum tillage with its higher energy-use efficiency and slightly higher crop yield levels relative to those from deep tillage practices seems to be promising for the lowland areas of the WANA region. Water-use efficiencies followed the yield level differences, since water use by each crop was similar across the tillage practices. Attention will now be focused on soil indicators of sustainability since these trials have now completed more than four cycles.

Two more cycles will be needed for the soil physical properties to be quantified in relation to tillage system practices. However, tillage systems should be compared also in different WANA soil types to identify the proper tillage systems for each of them and to provide data to validate models for the extrapolation of results to wider areas.

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4. Soil-based indices of sustainability in a long-term rainfed cereal/legume rotation

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Farming systems in West Asia and North Africa involve rotations of cereals with fallow or food/forage legume crops depending on location and rainfall. Barley (*Hordeum vulgare* L.) tends to dominate in the drier zones, and bread wheat (*Triticum aestivum* L.) and durum wheat (*T. turgidum* L. var. *durum*) in the more favorable areas. Sheep and goats comprise an integral part of these systems, particularly those dominated by barley. ICARDA is developing improved cultivars and management practices, so it needs to critically examine several systems in terms of efficiency, costs and sustainability.

Accordingly, a long-term trial was established in 1983/84 at ICARDA's main research station at Tel Hadya, near Aleppo in northern Syria, to evaluate the productivity of systems in which durum wheat is rotated with vetch (*Vicia sativa* L.), lentil (*Lens culinaris* Medik.), chickpea (*Cicer arietinum* L.), medic pasture (*Medicago* spp), water-melon (*Citrullus vulgaris* L.), wheat and fallow. Varying nitrogen (N) levels (0, 30, 60, 90 kg/ha) and intensities of grazing stubble (heavy, moderate, none) were imposed on the wheat phase. Both the wheat and the alternate phase were grown each year.

The effects of rotation and N were readily apparent, but the effect of grazing stubble was slower to manifest itself. While seasonal rainfall, which ranged from 210 to 486 mm, and residual soil moisture after the alternate phase dictated the magnitude of wheat yields, N increased water-use efficiency. Grain yields of wheat following watermelon, vetch, lentil, medic, chickpea and wheat, respectively, were about 95, 85, 85, 70, 70, and 45% of those of wheat following fallow; and concentrations of N in grain and straw as well as total N uptake varied with rotation and crop yield.

As the trial progressed, attention was focused on soil indicators of sustainability. With time there was a build-up of organic matter and total N, with values showing the same general variation as yield parameters. Similarly, measurements of aggregate stability (wet-sieved) were higher for the medic plots and least for continuous wheat. Values also increased with N fertilizer level. This index was reflected in infiltration and permeability measurements. Sharp differences occurred in labile and biomass forms of carbon and nitrogen; again, values were highest with legumes (medic, vetch) and least with continuous wheat. Bacterial biomass N and C were more sensitive to environment changes. Measurements of N-mineralization, both in the laboratory and in the field, followed the same trend as organic C and total N. Net mineral N showed a strong seasonal effect. Yield monitoring of the trial should continue along with assessment of soil water data. Similarly, soil properties should be measured until equilibrium occurs.

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5. Contribution of pasture and forage legumes to the sustainability of farming systems in West Asia/North Africa

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Forage and pasture legumes were researched and widely introduced into WANA agricultural systems on a wave of enthusiasm during the 1970s; but adoption by farmers has been very limited in most places, and questions arise as to whether these crops have a role to play and what that role is.

The technical benefits provided by these crops have been demonstrated in a trial, established at ICARDA's Tel Hadya station in the 1985/86 season, which (though initiated with wheat) now compares two-year rotations of barley with medic (*Medicago* spp), vetch (*Vicia sativa*), lentil (*Lens culinaris*), barley, and fallow, with integrated sheep production, in respect of: barley yield and total animal feed/nutrient output; soil organic matter and nitrogen status; and economic return. Barley in rotation with legumes yielded better than or equal to barley in rotation with fallow or cropped every year. In the rotations with medic and vetch, soil organic matter and total soil nitrogen had increased, by 32% and 43% respectively, up to 1995. Part of this was attributed to the estimated 30% of plant material returned to the soil as faeces by the grazing sheep.

The farm-level perspective on such legume-based systems is given in Abstract 16.

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6. Crop yields and soil properties as influenced by long-term dryland crop rotations in Central Anatolia

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Results of early crop rotations and farmer experience have shown that the replacement of fallow with certain crops is consistent with the achievement of sustainable yields. Experimental rotations to eliminate fallow, employing high-yielding and input-responsive wheat varieties, have been established since 1982. The objectives were to substitute fallow with crops with little or no yield loss in subsequent wheat, to increase farm output, to allow good distribution of farm labor over the season, to maintain soil productivity, and to provide feed for livestock.

The crops that replaced fallow were sunflower, safflower, spring and autumn sown lentils, chickpea, Hungarian vetch (for hay), cumin (rape for last 2 years) and wheat (barley for first 2 years). All crops were fertilized with N and P and weeds were controlled by chemicals or by hand.

Average wheat yield over the 14-year-rotations were highest in the fallow-wheat system. This was closely followed by the Hungarian vetch-wheat system with a 6 % loss relative to fallow-wheat. Wheat yields after lentils, cumin and chickpea similar to each other, at about 12 % less than that from fallow-wheat. Highest relative losses were found with the wheat-wheat and safflower-wheat rotations (43 and 32%, respectively).

At wheat sowing time, water and mineral N contents of the soil were very much influenced by the preceding crops and fallow. Much more moisture remained in the soil after fallowing than after any of the alternate crops. Cumin and winter crops (vetch and lentil) left the most moisture in the soil, wheat the least. Previous crops also affected soil moisture distribution in the profile. Values of mineral N- (NO_3 and NH_4) contents in the soil at wheat seeding time revealed that legumes were as effective as fallow for N accumulation. Some physical and chemical properties of soil as affected by the rotations were also studied.

It can be concluded that Hungarian vetch (for hay) can replace fallow particularly in livestock production areas. An important advantage of this crop is its early harvest time (mid May), when soil is still moist enough to allow good seedbed preparation for the next wheat crop. Winter lentil has the same advantage, but yield instability and weed problems are drawbacks for this crop. From the economic point of view, it seems that all crop rotations tested except for continuous cereal and safflower-wheat can be put into practice. Farmers have already been growing sunflower, chickpea, spring lentil and vetch in rotation with wheat in various parts of the Central Plateau.

* * *

7. Sustainability issues of a vetch-barley system

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Long-term rotation studies have been carried out in Cyprus since 1980. The systems under consideration are continuous barley, vetch-barley, fallow-barley and barley hay-barley. The systems have been compared regarding: barley productivity and yield stability, value in feedstuff production, farmers' income, rainfall use efficiency, N_2 fixation by vetch, nitrogen cycling and sustainability.

Productivity of barley following vetch was higher than any other system considered. Even with the application of nitrogen fertilizer, the continuous barley system was not able to match the productivity of unfertilized barley in the VB system. Relative to continuous barley the fertilizer replacement value of vetch for the subsequent barley crop was 60 kg N/ha, and that of the fallow 30 kg N/ha. Barley yield was more stable in the VB system and had the highest rainfall use efficiency. It was also shown to have the highest feedstuff value and quality and to be the most profitable to the farmer.

Based on the long-term data collected within these studies a model was developed to study the N cycle and N_2 fixation by vetch. It was estimated that on average vetch fixed 212 kg N per year. The amount of N_2 fixed was found to be: (a) 89 kg in the herbage of vetch removed from the plots, (b) 31 kg in barley the year after vetch, (c) 74 kg released and received by vetch and barley in subsequent cycles, and (d) 18 kg in the improved soil organic nitrogen under the VB system. The total amount of N_2 fixation estimated by this model is twice what is usually estimated using other methods. These findings strongly support the promotion of legumes into the farming systems.

Even though the vetch-barley system is the most sustainable system among the ones compared, the dominant system in Cyprus is still monoculture of barley, because barley is favored by subsidies and vetch production creates more marketing and management problems than barley. Nevertheless, to introduce a sustainable system it is imperative that legumes be used in rotation with cereals, and emphasis should be given to solving the marketing and management problems of legumes.

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8. Rotation, tillage and fertilizer effects on wheat-based rainfed crop rotation in semi-arid Morocco

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Water is often a limiting factor for crop production in the arid and semi-arid regions of Morocco. Water conservation techniques combined with proper crop management are necessary for using water efficiently to increase and stabilize crop yields. Different studies in these regions have shown that wheat yield is highly variable and depends on preceding crop, water and soil conservation practices, and on soil fertility management.

This paper summarizes a decade of research on wheat under different cropping and management systems in the semi-arid regions of Morocco. Rotations studied included wheat, forages, food legumes and fallow. Furthermore, management included no-till and minimum till as well as different tillage combinations and nitrogen fertilizer regimes. Response of wheat to rotation, tillage and fertilizer treatments was site- and year-dependent. Shortage of nitrogen was shown to be as critical as water to wheat yield. Biological nitrogen fixation and residual N could not satisfy wheat N requirements. Fallow management affected water storage, real N recovery and contributed to wheat yield the following year. Water conservation, water use and water-use efficiency as affected by rotation type, tillage and N fertilizer are discussed.

