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Sense and Sustainability: Sustainability as an Objective in International Agricultural Research

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Abstract

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This paper first discusses how to use sustainability as a criterion by which to evaluate agricultural research, then illustrates the difficulties inherent in applying the criterion and finally draws implications for international agricultural research. Seven propositions relating to sustainability are stated. Agricultural researchers are urged to (a) recognize the importance of the sustainability of agricultural systems. (b) devise appropriate ways to measure sustainability, (c) empirically examine the sustainability of some well-defined cropping or farming systems, (d) define the externalities that exist in such systems, and (e) develop methods to measure those externalities.

Introduction

The international agricultural research establishment, having achieved a degree of visibility following the so-called Green Revolution, has attracted the attention of international gadflies and social critics, each new generation proclaiming new criteria for the evaluation of agricultural technology. Previous criteria have included production, technology for small farmers, welfare of low-income consumers, technology for women, diversification and stability. Sustainability is the latest twist in the continuing elaboration of criteria by which agricultural development is defined and agricultural technology is evaluated.[1]

A spate of recent publications have explored the possible implications for the environment, human welfare, and the world food balance that have been signaled by indications that the agricultural resource base in the tropics is

[1]Two facts illustrate the gadfly nature of the word sustainability: one is hard pressed in 1988 to find an agricultural conference, publication or new research program that does not include 'sustainability' in its title, but the word does not appear in Webster's New Collegiate Dictionary or in the dictionary of WordPerfect 3.2.

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being over-exploited. These reflect a concern for the future and at their most profound represent an imperative for the world to plan more thoughtfully, and in some instances reconsider, the progress of tropical agricultural development. While fully accepting the need to be concerned about future development paths, this paper attempts the more limited and mundane task of considering how sustainability concerns might be incorporated into the research activities of the international agricultural research centers.

The emergence of the sustainability criterion has come from the recent visibility of ecologists in agricultural development in the Third World. Nevertheless, the theme of sustainability has been appropriated by a range of institutions interested in agricultural development and now includes a broad array of concerns about the maintenance of the resource base to ensure future levels of agricultural production. These concerns encompass such diverse areas as loss of genetic diversity in crop species, tropical deforestation, soil erosion, the effect of agro-chemicals on the environment, and the implications of global warming for agricultural production. Those concerns are high on the agenda of the international agricultural research establishment; however, because sustainability is essentially a set of concerns about future conditions, it is not easy to translate these into operational agricultural research activities.

The sustainability concept could be incorporated into the research process at three levels: (a) as an evaluation criterion in technology testing, (b) as a design criterion in the creation of crop technologies, and (c) as a set of concerns (objectives?) around which to organize research. Progression from (a) to (c) signifies the upgrading of sustainability from an intermediate to an end objective (Pinstrup-Andersen and Franklin, 1977). Moreover, at the first level, sustainability could be incorporated in existing research programs while the third level implies the reorganization of the research process.

The paper explores issues raised by the above structure. The first section addresses the question of how to conceptualize sustainability as a criterion for evaluating agricultural technologies. The second section illustrates the difficulties inherent in applying such a criterion in technology design problems. Finally, the implications for research within the international agricultural research centers are addressed in the third section. A number of propositions relating to sustainability, and five concrete steps that agricultural researchers should take, are stated.

Sustainability: an evaluation criterion

To use sustainability as an evaluation criterion requires a precise and unambiguous definition. No one would disagree with the statement that implementing sustainable development would "ensure that humanity meets the needs of the present without compromising the ability of future generations to meet their own needs" (*Our Common Future*, report of the World Commission of Environment and Development). But this does not provide a criterion for ag-

ricultural researchers. Papers by the Technical Advisory Committee of the Consultative Group on International Agricultural Research (CGIAR, 1988) and the World Resources Institute (Dover and Talbot, 1987) provide not so much a definition as a characterization of the term. The TAC suggests that it is not stability. Dover and Talbot appear to suggest that stability, used in an ecological way, comes closest to defining sustainability. Conway (1985) offers a precise definition but Dover and Talbot suggest that his is merely the definition for resilience, another specific ecological concept. Holling (1973) provides a discussion of resilience and stability in ecological theory. All this points to a concept entailing substantial ambiguity in any particular application.

Conway's (1985) definition, nevertheless, provides a useful starting point, namely "sustainability is the ability of a system to maintain productivity in spite of a major disturbance, such as is caused by intensive stress or a large perturbation." In this definition sustainability is a property of a system operating over time, a framework which this paper also advocates. The crux of the conceptual problem involves specification of the boundaries of the system and the time period, in particular as a framework for evaluating crop technology.