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9. Long-term effects of grain legumes on rainy season sorghum productivity in a semi-arid tropics vertisol

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In semi-arid regions of southern and central India, in areas receiving annual rainfall around 750 mm, vertisols are generally kept fallow and cropped in the post-rainy season, owing to problems of land management and waterlogging during the rainy season. To facilitate crop intensification in these soils, ICRISAT developed an appropriate vertisol technology. As most of these vertisols are poor in major plant nutrients (N and P) and crop intensification increases nutrient demand, nutrient supply is one of the major constraints to crop intensification. Grain legumes not only serve as a source of dietary protein but also add nitrogen to the soil. A long-term experiment was established at ICRISAT Center with the objectives of quantifying the benefits that grain legumes provide to non-legumes in the crop rotation and to monitor long-term changes in soil quality for sustainable crop production.

The beneficial effects provided by different legumes, in various combinations, to succeeding rainy-season sorghum were critically analyzed in relation to a complete non-legume system (sorghum+safflower). Rainy-season sorghum production was sustained and increased over a 12-year period within a continuous sorghum/pigeonpea intercrop system. A cowpea/pigeonpea intercrop was found to contribute about 40 kg N/ha fertilizer equivalent to succeeding rainy-season sorghum, but legume benefits were more conspicuous in the pigeonpea system than in the chickpea-based rotation. Over 12 years, a significant build-up of soil total N (125 mg/kg) was observed in the pigeonpea system. The sorghum benefited significantly from this system, but yields of pigeonpea declined over the years due to soil-borne fungus and nematodes. A wider rotation of cropping systems with pigeonpea may avoid these problems and still sustain sorghum production.

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10. Dynamics of soil structure amelioration and degradation of a semi-arid tropical Alfisol under different management systems

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Structural degradation is widely perceived as a major problem in the cropping of Alfisols in the semi-arid tropics. Poor structural stability is the result of a low and inactive clay content and a low content of decomposed organic matter. The consequence of poor and unstable soil structure is susceptibility to the formation of a surface crust or seal with a resultant decrease in infiltration and increase in runoff. Prevention and/or reversal of this deterioration is essential to the improvement of the long-term productivity and sustainability of this important group of soils.

ICRISAT, in collaboration with the Queensland Department of Primary Industries, Australia, initiated in 1988 a systematic study to quantify the effect of fifteen soil management options on soil structure and the processes associated with it, on an Alfisol (or rhodustalf) of the Patancheru series, under an average annual rainfall of 784 mm, with over 80% falling in the June-October period. The treatments were each applied to runoff plots, 28 m long and 5 m wide, with slopes of 1.5-2.0%. Rainfall and plot runoff amounts were measured at one minute intervals using a tipping-bucket system. The fifteen treatments consisted of: the nine factorial combinations of three tillage depths (cm), 0 (ZT), 10 (ST) and 20 (DT) and three organic amendments, zero control (B), farmyard manure (FYM) at 7.5 t/ha/year (F), and rice straw at 5 t/ha/year (S); and six perennial pasture treatments, involving pigeonpea (P), *Cenchrus ciliaris* (C), and *Stylosanthes hamata* (St), grown sole or as mixtures. In 1992, the perennial crops were removed and the plots planted to a cereal to compare the cumulative effect of the different soil management histories. Since 1995, further application of manure and straw amendments was stopped in the treatments previously under deep tillage (DT)

Changes in soil structure were monitored in terms of changes in rainfall infiltration and runoff. Tillage effects on runoff varied from year to year. Runoff from the STB system was very similar to that from the ZTB system. A 20% reduction was observed for the DTB system, which was not statistically different from that of the ZTB in most years. Further analysis indicated that benefits from tillage are evident during the first 200 mm rainfall after tillage. The two approaches to surface management, mulching with straw and improving the structure with FYM, were both very effective. Runoff was consistently low from plots amended with manure or straw. Cumulative effects of FYM and perennial systems were evident from the second year. Among the perenials, systems with 'stylo' (St) were very effective in reducing runoff. The benefit from perennial systems arose mainly from the existence of ground cover for extended periods and improvements in soil structure from the action of roots and litter additions. A gradual increase in runoff was observed in these plots after their return to annual cropping in 1992, suggesting structural degradation; and a sharp increase from DTF and DTS system since 1995 when straw and FYM additions were stopped. These temporal changes under different systems and their implications for soil management are discussed.

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11. Integrated nutrient use in a pearl-millet-based system in the semi-arid tropics

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Four pearl millet genotypes having high nitrogen fixing ability were grown annually, at three rates of nitrogen application, in an Alfisol at ICRISAT Center, Patancheru. Annual grain yields varied significantly from 730 to 2040 kg/ha over the period 1981 to 1995 and showed significant interaction between genotype and environment. Cluster analysis separated genotypes into two main groups, and environments similarly into two groups. Further principal component analysis and biplots indicated that these two components accounted for about 84% of yield variation. Mean yield over 15 years was increased to 1580 kg/ha by 40 kg N/ha compared to values of 1340 and 1350 kg/ha from 0 and 20 kg N/ha, respectively. Mean total dry matter production ranged from 2.8 to 5.4 t/ha between 1981 and 1995, as did harvest index (HI), 25.2 to 39.8%, and N transaction index (NTI), 32.5 to 68.6%. Application of N did not change HI and NTI. Total nitrogen uptake was similar in all four pearl millet genotypes, but the 20 and 40 N rates showed significant increases over the zero N control (35 and 43 compared with 31 kg N/ha). Moving averages for grain yield, total dry matter and total N uptake showed stable patterns over the years. Mean apparent fertilizer recovery varied significantly between genotypes and over 15 years varied from 16 to 84%; but total 15-year N uptake was similar in all four genotypes. Soil total N content showed a marginal increase between 1981 and 1991 in the 0-15 cm layer but marginal decreases in other sampled layers down to 60 cm.

Soil mineral N content at sowing time was always considerably greater (1.5 to 8 times) than at harvest time indicating build-up of mineral N during the dry sea-

son, results that were supported by the findings from microbial biomass C and N measurements. Values of nitrogen mineralization potential (N_0) for the 0-15 cm soil were similar irrespective of previous N-rate plot treatments; the nitrogen mineralization constant was slightly higher in the 40 N plots; but the active N fraction was similar (>>15%) in all plots. Nitrogen application up to 40 kg/ha increased mycorrhizal colonization of millet roots, but genotypes showed some differences in colonization (25 -35%).

These long-term studies showed that selected pearl millet genotypes having N_2-fixing ability continued to produce grain yields of up to 2 t/ha year after year. Lack of major change in soil mineral N or N_0 values showed that soil N capacity had not decreased even after 15 years of millet cultivation. Detailed N budgeting is now in progress. It appears that on an Alfisol in this SAT environment, selected pearl millet genotypes can be sustainably grown with low levels of applied N or even zero N.

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12. Long-term effects of tillage, P fertilization and crop rotation on pearl millet/cowpea productivity in the West African Sahel

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The millet-based cropping systems that dominate the Sudano Sahelian Zone of West Africa cannot, as they are currently practised, meet the growing food needs of the region. They must therefore be intensified in a sustainable manner. The present study was initiated in 1986 and continued until 1996, to evaluate the effects of P fertilization, tillage, and rotation with sole cowpea, on an operational scale on two cropping systems, sole millet and intercropped millet/cowpea. A randomized complete block design with four replications was used.

The effects of P fertilization, planting on ridges made with animal traction (AT), and rotation with sole cowpea, on the productivity of millet were substantial in 10 out of 11 years. Based on the 11-year average, P fertilization alone improved grain yield by up to 52% and, with AT, improved it by nearly 135%. Combining AT, P fertilization, and rotation with sole cowpea gave a 200% increase in grain yield over that of the traditional system of production (TS). Millet productivity did not decrease significantly when intercropped with cowpea. Analysis of stability, and of relative stability, showed that the TS was more stable than the various improved agronomy packages but gave the lowest yield. Conversely, the agronomic package with the highest yield advantage over the TS was the least stable.

A major portion of the annual variation in environmental index for millet grain yield and total dry matter was attributed to the seasonal variation in rainfall and to soil organic matter depletion. Soil organic matter content declined linearly with years of cultivation. Significant differences were found in the rate of depletion between the different agronomic treatments tested; but, after 11 years, nearly 60% of the organic matter was depleted irrespective of the agronomic package.

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13. Salinity build-up and changes in the rice-wheat system of the Indo-Gangetic plains

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Green revolution technologies have led to the emergence of rice-wheat (RW) as the major cropping system in the Indo-Gangetic Plains (IGP). The strategy of groundwater development and its conjunctive use with canal supplies has paid rich dividends in the control of waterlogging and secondary alkalinization and in an increase in the pace of alkali soil reclamation programs in areas underlain by freshwater aquifers. Rice-wheat systems were the preferred choice of the farmers, but their adoption has changed the salt and water balance in the northwestern parts of the IGP. It has led to receding water tables in the northeast of Punjab and Haryana and to waterlogging and associated problems of secondary salinization in southwestern parts. In the eastern IGP, in West Bengal, development of groundwater aquifers to meet the irrigation requirement for intensification/ diversification of agriculture has led to a serious problem of groundwater contamination due to dissolution of arsenic-bearing minerals, under altered soil moisture regimes conducive to the oxidation of pyritic sediments.

These experiences suggest that there is an urgent need for a change in the way food is produced in the IGP, to ensure the sustainability of the natural resource base. This will depend on our ability to predict the long-term consequences of the intensification and diversification of agriculture at farm and regional scale. Whereas issues of favorable regional salt and water balances need attention in northwestern IGP, the management of rainwater and alleviation of drainage congestion can facilitate the adoption of agricultural technologies and improve the productivity of RW systems.

14. Disease occurrence in long-term rotation trials in northern Syria

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The occurrence and intensity of diseases of barley, wheat and legumes grown in the long-term rotation trials at Tel Hadya and Breda in northern Syria, were determined during the 1996/97 cropping season. In barley-based cropping systems, rotations of barley-forage legumes (B-L), barley-fallow (B-F) and barley-barley (B-B, 'continuous barley'), with and without NP fertilization, were evaluated for foliar and root diseases of both barley and forage legumes (*Vicia* and *Lathyrus* spp.). Root diseases of barley, especially common root rot (CRR), were evaluated according to symptoms observed on subcrown internodes at both locations, but barley scald (*Rhyncosporium secalis*) was evaluated only at Breda. In wheat-based cropping systems (Tel Hadya), selected treatments—'heavy-grazing' stubble management and +N treatments—were evaluated for CRR of wheat and for nematodes.

In the barley-based systems at both locations, disease intensity (DI) for CRR of barley was low in plots rotated with legumes compared with that for barley in rotation with fallow or continuous barley. Moreover, at both locations DI was higher in unfertilized plots than in those receiving biennial NP fertilization. Barley scald severity was lower in plots in B-L rotation than in those carrying continuous barley (B-B) and was higher in plots fertilized with NP in the previous season. Downy mildew (*Peronospora viciae*) and ascochyta blight (*Ascochyta* spp.) were observed on the forage legumes. For both diseases severity was generally higher in plots fertilized with NP in the previous year than in non-fertilized plots. Lathyrus was severely affected by stem and leaf blight at Breda but not at Tel Hadya. Severity was greatest in plots that were fertilized during the previous year. In the long-term barley-based tillage trial at Breda, the B-B rotation showed significant differences in CRR incidence between N rates and their interactions with tillage but not between the main-treatment tillage practices themselves. Greatest disease intensity was observed in plots with high N applications. In the B-V rotation in that trial, however, no significant treatment differences were observed.

In the Tel Hadya wheat-based cropping systems, significant differences between N-rate treatments in CRR intensity were observed, with the highest DI values in plots with high N applications. Rotations and N applications significantly affected cyst nematode (*Heterodera latipons*) populations, cyst numbers decreasing both in the soil and on the root with increasing N rate. In the legume phase, significant differences were observed between legumes with respect to populations of cyst (*Heterodera ciceri*) and root knot (*Meliodygne artiellia*) nematodes in the soil and on the roots. Plots fertilized with NP in the previous year had lower nematode populations than non-fertilized plots.

Session III

Observations
on
Farmers' Fields

15. Evolving cropping systems

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Nine basic traditional systems may be described in West Asia and North Africa (WANA). Each could have been found in the region at least a thousand years ago, and, although their technology has changed dramatically, the fundamental dependencies on the resource base have not greatly changed. Such systems may be classified either as intensive or extensive, intensiveness indicating the degree to which land, water and human resources are employed to sustain production. In WANA today the main trend is one of intensification: for instance, in rainfed systems, cropping intensities are going up as fallows are reduced; all irrigated systems are expanding in land use and water use; both traditional tree crops and non-traditional protected agriculture are expanding; and classic nomadism is giving way to transhumance, which in turn is intensifying in its utilization of agricultural products and by-products, with feedlotting now a common phenomenon in many areas. Nevertheless, there are also significant areas where de-intensification, that is reduced human attention to maintaining the resource base through continued agricultural use, is the major threat to resource sustainability. Two environments where this is occurring are the terraced rainfed production systems in highland areas and extensive cereal systems in plateaus and plains.

How do we relate the observable changes in farmers' production systems to experimentation and, particularly, long-term experimentation? First, the main objective of farmers is production; and, although the great majority of farmers recognise its importance, maintaining resources cannot be achieved at the expense of production. Experiments meant to have direct relevance to farmers must incorporate this reality into their design. Secondly, 'systems' experiments (rotation trials, etc) must accommodate to the reality of shifting targets, and care must be taken to avoid addressing any system with little future prospects within the intended environment.

In discussing long-term experimentation, it is convenient first to identify where the research falls within the research continuum and what 'deliverables' are required from it. If it lies within the domain of basic or strategic research, then direct relevance to farmers is not important; relevance and application to problem solving will necessarily involve additional applied and adaptive research activities. But if long-term experiments are required to produce outputs of more immediate relevance to farmers, that is, if they are seen as applied and adaptive research, then the prior analysis and understanding of what is actually happening within farmers' production systems, including likely patterns of change, becomes crucial to proper experimental design. Targets should be long-term and anticipatory, based on what is likely to be problematic for farmers in the future.

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16. Promoting pasture and forage legumes in West Asia and North Africa

16a. Tah village project in Syria: another unsuccessful attempt to introduce ley farming in the Mediterranean basin

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A participatory on-farm project was initiated at Tah village, 100 km south of Aleppo, Syria, in 1984. The objective was to introduce medic (*Medicago* spp.) as a replacement for fallow in dryland wheat/fallow farming systems. About 50 farmers were directly involved in the project while an equal number were passive participants, receiving seed but no technical advice. The project did not attain its objective. An array of profitable crops such as lentil, cumin, sesame or watermelon, as well as price support on wheat, presented formidable economic competition to the use of pasture on cultivated land. Technical constraints included insufficient farm size, lack of a medic phase in every year, deep ploughing, overgrazing and inability to protect medic fields from other flocks. The Tah project experience suggests that feed production projects must also include an assessment of how the feed benefits animals and should be designed in such a way as to demonstrate the economic advantages of integrating livestock and crops in dryland farming systems.

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16b. On-farm trials with forage legume/barley compared to fallow/barley rotations and continuous barley in northwest Syria

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On-farm forage legume trials were conducted for 7 cropping seasons at a site (El

Bab) in northwest Syria where mean annual rainfall is about 270 mm and barley the most common crop. Trials aimed to involve farmers in studies to quantify the benefits of using common vetch, *Vicia sativa*, (V) or chickling, *Lathyrus sativus*, (C) to replace the fallow year (F) in a barley-fallow rotation or to introduce forage legumes into continuous monocropped barley (B). Thus, there were four rotations, B-F, B-B, B-V and B-C, with both phases being represented each year. The trials were replicated on 6-8 farms, depending on the year, and each site covered 4 ha divided equally between the two phases. Each year 30-60 kg N/ha was applied to half of the barley area. Several farmers chose to graze lambs on the vetch and chickling crops in the spring.

Feed yield from both phases was greatest from the B-V and B-C rotations. Mean 7-year dry matter yields (t/ha), summed for both phases of each rotation, were: 2.91 (B-F), 4.82 (B-B), 5.02 (B-C) and 5.32 (B-V), respectively. Total outputs of crude protein were twice as high for the rotations including legumes as those from B-F and B-B. The B-V rotation gave the highest output of metabolizable energy. Application of nitrogen increased barley dry matter yields by about 1 t/ha in all rotations. There was no significant nitrogen x rotation interaction. Lamb liveweight gains averaged 194 kg/ha.

Farmers realized the beneficial effect of introducing vetch in the rotation and started to adopt the technology. Whereas in 1991 only three farmers in three villages were growing about 7 ha of vetch in total, by 1997 the number had increased to 174 in 15 villages, with a total area of about 420 ha. However, farmers say that the growing of forage legumes will not become widespread until inexpensive and efficient mechanized methods of harvesting the mature crop are available to avoid the high cost of hand labor. Drought and cold tolerance, early maturity, and high harvest index may also enhance farmers' interest in forage legumes. These attributes are being studied by ICARDA's forage breeders.

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17. Strategy for long-term sustainability of rice-wheat in a high-production system

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To meet the stipulated 240 million tonnes of food grain requirements of India by the year 2000, to provide food security for her burgeoning population, and to counter shrinkage of the arable resource-base resulting from rapid urbanization and industrialization, new alternative crop production technologies are urgently needed to raise crop productivity. Maximum Yield Research (MYR), which involves balanced high fertilizer-use, offers one such option. A study conducted for 9 years (1986-87 to 1994-95) at Punjab Agricultural University, Ludhiana, showed that the application of N-P_2O_5-K_2O at 180- 30-30 to rice and at 180-60-30 kg/ha to sequentially grown wheat under high population stands (44 hills/m^2 in rice and wheat at 15 cm spacing) that 2-crop total yields of 13-15 t/ha/year could be harvested (rice: 7.2 to 9.6 t/ha and wheat: 5.7 to 5.9 t/ha). The MYR technology showed a higher crop leaf area index of 0.84 and 0.99; biomass increase of 1.2 and 1.1/t ha; tiller numbers at harvest were more by 19 and 17, and NPK uptake increased by 10 and 21 kg/ha for rice and wheat crops, respectively. All these factors together resulted in a grain yield advantage of 0.7 t/ha for rice and 0.8 t/ha for wheat, over the treatment in which recommended levels of N-P_2O_5-K_2O at 120-30-30 to rice and 120-60-30 to wheat were applied. The incorporation of green manure resulted in high yields of a similar order together with a net saving of 60 kg N/ha.

The results of the evaluation of the MYR technology on farmers' fields at 126 locations in six districts of Punjab state over five years (1990-91 to 1994-95) confirmed its technical superiority. A 1.8 t/ha/year net increase in grain yield of rice + wheat was observed. Further surveys revealed that a sizeable number of farmers were using higher than the presently recommended rates of fertilizer, which for rice are set at 120-30-30 and for wheat 120-60-30, of N-P_2O_5-K_2O kg/ha. However, the added advantage due to higher plant populations was currently not being realized by the farmers.