The problem of boundary specification arises from choosing the system level at which sustainability becomes a relevant characteristic. Much of the confusion in the discussion of sustainability reflects a mixing of system levels, namely the lack of recognition that a plant photosynthetic system is embedded in a plant system which is embedded in a cropping system which is part of a farming system, which is embedded in a regional or national agricultural marketing system, which lies within the international market system. Alternatively, one could mention cell, plant, field, continent, globe and even solar system. Except for the highest system level, i.e. the international market, each of the lower systems is, except under quite special circumstances, open to influences from outside. Openness creates the very difficult problem of determining when sustainability is an inherent property of the defined system, dependent on endogenous system relationships as for Conway, or when sustainability is so dependent on external forces that the system level should be upgraded in order to define sustainability adequately.

Given that sustainability is a characteristic of a system's productive performance over time, it follows that the effect of a crop technology on the sustainability of the system is measured through its effect on output–i.e. the "ability to meet needs." Technology modifies the sustainability of the system in which it is being applied; it is not an inherent characteristic of a variety, a cultural practice, or a particular input. A technology's effect on a system's sustainability is thus contingent on the specification of the system and is measured by the system's output performance over time. The output measure will depend on the system level. At the crop variety level it is yield per plant or per hectare, at the crop level or the cropping system level it is total factor productivity, at the farming system level it is income, and at the market level, com-

modity supply. We define sustainability as the capacity of a system to maintain output at a level approximately equal to or greater than its historical average, with the approximation determined by its historical level of variability. Hence, a sustainable system is one with a non-negative trend in measured output; a technology adds to system sustainability if it increases the slope of the trend line. This definition differentiates sustainability from stability, which is the variation in the output measure around the trend line.

Measuring the slope of the trend line of a system's output measure involves specifying the system, the measure of output, the time period of concern and observing the measure over the specified time period. It will be obvious that empirical tests of sustainability will be costly and therefore applicable to only a few elite technologies within a few systems–raising an interesting issue of the value of the information in relation to the experimental costs. Moreover, none of the three specifications is straightforward.

Selection of the system level requires a choice (and therefore a trade-off) between the number of alternatives that can be screened and the range of exogenous variation to which those alternatives are exposed. The lower the system's level, the fewer the number of potential system interactions, and the less complex the experimental design. One issue then is the lowest system level at which sustainability can be defined. Moreover, evaluation criteria at lower levels must be compatible with criteria at higher systems levels, e.g., increased yields or more efficient input use must translate into higher profitability as well as output that better satisfies market demands. At the plant level, sustainability is measured as a yield trend line, and the problem is in defining the conditions when sustainable yields at the plant level lead to sustainable productivity at the cropping system level, which lead to sustainable incomes at the farming system level, which lead to sustainable commodity supplies, and so forth. But above the farming system level so many factors outside the system impact on its sustainability, it is virtually impossible to determine the source of such impacts. The implications of the above discussion can be summarized in a first proposition, namely: *sustainability is a relevant criterion for evaluating agricultural technologies only when a system using a technology has been well specified, and therefore in most cases the criterion cannot be empirically applied above the farming system level.*

The second specification problem, interrelated with the choice of system level, is the definition of output. Where crop output is evaluated under a fixed sets of inputs over time, crop yield per hectare is the appropriate output measure. On the other hand, agronomic yield trials conducted over time often involve changes in specific inputs like fertilizer materials or insecticide compounds where these are not the 'test' variables, often in order to protect the crop against unexpected or changing conditions. Output measures of cropping systems, which by definition include several crops, must use some means of adding together different crops, perhaps fodder and grain or fuelwood and fruit.

This leads to proposition 2: *the appropriate measure of output by which to determine sustainability at the crop, cropping system or farming system level is total factor productivity, defined as the total value of all output produced by the system during one cycle divided by the total value of all inputs used by the system during one cycle of the system: a sustainable system has a non-negative trend in total factor productivity over the period of concern.* The value of inputs and output must be computed at a set of standardized prices which should reflect their long-term economic value.

The third specification problem is defining the time period of concern–a sufficient length of time over which the sustainability of a system can be determined. Cost considerations imply a need to delimit a sufficiently short time period to provide a projection of system output into the future with a sufficiently low probability of error. The time period of concern is clearly greater than one crop season, in nearly every case greater than 3–5 years and perhaps greater than 10–20 years. However, we believe the most decision makers, even those concerned about the distant future, would choose a time period of less than 20 years.

Using the analogous, but far simpler, case of yield stability, it is apparent that such time-dependent parameters are rarely measured without prior information both to improve the value of the experimental information and to reduce the cost. For example, yield stability is tested in relation to available information on rainfall variability over time. This leads to the third proposition: *sustainability of a system cannot be feasibly measured without a prior determination of the factors likely to make that system unsustainable.* For an agricultural research program, there needs to be a prior determination of how a technology could lead to an unsustainable system. This leads to a very difficult chicken/egg issue, which in the physical sciences has motivated development of a theoretical structure leading to hypothesis testing and model simulation. Agricultural experimentation is only hesitantly moving in this direction.