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18. Developing a sustainable land management research strategy for the GAP project in Turkey

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With food security as an important concern, the Government of Turkey has embarked on an ambitious project to develop the southeastern part of the country. The southeastern Anatolian development project, with an acronym of GAP (Guneydogu Anadolu Projesi), is one of the largest irrigation and hydroelectric power projects to be undertaken in Turkey. The GAP project was conceived in the sixties when productivity and food production was the only concern, and all the past research was focused on this. However, since sustainability emerged as an issue in the eighties and nineties, the integrity of the environment has almost become an overriding factor. Research institutions, particularly those traditionally concerned with enhancing production, were, and many still are, ill-prepared to meet these new challenges. The agricultural research community appreciates Sustainable Land Management (SLM) as a concept, but there is considerable hesitation in launching SLM related research activities. The environmental component still baffles the agricultural scientists. As a result, progress in this area is slow.

A good strategy anticipates constraints to sustainability and develops technology to address them. The research strategy considered here will focus on the technical solutions needed to ensure sustainability. As the emphasis is on sustainability, system monitoring is considered an essential feature of the strategy. The indicators must be carefully selected prior to commencement of the project and monitored during the duration of the research activity. The indicators considered here supplement the data collected in agronomic trials. They are generally monitoring the system (project area) as a whole and are measures of its quality and health. Socioeconomic indicators serve as proxies for such purposes. Ecosystem indicators are more difficult to determine and require greater effort to monitor. They are as important as the socioeconomic indicators when sustainability is being studied. Some important questions need to be considered to develop a research strategy, and these include the following:

1. Has the quality of life of the communities in the area been significantly enhanced?
2. What changes can be recommended to maximize profits and minimize risks?
3. What components of the ecosystem are being aided or hampered by irrigation?
4. Is land degradation (or components of it) being changed and in what direction?
5. Is the productivity of the soil resource base being attained and maintained?
6. Is the current pattern and mix of land use the best for the goal of sustainability?

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Session IV

Philosophy and Methodology

19. Design perspectives in long-term experimentation

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During the last decade, increasing interest in global change has been demonstrated worldwide. Changes to the natural environment relate to climate change resulting from natural disasters, influences of pollution and agrochemical usage upon the production of gases, and biological change to renewable natural resources such as land, forestry, wetlands influenced by management of land and marine productivity. Population changes result from the effects of urbanization, the impact of fertility controls and fluctuations in health caused by population pressures and the declining availability of natural resources. Of immediate importance is the conservation of biodiversity, assessment of long-term sustainability and the management of sustainable development.

Influencing these are changing priorities of political and developmental institutions. Political change has resulted in the movement of aid funds to new areas of the world and fluctuating availability of funds for the continuation of existing projects. Yet developmental change has resulted in greater emphasis being placed on participatory studies to assess uptake of interventions by farmers and long-term social and economic impact of research upon communities. The assessment of multidisciplinary integrated systems over lengthy periods of time is crucial to this.

The design of long-term experiments to incorporate systems and impact upon communities is necessarily complex, and their management must be well controlled to ensure that objectives remain adhered to, that mishaps and undesirable changes to treatments do not occur and that data structures are consistent in time. To handle the complexity of multicomponent studies, specific approaches to design relating to the study objectives must be chosen. These can be categorized as:

- detailed studies on one or two system components, and which can depend much on traditional, documented designs for long-term studies with the additional possibility of controlled modifications in time;

- whole system studies which require monitoring of all system components and their inter-relationships in time and which may involve rapid assessments to identify changes or complex data collection exercises to model the detail of system changes; and

- assessments of sustainability of the system and/or of impact of the system upon the environment including local communities and which demand clear definition of indicators for continuous assessment.

Underpinning any long-term experiment is the need for good management and accurate data collection and storage. The ERA database, developed at Rothamsted Experimental Station, provides a format to ensure this for any experimental regime.

Finally, no experiment should be designed without consideration of the analyses which are to be done; otherwise, design and sampling features may be inadequate to achieve them. Recent advances in computer power have resulted in the availability of powerful statistical methods which can estimate changing correlation patterns and provide precise models for sustainability assessments for all types of data that may be generated from any long-term study.

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20. Time trends of yields in long-term trials

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Trends over time of annual crop yields potentially provide measures of the likely long-term sustainability of cropping systems. However, where large interannual variability in the growth environment is responsible for most of the large year-to-year yield differences, appropriate analytical techniques must be developed to distinguish real long-term trends from the 'background noise'. This paper presents models (having a first-order auto-correlation structure to allow for plot errors over time) for the estimation of time-trends in the yield data from crop rotation systems and discusses the results of applying these models to yield values from two types of long-term trial (one under crop rotation, the other under monocropped barley), each conducted at two sites in northern Syria.

Twelve years of data for barley grown in rotation with annual forage legumes, clean fallow or more barley (monocropping), with and without biennial N and P fertilization, show some positive and some negative time-trends. At the wetter site, trend values for grain and straw were all negative in the absence of fertilizer and were mostly positive in its presence; but many values were not statistically significant, and the analysis indicates that for many treatments more cycles of the rotation are required for the detection of significant time trends. The second trial, comparing the effects over nine years of different annual nitrogen and phosphate applications, factorially combined, on monocropped barley, also gave a mix of positive and negative trends; and here also many treatments require more time to establish a

significant trend. Altogether, the clearest result, supported by both trials, was at the drier site, where it appears that the grain yield of monocropped barley declines over time irrespective of the use of fertilizer.

The models used in this analysis were linear with respect to time (years) and allowed for seasonal effects by means of a relationship quadratic on total rainfall and linear on planting date. A more complex model might account for more of the variance and allow significant trends to be identified earlier, but restrictions are imposed by the limited number of degrees of freedom (number of years less one) and the choice of meaningful single-valued parameters of growth-season conditions. It was noticed that for many experimental treatments the model accounted for less of the total variance at the wetter site. This may be due to seasonal buffering by soil moisture stored at depth from one year to the next, and future iterations of the analysis will try to allow for this. The appropriateness of the linear time function is also questioned, and alternative functions will be tested. Finally, it is noted that the trials from which the data analysed here came were not originally designed for this purpose. Improved design might be expected to lead to greater precision and the earlier identification of significant yield trends in new trials.

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21. Some statistical issues and approaches in long-term experiments

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Long-term experiments are characterized by field plots which are repeatedly measured for the same variable or set of variables over a long period of time, any particular plot being subjected to either the same treatment continuously or to a well-defined sequence of changes in treatment over time. Statistical methods currently available for the analysis of these repeated measurement data are reviewed. The practical limitations of these methods are discussed. Some alternative approaches, based on pattern analysis, to overcome the limitations and/or to supplement the present methods are suggested.

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22. Progress towards modeling whole-farms: the need for long-term experiments

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Data available from a long-term experiment at a research station at Wongan Hills (in the Central Wheatbelt of Western Australia) inspired the development of a process-based simulation model (WASP) to explore the effects on farm-level biophysical processes, and possible long-term implications for productivity and profit, of various styles of management on a typical mixed cereal-sheep farm, set on a loamy sand soil under 350 mm mean annual rainfall. Examples are given of the usefulness of the long-term data sets in the construction of the model. From published results from up to 16 replicates spread over 8 years of four-year sequences of wheat crops following 2, 3, 5 and 7-year pastures dominated by subterranean clover, a model for wheat yield was constructed that regresses yields on soil N conditions and the number of crops grown since the pasture phase. Long-term soil N dynamics was modelled for both pasture and wheat phases. Under wheat, a balance sheet approach showed that all total soil N in excess of 450 kg/ha was apparently available, but once this available N itself exceeded 250 kg/ha, losses by leaching and/or wind erosion occur. Using data from another long-term trial, it was shown that the increase in soil-N under pasture gradually stops. Model validation, using later (unpublished) data from the original trial, indicated that the model had correctly captured the main features used to build it.

An example of the use of the model shows how critical it is to control ryegrass which, though a good pasture species, is also the system's worst weed. Results show that, if the farmer cannot control his ryegrass, his farm's profits will be cut by half in four years. Although pastures thrive and stocking rates rise, wheat yields fall rapidly because of grass in the crop. However, suppression of clover in the pasture leads to a decline in total soil N; and, in the long term, as soil N is depleted, ryegrass is replaced by returning clover, a cycle of around sixty years.

The development of a model of this type raises many questions, and some have no immediate answers. However, it seems acceptable to model fast-moving variables (eg. seed pools near the soil surface) using data from short-term experiments, even though there is some risk that too few types of season are sampled; but for slow-moving variables like total soil N, only long-term experiments can give really reliable data. The time horizons of predictions are discussed. Uncertainty increases with length of prediction. With complex models, unexpected interactions between component models and the compounding of errors become more likely. Hence, the use of models to assess sustainability, especially where slow-moving

variables are important, seems to demand the existence of long runs of data. Simulation without long-term data to test the model introduces uncertainty and, probably, trouble.

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23. Modeling dryland cropping rotations in ICRISAT's watersheds

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A simulation analysis was conducted on some promising rotations from one of ICRISAT's oldest long-term experiments, Black Watershed No. 1 (BW1) at Patancheru. The purpose was to extrapolate response over a wider range of weather conditions. Rotations selected for analysis were subsets of more complex rotations. In this analysis we compared: (1) a traditional 1-year cycle of *kharif* (rainy season) fallow followed by *rabi* (post-rainy season) cropping of sorghum; (2) a 1-year *kharif-rabi* cycle of maize followed by chickpea; and (3) a sorghum/pigeonpea intercrop rotation (in which pigeonpea was sown with sorghum as an intercrop in the *kharif* and harvested at the end of the *rabi* season). Over 8 years of the experiment (1981-1988): sorghum in the traditional rotation yielded an average of 1.2 t/ha (range, 0.37 to 2.6 t/ha); maize yielded 3.54 t/ha (3.22 to 4.71t/ha) and chickpea 0.97 t/ha (0.65 to 2.17 t/ha); and intercrop sorghum 3.26 t/ha (1.06 to 4.45 t/ha) and pigeonpea 0.76 t/ha (0.12 to 1.92 t/ha).

The APSIM simulator was used to simulate yield after parameterisation of the cultivars in the experiment with the data observed in the years 1989 to 1994. Simulated yields were similar even though they tended to be a little higher than those measured, but there were some significant departures. Coefficients of determination (R^2) were generally low, ranging from 0.01 to 0.5 for grain yield. This reflects the narrow range in observed yield, but over all crops R^2 for grain yield was 0.66. Overall, the accuracy of the simulation of yield was similar to what has been achieved with other comparable models (Residual Standard Deviation = 0.78 t/ha).

The analysis of simulated response over 23 different years of weather conditions per rotation showed that the inclusion of two crops, one a highly productive *kharif* cereal (maize, mean yield 4.27 t/ha) and the other a profitable *rabi* grain legume (chickpea, mean yield 1.50 t/ha), offers a greater productivity potential than the traditional fallow-sorghum system (mean yield 2.10 t/ha). The more intense system, however, required more nutrient inputs, but the high water-holding capacity of these vertisols makes this possible. The intercrop sorghum (2.60 t/ha)/pigeonpea

(0.70t/ha) rotation was also very productive, requiring less nitrogen fertilizer, an important consideration when rainfed farmers of the semi-arid tropics do not have access to the high inputs needed by the maize/chickpea system.

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24. A new research paradigm for sustainability research in Egypt

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The sustainability of intensive irrigated agriculture in Egypt has become an increasingly critical issue, given limited land and water resources on the one hand and rapid population increase on the other. Salinization, heavy use of inputs, nutrient export, and pollution all threaten the health of soils that have been feeding Egypt for centuries. At the same time, the build-up of newly reclaimed desert soils to an economically sustainable productive capacity is a major challenge. In a collaborative initiative between the Agricultural Research Center (ARC) of the Ministry of Agriculture and Land Reclamation in Egypt and ICARDA, funded by the European Union, a long-term research program has been developed to address the issue of agricultural resource management in a multidisciplinary way.

Program activities began with a preparatory phase, comprising inventory studies, rapid rural appraisal and multi-disciplinary surveys. The knowledge gained was used in the planning of two closely related research activities: long-term agronomic trials (LTT) and long-term farm monitoring (LTM). The long-term trials (with such variables as water quantity, water quality, nutrient input and crop rotation) have been established at sites representing the old irrigated lands, the areas newly reclaimed from desert, and the rainfed agricultural areas. Each trial is complemented by extensive long-term monitoring in villages close to the experimental site, recording farmers' perspectives, farming practices and the condition of their soils and crops, with the aim of identifying over time sustainable and non-sustainable practices and the social and economic factors that underlie them. Now the program is functioning, we suggest that the complementarity of LTT and LTM activities within an integrated multidisciplinary approach provides a new research model for the identification of sustainable, intensive production systems that has wider application to other agro-environments.

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Session V

Agricultural Sustainability in a Global Context

25. Sustainability perspectives in the agricultural research of developed countries

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The current approach of developed countries is to aim not merely for sustainability but for sustainable development. The most commonly used (Brundtland) definition of sustainable development is "Development that meets the needs of the present without compromising the ability of future generations to meet their own needs." There is much debate about how to achieve this aim and what can be used to indicate progress towards it.

In developed countries intensive agriculture has produced plentiful supplies of relatively cheap food; problems of surpluses and food 'mountains' or 'lakes' still occur. Reserves of raw materials to support intensive agriculture are sufficient for decades to come, but the emissions of carbon dioxide, nitrous oxide, nitrate and ammonia from agriculture are contributing to climate change and air and water pollution; intensive farming also changes the landscape and employs fewer people. Food quality and health problems, such as BSE, are seen by consumers as being the result of intensive agriculture. Pressures on the industry (as it is now called) come mainly from these environmental and social concerns. The immediate effect of this is research and legislation to reduce emissions, but with the underlying view that such losses imply waste and that there is, therefore, a need to strive for sustainability.

A proper approach to sustainability must include all its aspects - agronomic (can the ecosystem maintain adequate food production), economic (can the ecosystem maintain a profitable farm system), environmental (what are the effects of farming on the environment and biodiversity) and social (what kind of social structure or community is required). The assessment of these four aspects is at best semi-quantitative. The idea of acceptability in terms of level of farm income, landscape, and community structure, is central to any assessment of sustainable agriculture.

There are three main views as to how agriculture in developed countries can become more sustainable: (i) increase production through intensification on the best land, with some extensification on poorer land or in sensitive environments; (ii) low(er)-input farming, with profits maintained by reducing input costs that compensate for reduced yields; and (iii) fundamental change towards ecological/organic farming, with no fertilizers and pesticides. The present Market Economy favored by most developed countries, and especially the price support system of the European Union's Common Agricultural Policy (CAP), favors option (i). Reform of the CAP is changing this, however.

Some novel research approaches have been used to assess agricultural sustainability: sustainability is favoured by minimizing the increase in entropy of a system; this can be measured via an audit of small molecules (carbon dioxide, nitrate, etc.). The Rothamsted Classical Experiments were used to show how sustainability might be quantified using Total Factor Productivity, which measures all on-site and off-site inputs and outputs, including social and environmental factors. Whatever technique is used, research into sustainable agriculture requires a 'Systems' approach; i.e. the inclusion of whole farms and, preferably, their local environments. This is the only way that the agronomic, economic, environmental, and social aspects of sustainability can properly be researched. This was the objective of the UK's Organic Farming Study, carried out on the Duchy of Cornwall's Home Farm in Gloucestershire. Research into nutrient flows on this mixed arable, dairy, beef and sheep organic farm produced an environmental audit, showing the true 'costs' of different types of farming.

However, the world population is increasing. People in developed countries will not easily accept reduced or greatly changed diets; and people in developing countries want the lifestyle of those in developed countries. Continuous technological development, such as the introduction of genetically-modified crops, will be needed for sustainable development that is socially acceptable. This must be supported by 'Systems' research that assesses the agronomic, economic, environmental and social impact of farming, with the aim of producing abundant healthy food at an economic return to the farmer, whilst maintaining an acceptable (to the local/national population) environment and biodiversity and social structure. It is unlikely that every requirement for all four aspects will be attainable.

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26. Towards sustainable land management in the twenty-first century with long-term trials

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IBSRAM is an international 'institution without walls' which promotes and conducts collaborative research on all aspects of land management. It operates globally in partnership with national agricultural research and extension systems by building links between national and international research organizations, in both developing and industrialized countries. The network or consortium mode of operation is used to overcome the problem of fragmentation arising from the location specificity of much research on land management problems, and to promote a partnership approach focused on the needs of national systems. IBSRAM's partnership programs encompass the spectrum from adaptive to strategic research. The adaptive research is vital to the focus on rural communities of developing countries. However, effective research across a range of different agro-ecosystems requires an adequate understanding of the processes in these systems. IBSRAM therefore aims to bridge the gap between adaptive and strategic research. Its programs operate at the systems level, targeting land management in an interdisciplinary mode, with an emphasis on soils; and its scientific staff include network and consortium coordinators based at headquarters in Bangkok and outposted in the Pacific and Africa.

Long-term trials have been in progress for 5-10 years in four networks, in Asia, Africa and the Pacific, and long-term trials at a water-catchment level started recently in a fifth network across seven Asian countries. A feature of many of these trials is that their designs are dynamic and respond to research findings, to concerns of the decision makers (farmers, leaders of small communities, local plannners), and to donor suggestions. With new interview techniques, a particular effort is made in all networks to learn the objectives and constraints of the prime target group (subsets of farmers with different needs), to combine indigenous knowledge and scientists' knowledge into an R&D project, and to monitor adoption of the new technologies. In that way, IBSRAM projects address biophysical and socioeconomic aspects of production systems in an integrated manner, and reconcile the immediate need of farmers for more productive systems with the long-term need for sustainable land use.

In biophysical systems that continue to change for many years after a perturbation, well-focused field trials are required to quantify the rate constants for the slow processes. Such processes include: build-up and breakdown of pools of soil nutrients, of weed populations and of (soil-borne) diseases. There is no need for farmer participation, except in the selection of the conditions for the trial. The rate constants are crucial in models for the dynamic exploration of yet unknown situations.

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27. Donor expectations in long-term research for agricultural sustainability

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USAID is a development agency and needs answers to development questions, but research is an important component of development. Agency activities are driven by politics, and the view tends to be short-term, but there is an interest in sustainability. Attitudes to a changing world are driven by such phenomena as GATT. The foreign assistance budget has shrunk, making it necessary to be more selective. There is an increasing tendency to seek more collaboration and coordination, to look for partnerships, for instance with the commercial sector, to get done what needs to be done. At the same time, the Agency is promoting bottom-up approaches and more 'ownership' by those most closely affected.

Economic growth is the key concept. Other prominent issues include food security, rural development, poverty reduction, and, in the environment sphere: climate change, carbon sequestration, and economic growth effects on health. Above all, for continued funding support, it is necessary to demonstrate impact - in readily comprehensible ways. Long-term research is not ruled out, but it needs to accommodate short-term accountability, by showing progress in terms of the achievement of pre-set milestones and in relation to indicators. Integration into the development process is highly desirable. The opportunity here is for research organizations to play a catalytic role, bringing people together, developers, researchers and beneficiaries.

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28. Potential versus practical sustainability: the importance of uptake and impact

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The UK government view is that eliminating world poverty is the challenge for the twenty-first century, and this is now the area of focus for DFID funding. Within the Natural Resources Research Division of DFID, current policy, at least for UK-based programs, includes strict monitoring of project performance. Funding must be justified in terms of impact. Output in the form of research results is not enough; there must also be uptake leading to impact. Research for its own sake is out. However, it is accepted that impact on farmers is not the only impact possible; impact on other researchers, through new thinking and new methodologies, and impact on policy makers and policies is also recognized.

In this there is some danger of short-termism. To make impact in the short term, there is need to identify key technologies, low-cost, low-risk interventions, to 'unlock' farming systems and induce further improvements. In other words, catalysis. Are there key technologies in relation to sustainability, legumes possibly, and can they be promoted by changes in the local policy environment? But long-term experiments are worthwhile only if the interventions under scrutiny have real potential for uptake by farmers; otherwise we are considering only *potential* sustainability.

Workshop Conclusions

Introduction

Throughout the dry areas of the developing world and, in particular, West Asia and North Africa (WANA) and the Semi-Arid Tropics (SAT), economic and demographic pressures are driving agricultural producers to intensify their systems. This raises serious questions about the long-term sustainability of both the systems and the supporting natural resource base, as well as the possible environmental consequences. At present, coherent multidisciplinary programs that bring these concerns together across the broad 'upstream-downstream' research spectrum are rather few; and, despite widespread perceptions among environment and development specialists of the need for longer-term research perspectives, most donor agencies and research managers increasingly require shorter-term research accountability and the more rapid achievement and demonstration of impact. Indeed, strategic long-term agronomic studies set up with donor support 15-20 years ago are now criticized for having no results directly transferrable to farmers. In fact, many such trials contributed useful basic knowledge that guided subsequent adaptive and participatory research, but in a rapidly changing world this is no longer seen as sufficient. It is clear that the time is ripe for new thinking. New research methodologies are required that accommodate both urgent productivity concerns *and* long-term sustainability and resource management issues. This paper summarizes Workshop discussions on these themes and attempts to define a new research paradigm, *Anticipatory Long-term Research for Sustainable Productivity*, that addresses the needs of the many different stakeholders of agricultural research (farmers, national policy makers and development agencies, rural and urban poor, and donors) for sustainable, high-yielding, profitable, environmentally-friendly agricultural production systems.

The problem

Two contrasting, and sometimes competing, viewpoints currently influence the planning and funding of third-world agricultural research. The first sees poverty, food shortages, and population increase, and puts high priority on problem-solving measures to boost production quickly. The second believes that productivity increases cannot be isolated from resource utilization issues; that most management actions produce cumulative effects, causing production environments to evolve (for better or worse); and that intensification of production incurs costs. Particularly in poverty-driven, low-input systems, those costs are charged to the natural resource base, which in many situations is visibly deteriorating. Protagonists of the first view often argue that if big enough productivity advances can be made sufficiently rapidly, then protection and recovery of the resource base will follow later when the users are more prosperous; others are less optimistic. What is needed is a greater coordination of purpose in activities promoted by these two schools of thought, a research approach that balances present and future priorities according to a more holistic understanding of short- and long-term processes in the production environment. Long-standing institutional structures rarely encourage this and cannot easily be restructured. Nevertheless, it is necessary to continue to argue the case for maintaining a body of strategic long-term research and, further, for conducting much of the short-term research more consciously within that longer-term framework. Hence the need to develop, and gain acceptance for, a broader, long-term research paradigm.

Perceptions of what is meant by 'long-term research' differ widely. To the skeptic, it is simply an 'ivory-tower' activity that *may* have a payoff sometime in the future. More optimistically, it is (or should be) a broader conceptual framework within which practical questions of both a short- and long-term nature may be answered in a coherent manner. This is a matter of research design. The most widely practised form of long-term research at present is long-term agronomic plot-trials (LTT), and most of these have formal designs, in which predetermined treatments are applied every year without change. Most were initiated to compare the productivity, biological and economic, of different rotations and management/input sequences, although, after a number of years, they also begin to provide information on yield trends and cumulative effects. Their output is useful for ranking rotations and management options under controlled conditions, for establishing basic long-term relationships, and for quantifying slow-moving processes for the purposes of modeling. The consistency of the applied treatments greatly facilitates the analysis and interpretation of results. In themselves, such trials are essentially 'strategic' (or at least 'basic') in that they were not usually *designed* to lead directly to farm-level recommendations (and this is, in the current climate, a major point of criticism). However, to the extent they are used also as the framework for other more short-term studies, specific recommendations can and do emerge. In any case, their main function is to provide a strong knowledge base to underpin problem-solving research conducted at the farm level.

A second criticism of formal designs is that the experimental treatments chosen initially may decreasingly match farm-level realities as time goes by (even though for certain strategic objectives that may not matter); and the observation that many real farming systems are undergoing rapid change generates a demand for a 'dynamic' approach to long-term studies. Yet a third criticism concerns experimental venue. Until quite recently (and in some countries still today), agricultural research was conducted only on research stations. Following the introduction of farming systems research approaches (FSR) and on-farm testing, much short-term research is now spread across both on-station and on-farm sites. Most LTTs, however, are still found within the research station fence, partly for historical reasons, and partly because of the need for long-term control of the land. Although such locations are highly advantageous for strategic research, isolation from the real-farm environment is felt by some to hinder practical relevance. It follows that any new long-term paradigm must encompass the possibility of long-term research that is both dynamic and, at least in part, conducted outside the research station fence. A major challenge is to involve farmers (and their indigenous knowledge and perceived constraints) in the design and conduct of long-term research.

But whatever the approach, it is essential to be clear about research objectives, both long-term and short-term. The skeptic's watchword is relevance, but the question then is: relevance to what? Long-term issues, though possibly of little consequence to short-term productivity priorities, are not therefore *ipso facto* irrelevant. Good research programs not only solve present problems but also anticipate those that could arise later. While addressing current constraints to system productivity, they should seek also to identify the underlying long-term threats to that system and its resource base, which, if left unrecognized or unchecked, could trigger urgent productivity crises at a later date. Thus the *context* of all research should be strategic, anticipating change. That context includes, for example, scenarios in which increasing inter-sectoral competition for water progressively raises the profile of water-efficient rainfed farming and also leads to the preferential allocation of irrigation resources to higher-value crops (within a more open global trading environment). It includes situations, too, in which the 'mining' of arable land will, if continued, reduce yields eventually to zero and open the soils to final degradation by erosion. Rapid decline in soil organic matter is a matter of serious concern for many agroecosystems.

Options for change

The need is therefore not for less long-term research, but for new, more efficient designs that host, within the same activities, objectives and potential outputs useful at the farm level with different time-scales and with sufficient built-in flexibility to accommodate change. Potentially, such dynamic designs might take several forms:

A. LTTs, in which initially 'fixed' treatments are reviewed (and possibly amended) every few years. A variant of this keeps some treatments permanently fixed, to meet strategic research objectives, while amending others, as necessary, in response to external changes.

B. Sequences of related shorter-term activities (each with its own milestones and potential impacts) designed to link together, as a program, to realize strategic longer-term objectives. This model has the advantage of flexibility, with early results feeding back into possible refinements of objectives, while matching better to demands for short-term accountability and early impact.

C. Integration of formal LTTs (with consistent treatments) with parallel long-term, on-farm studies within local (and evolving) farming systems [as in the Egypt resource-management study, being jointly conducted with ICARDA].

Almost certainly, other designs may be conceived. Design must be matched to purpose. It is important to erase the notion that there are or should be standard recipes for long-term research; rather, it is an open conceptual system. LTTs are not a uniform species of experiment but, potentially, highly flexible tools that can deliver the requisite new information *if the right questions, and designs to answer them, are appropriately formulated.* Among other functions, LTTs provide opportunities to check out the performance, and possible side effects, over time, of new technologies recommended to solve short-term productivity constraints.

The present aim then is to promote a new, broader, anticipatory long-term research paradigm. However, as already noted, there are many, usually 'formal-design', long-term trials currently operating, and an early question asks if and how these fit within the new paradigm. Investments have been made; and, in some cases, large information bases have been built up. By what criteria do we judge how best to continue this work, either in its present form or with modifications, and what items might be discontinued without serious loss, to make way for new initiatives? First, most existing LTTs, at least implicitly, have two main types of objective:

(a) To compare the productivity of different sequences of crops and management inputs.

(b) To monitor yield trends and other indicators of sustainability.

Most trials started with objective (a) that tended to determine trial design; but the perceived importance of objective (b) has increased in recent years, as the databases have lengthened and 'sustainability' has become a prominent issue. In many cases, old productivity-oriented LTTs are a resource, by which scientists can now look at certain aspects of the sustainability of cropping systems without incurring a long lag period inevitable in starting a new trial. Nevertheless, some hard decisions are required. Issues include:

1. *Productivity comparisons*: most of the original 'productivity' questions are probably answered in the first 6-10 years. Review at this stage should ask whether there are new productivity questions, or revised versions of the old ones, that can be pursued effectively within the same trial - in other words, is it possible or useful to modify the trial to serve new problems and new on-farm realities? (This is the 'dynamic' principle, (a) above).

2. *Sustainability comparisons*: to what extent can LTTs set up first to distinguish productivity differences, be used later to provide information on long-term 'sustainability' trends, e.g., through:
   - analysis of historical data? (New analytical methods may be needed.)
   - design changes and/or introduction of new forms of measurement?
   - the involvement of a wider range of disciplines?
   - contributions to modeling (and model validation) processes?

And to what extent does this new function justify continuing the LTTs for a longer period?

[Skeptics question whether this more detailed mining of data from LTTs really gives *new* information or just serves to confirm what we already knew - for instance, that legumes build up soil organic matter and nitrogen, or that improved soil structure enhanced infiltration and so plant growth. Certainly, the value of such data will depend on local perceptions of the need for better *quantification* of well-known processes, but not all processes are 'well-known', and - for most - quantification *over time* and, comparatively, between *different systems* will usually be new. Moreover, hard data are required to extend modeling from single crops to whole systems.]

3. Can existing LTTs also provide '*short-term deliverables*,' that is, recommendations of immediate productivity relevance to end users? The answer in most cases is certainly 'yes'. In fact, many long-term trials already play host to secondary projects or shorter-term studies (e.g. N-cycling and water-use efficiency, and control of weed, pest and disease build-up under different management regimes) which should have useful outputs; and there is undoubtedly scope for more. An ideal LTT is a multi-purpose, open-ended, multidisciplinary research laboratory, with new studies fitted in as need arises. This gives high value per unit cost of trial maintenance.

4. How can the findings of LTTs that relate to yield and soil trends and production sustainability be conveyed to farmers? This question relates directly to the crux of the matter. *Effective transfer of technology* to farmers is rarely possible without the convinced, whole-hearted involvement of extension agents and also, very often, an appropriate enabling policy environment. Where long-term research has so far been primarily of a strategic nature, there will usually be a large gap to bridge before benefit to farmers is achieved. The principle by which the knowledge base generated by strategic, on-station research underpins problem-solving at the farm level is actually quite difficult to apply in the realm of sustainability. It involves such issues as land (and land tenure), soil, water, and pest populations, which are much less amenable than, e.g. crop variety and husbandry to quick technical fixes. The time scales are different. Early economic returns are difficult to demonstrate and cannot be guaranteed. Not least, the promotion of technologies with longer-term, sustainability-oriented objectives is outside the experience of most extension workers and even agricultural policy makers.
This last issue moves us on from a consideration of how to capitalize on existing LTTs to what is needed in the new long-term research paradigm. Most of our present LTTs operate towards the left-hand end of the spectrum of research modes:

strategic - basic - applied - adaptive - adoptive

However, for eventual farm-level impact, long-term studies must be extended across the spectrum, with bi-directional interaction. We may expect output from strategic research to feed into the other modes both directly, through linked on-farm testing, and indirectly, e.g., through modelling generalizations. At the same time, indigenous knowledge and farm-level constraints identified through adaptive and participatory activities will feed back into applied and basic research. It may be possible to fit some existing LTTs into this concept. New-style LTTs will likely have a different balance between productivity/sustainability objectives as well as greater design flexibility and spectrum width, with built-in linkage to farm-level activities. This holistic approach will, where appropriate, include the animal component of mixed systems and issues of integrated pest management. It will also link closely to farming systems research (FSR) activities for improved productivity and technology testing, to the new field of user-participatory resource management research, and to projects for *in situ* biodiversity conservation. Indeed, all such research activities necessarily have long-term perspectives and, on many issues, have overlapping aims with long-term agronomic research.

The new paradigm

The above thinking leads to the conception of a new frame of reference (or paradigm) for planning and conducting research to support evolving agricultural production systems in a rapidly changing world. The new paradigm, ***Anticipatory Long-Term Research (ALTR),*** puts a stronger time dimension and dynamism into traditional agronomy, enhancing ties to socioeconomic and resource management disciplines, and linking current priorities for increased productivity with strategic long-term issues concerning the sustainability of production and the natural resource base. An essential feature in the choice of research issues is *anticipation of* and *precaution against* problems that may arise from current rapid agricultural development, especially from an increasing intensity of production and resource use. Major deliverables will include technical interventions and policy options to avoid, as well as to solve, future problems of production decrease and resource-base degradation. Activities are conceived and justified in terms that seek to marry current needs with such concepts as intergenerational equity and long-term poverty alleviation.

The paradigm incorporates such ongoing research approaches as long-term trials but is altogether a broader concept, based on prior environmental characterization and encompassing a wider range of objectives and methodologies. Research venues will range from research-station trials and farm plots to full catchments and landscapes (with appropriate linkage between them). At larger scales, we may envisage data coming from an array of georeferenced sites, backed by appropriate remotely-sensed databases, agroecological characterization and GIS systems.

Particularly at larger scales, ALTR will often be closely linked to (or be an intrinsic part of) rural development or resource conservation activities. Research-development liaison on long-term effects, particularly follow-up and monitoring of earlier development projects, could be an important mode of ALTR activity.

However, at all scales, the design of new ALTR should build in relevance to evolving farming systems (and the socioeconomic and policy climates within which they are embedded), and seek to combine:

- a focus on technologies for immediate transfer *with*
- an anticipation of future problems (in the light of what farmers actually do and could do).

To achieve this, it is necessary in each case to work with and understand the present farming system and its likely evolution, at the same time identifying those non-homogeneities of aims and constraints within it that define targettable niches or recommendation domains. It will be necessary also to beware of possible adverse downstream effects, and to seek ways, acceptable to the local community, to avoid them. Most farmers rate short-term profitability much higher than long-term sustainability (and certainly avoidance of downstream nuisance). No sustainability innovation will be adopted unless it is also profitable.

The above concept is very general and, indeed, idealistic. It outlines a new thinking for research planning but, since local circumstances differ, it cannot prescribe a detailed methodology. That will always be, to a considerable extent, location-specific. Nevertheless, the resource-management program initiated some years ago in Egypt, a collaborative activity between ICARDA and a group of national research institutions, provides an early example of the paradigm in action:

Program activities began with a preparatory phase, comprising inventory studies, rapid rural appraisal and multi-disciplinary surveys. The knowledge gained was used in the planning of two closely-related research activities, long-term agronomic trials (LTTs) and long-term farm monitoring (LTM). The long-term trials (with such experimental variables as water quantity, water quality, nutrient input and crop rotation) have been established at sites representing the old irrigated lands, the areas newly reclaimed from desert, and the rainfed agricultural areas. Each trial is complemented by extensive long-term monitoring in villages close to the experimental site, recording farmers' perspectives, farming practices and the condition of their soils and crops, with the aim of identifying over time sustainable and non-sustainable practices and the social and economic factors that underlie them. The complementarity of LTT and LTM activities within an integrated, multidisciplinary approach provides a new research model for the identification of sustainable, intensive production systems that has wider application in other agroenvironments.

Other issues

The Workshop covered a broad field. Although consideration of the past, present and future of dry-area agronomic long-term trials provided the initial basis of the meeting, a number of other topics closely involved in the 'long-term' issue were discussed:

Modeling and extrapolation. Models are essentially hypotheses about relationships, usually expressed in mathematical form. In cropping systems, the simplest models express, for instance, values of crop yield or soil properties in terms of relevant environmental parameters. They may simply be static regressions, or may involve iterative processes that simulate development, dynamically, on a time-step basis, e.g. from day to day. Though initially only descriptive (summarizing existing information), after validation against additional experimental data from a range of situations, such models can be reliably predictive (within limits); and through linkage to spatial arrays of environmental parameters, particularly weather, they can be used to extrapolate point-source information spatially. Further, dynamic time-step models can be extended from single-season to multi-season mode and may therefore, from an optimistic viewpoint, be used to replace or at least augment LTTs (and, possibly, other forms of ALTR). However, there are several issues here:

- Single-season crop models are built from real-crop databases; and multi-season 'long-term' models must, no less, be built from appropriate long-term databases (which requires LTTs or other systematic long-term observations). Validation requires a similar range of real long-term data sets, independent of those used originally to construct the model. Thus there is a paradox: models could replace LTTs but only if there is enough real long-term data initially to build and validate the models (bearing in mind that the real farming systems which the models should simulate are themselves dynamic).
- Extrapolation in time is of a different nature from extrapolation in space - because at any given site local changes may accumulate. Sustainability is concerned with the long-term future. A model built and validated even with the best real-world data sets cannot be expected to predict reliably for much longer time spans than those inherent in the original data. Apparently linear relationships may in the long run prove curvilinear, causing reality to diverge from prediction. Inference from short periods to long periods is inherently risky.
- It is useful to distinguish between models for systems and models for particular resource-base mechanisms. Stable models may be more easily achieved for mechanisms involving fairly simple input/output processes; for example, it may be possible, from fairly short-term data to estimate with a fair degree of accuracy future long-term trends in soil nutrient pools or the build-up of salinity, thereby contributing to the anticipation of management problems.

- Some relationships are changed by extrapolation across scales. Thus results from plot trials cannot necessarily be transferred to the catchment scale and/or need to be re-validated at that scale. One future component of ALTR may be long-term catchment-scale resource monitoring, perhaps feeding into models for other catchments.

Natural resources as capital. Many farm-level production systems, essential to the welfare of present societies, are currently non-sustainable, because year by year they are consuming their own resource base (through soil erosion, nutrient/organic matter depletion, etc). Accepting that sudden improvements are not humanly or economically possible, long-term research needs to focus on

- Resilience of these resources - what are the threshholds from beyond which they will never recover? [Sustainability indicators are not enough; we also need targets for those indicators.]
- What are the systems needed to rebuild and sustain these resources?
- How may we guide the evolution of current systems towards those sustainable systems (while maintaining viable, economic production and farmer confidence/cooperation)? In some marginal situations, it may be necessary to encourage changes away from arable production to tree-crop or pasture systems (for the economically more efficient use of the water supply and for the protection of the soil).

Swaminathan's concept of three zones, of intensification, maintenance or restoration, is relevant here, indicating the need to refer to land-use quality or capacity indicators. Alternatively, we may think in terms of low, medium or high input systems, although the key word in any given environment is probably 'appropriate.' Whichever concept is used, identifying the level appropriate for the environment and its people and the timescale involved is clearly an essential first step in the development of the research strategy. Another key insight is the occurrence in some situations of system de-intensification. Although it is widely agreed that most systems will (and must) intensify, de-intensification can also occur (for example, the abandonment of mountain terraces in Yemen) and gives rise to different issues for the sustainable long-term management of the natural resource base under lower-productivity systems.

Sustainability indicators. The most direct measure of sustainability is crop or system productivity. If, with steady inputs, yields stay steady over relatively long periods of time, there is an implication of sustainability. Declining yields imply non-sustainability, although they may later stabilize at a lower levels. There are similar uncertainties about rising yield trends. Statistical estimates from yield data can give early indications of trends otherwise obscured by seasonal 'noise', but there may be hard decisions over the type of mathematical function to fit (linear or curvilinear), and the choice made can affect the perceived result. Such estimates of yield trends can be used to compare the relative sustainability of different systems running side by side.

'Indicators' are indirect measures of sustainability, independent of systems. Thus a simple soil parameter is more generally applicable than the yield trend of a chosen crop. In the technical context, indicators are essentially measures of resource-base capacity or condition that bear directly or indirectly on productivity. At the field or catchment level, losses of soil through erosion indicate non-sustainability of the resource base and, eventually, of the production system. Quantification may be unnecessary except to estimate system lifespan or to make comparisons between systems. Similar remarks apply to finite underground water resources (renewable or non-renewable).

Most other indicators involve routine measurements to detect changes over time. For instance, a decreasing soil content of any plant nutrient implies an imbalance between input and export which, unchecked, must lead to declining productivity; but the solution technically, if not always economically, is usually easy. A build-up in salinity may be similarly detected but much more difficult to remedy. Other gradual changes in soil condition inimical to sustainable yields can pass unnoticed until they suddenly pose serious problems, for instance: pest infestation (especially nematodes), heavy metal build-up (particularly where effluent water and solids are applied), and the degradation of structural properties. Two widely considered indicators are soil organic matter, changes in which are taken to imply likely changes in chemical fertility and/or structural stability, and biomass (or microbiological activity) which is taken as a measure of 'soil health.'

However, the relationships between technical, resource-base indicators and yields and yield sustainability are not straightforward. Some decrease in soil organic matter and biological activity to lower equilibrium levels may be consistent with sustainable production, although linear decreases that continue indefinitely undoubtedly imply non-sustainability. For most indicators there are threshhold values, above which the system may be regarded as 'safe.' For any given indicator, such values will be specific to location and, possibly, system. Where values are currently below the threshhold, system productivity is probably suboptimal and non-sustainable; and the threshhold may be seen as a target for system improvement to aim at.

Depending on need, any of these technical indicators may be adapted for use in monitoring regimes at farm, catchment or zone level. However, it is important to distinguish such technical indicators, appropriate to scientific discussion, from indicators likely to be meaningful to non-scientists. Indeed, alternative indicators are needed for such different stakeholders as policy makers, donors, scientists, and farmers. A herder may, for instance, be particularly sensitive to the disappearance of a key plant species, by which he judges rangeland quality for grazing; whereas national policy makers will react to the amounts of sand blown across important roads or silt deposited in reservoirs. Other indicators may be dynamic or opportunistic, measuring system responses to policy changes, technology transfers in space (e.g. from one village to the next) or population migration. Particularly at system level, there are many dimensions to 'sustainability' and hence many potential indicators to measure. The temptation to combine these measures together mathematically in compound indices of overall sustainability, even for non-scientists, should be avoided.

Economic or non-technical indicators may be applied to the performance of whole systems. In developed countries, where the environment is of greater current concern than the food supply, attention tends to focus on 'environmental auditing.' Attempts are being made to cost farming in terms of environmental effects, such as water and air pollution, the reduction of biodiversity, as well as the cost of energy, seed, fertilizers, sprays and labor. One method of environmental auditing is total factor productivity (TFP), in which all factors that relate to crop production, including those listed above, market prices, etc, are calculated, weighted and combined to give a single, numerical factor (Barnett *et al* 1994). The system is considered sustainable if the TFP is >1. For example, in a long-term wheat experiment on a sandy soil (Woburn, England), where structure failed and the soil became acid, TFP declined to almost zero; but on a silty clay loam soil (Broadbalk, Rothamsted) exactly the same production system remained sustainable, with TFPs between 1 and 4. Significant improvements in TFP followed the introduction of new, high-yielding varieties and pesticides. Interpretation of single estimates of TFP need great care. Utility is greatest when patterns of changing TFP over time are compared for different systems (as at Rothamsted and Woburn). Any changes in their relative patterns need to be explored and the reasons, both mathematical and agronomic, discovered (Goulding & Riley, *personal communication*, 1998).

WANA/SAT and the rest of the world. In the developing world, sustainability means primarily 'sustainability of food production' (preferably on a rising curve), followed, at lower priority, by sustainability of the agricultural resource base, with avoidance of downstream effects and pollution running a poor third. Confusion in communication may arise with developed-world institutions principally concerned with environmental issues, and this may even color donor perceptions of funding priorities. Current funding opportunities with Western donors are said to be in the environmental rather than agricultural arena.

At the same time, the increasing globalization of world trade may disadvantage the dry areas in the production of certain commodities. Possible implications include:

- shifts in farming systems towards higher-value crops (with comparative advantage locally) that use the resources (especially water) with greater economic efficiency.

- shifts in farming systems, in the most marginal environments, away from arable crops to pastures and/or permanent crops.

There may be opportunities here for exploiting synergisms between global economic forces and local requirements for long-term production sustainability and resource conservation.

However, the importance of agriculture as a livelihood for large sections of the dry-area population (especially in the semi-arid tropics)—again a contrast with developed countries—should not be forgotten and must be factored into all policies to promote sustainable production. In many places, subsistence systems are evolving towards high-productivity (market-oriented) systems, partly as a response to a changing balance between urban and agricultural populations. Anticipatory research, and other development measures, are needed to ensure that such initiatives can be sustained in the long term.

Impact. Research must have demonstrable value. The popular measure is impact, but what is meant by impact differs between stakeholders. The impact may be on: other researchers (their knowledge and ideas); farmers (their incomes but also their resource base); policy makers (and the achievement of national targets); or donors and their domestic constituency. Some would say that the ultimate test of research value is farm-level adoption, although, to achieve that, appropriate policy adjustment is often necessary. At a different scale, policy makers and donors are looking for impact in the form of national production increases, economic growth, poverty alleviation and natural resource conservation. The increasing challenge to agricultural research scientists is to satisfy each of the stakeholders simultaneously. The new paradigm 'Anticipatory Long-Term Research for Sustainable Productivity' offers the opportunity to do this effectively and efficiently.

Conclusions

- In the developing world, farmers are being driven towards more intensive systems, but—particularly in dry areas—the question arises, are these systems and their natural resource bases sustainable?
- The current funding ethos tends to favor agricultural research activities that promise quick impact on production levels for poverty alleviation. At the same time, many western donors give high priority to environmental concerns but, in many cases, without linkage to agricultural imperatives. The prevailing gap between production intensification and environmental protection is potentially a dangerous one.
- Agricultural scientists have the responsibility to urge that longer-term strategic research is an essential part of their agenda. If production (on a rising production trend) is to be sustained in an uncertain world of increasing population, finite resources, and climate change, research must have a major anticipatory function. This need not conflict with urgent concerns for poverty alleviation. Flexibility and dynamism in research design will provide both short- and long-term outputs.

- This multiple challenge demands a more integrated framework for agricultural research, and a new paradigm, *Anticipatory Long-Term Research for Sustainable Productivity (ALTR)*, is proposed. This paradigm enshrines the concepts of sustainability, equity and poverty alleviation and envisages research approaches that are holistic, dynamic and anticipatory. Potentially, it includes system-focused activities across the full spectrum of research modes, from basic, through applied and adaptive to adoptive (farmer-participatory).
- ALTR is much broader in concept than traditional long-term experiments, but such experiments will likely comprise a core function in many ALTR programs. They will need clear objectives, with frequent reviews, and must be carefully run with regular sampling and data archiving to enable their application to future, as yet unknown, problems. Considerable ingenuity will be needed at the design stage to ensure that dynamic treatments in no way preclude subsequent meaningful data analysis/interpretation for both short- and long-term objectives.
- ALTR provides no fixed methodology for general application. It is, rather, a research philosophy, which may be variously applied according to the needs of the situation. However, it might often be set up on a 'core + satellites' model, with interdisciplinary activities to establish principles at a few core sites *closely linked* to satellite experiments, field observations, surveys and monitoring programs conducted at the level of farming community and farmers' field—altogether providing two complementary bodies of information.
- ALTR programs will output information at different levels and over different timescales (according to specified research aims); but the utilization of this information, both for interpretation and extrapolation, will be optimized through the use of modeling.
- Since sustainability of agricultural production and the supporting natural resource base are key concerns, all ALTR programs will include the development and testing of indicators of sustainability appropriate to the local environments and production systems.
- Impact of ALTR programs will be judged on a multi-criteria basis, to include effects on: farmers and other resource users; national research and extension services, their methodologies and institution building; national policy makers; and the contribution to international public goods in the form of tested and effective research methodologies.

Acknowledgements. Helpful and constructive comments on an earlier version of 'workshop conclusions' from Drs K. Goulding, J. Riley, I. Papastylianou, A. Taimeh, R. Dudal, H. Eswaran and F. Penning de Vries are most gratefully acknowledged.

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ICARDA-007/750/Mar 1999