Sustainability, technology design, and ecology

Ensuring that technologies arising from crop research do not lead to unsustainable systems will require more than the mere development of testing procedures. Empirical tests are too complex and costly to implement in more than a handful of cases so that the capacity to measure sustainability at the testing and evaluation stage of the research process will be limited. Therefore, it is necessary to incorporate sustainability as an objective in research planning and technology design.

One viewpoint in the sustainability debate holds that high-industrial-input agricultural systems are inherently unsustainable. Proponents of that view have shifted the focus of debate away from production or income distribution to

environmental degradation and input use. Agro-ecology, as a scientific discipline, has led the critique of developed-world agricultural innovation over the post-war period and has led in the formulation of alternatives to this "high-input, industrial" model (Douglas, 1984). Moreover, it supports the view that the high-input model is inappropriate for agricultural development in the tropics, giving as a principal reason that tropical farming systems based on such a model are 'unsustainable'. Sustainability, according to this view "requires new directions for agricultural development, directions based on the principles and practical knowledge of ecology" (Dover and Talbot, p. 7). This dichotomy has tended to politicize the term sustainability and associate it with a particular research agenda based on ecology.

In contrast, our concerns about the sustainability of tropical agricultural systems are directly related to how these systems will meet the increasing demand for food over the next 5, 10 and 20 years, especially in those countries where population is still growing rapidly. Agricultural research having sustainability as a criterion will aim to understand how input or output mix are modified in systems in order to increase agricultural production and whether those shifts result in systems that give sustainable growth over time. In a dynamic environment new agricultural technologies can facilitate such shifts or in an otherwise static environment may precipitate system changes. Agricultural research programs which use sustainability as a design criterion, would give higher priority to research on farming systems which had difficulty in making a sustained adjustment to higher productivity levels. This is fundamentally different from evaluating how new technologies may affect the sustainability of the system. Design of technologies would thus increase the priority given to those elements in the system which were degrading as a result of more intensive exploitation, almost invariably either some aspect of the soil resource or pathosystem (Robinson, 1976).

Designing sustainable farming systems therefore requires an understanding of the process by which farmers adjust to a changing external environment, whether that is induced by climate, market expansion, or a growing population density. The ability of farmers to develop more intensive systems has been widely documented. The classic example is the farmer-initiated irrigation systems of Asia. Others include farmer development of varieties, farmer initiation of varietal exchange, crop substitution such as the substitution of yams by cassava in West Africa in response to declining soil fertility, and the development of mulching, fallow, and burn systems to maintain soil fertility (Binswanger and Pingali, 1987). Paul Richards (1986) adopts the more extreme view that, in order for agricultural research to enhance the development of sustainable agricultural systems in West Africa, it should principally strengthen this existing capacity of farmers to develop their own technological solutions to changing needs.

However, we believe that population growth can be so rapid, climate change

so abrupt, or market penetration so quick as to stymie the ability of farmers to adapt. Research to improve farmer's ability to sustain production will be necessary, judging from many case studies that have documented the inability of traditional farmers to intensify at a sufficiently rapid rate to meet increasing demands on the farming system. Examples extend from Geertz's classic case of agricultural involution on Java to soil erosion in the East African highlands to desertification in the Sahel. A fourth proposition would follow, namely: *whether sustainability should be a criterion of research programs depends on their target area; unsustainability is often locally or regionally defined and depends on such factors as the rate of increase in exogenous demand on the system, agro-climatic environment, and the relative intensity (generally in land use) of existing systems.* Targeting thus becomes a key issue for agricultural research programs where sustainability is a principal objective.

Ecology, with its focus on ecosystems, has extended these concerns to higher system levels. But, as argued earlier, when dealing at a higher level than the farming system, sustainability is fraught with a series of definitional problems. The boundary of the system becomes hazy, and even if defined, the system will likely be expected to meet several simultaneous criteria, not just sustainability. The concerns at levels above the farming system usually encompass environmental degradation and may arise from (a) overexploitation of a common property resource and (b) production externalities.

The 'tragedy of the commons' arises in a situation of increasing population density (either human or animal) where decisions that individually have imperceptible ecological impact, collectively can have substantial impact. Traditional regulatory mechanisms (collective decision making) may be effective protection against the tragedy for peasant societies, but the protection may break down in the face of rapid population growth or expanded market opportunities. Such common resources may be grazing areas, water resources, firewood, fishing areas or forest areas. The definitional problem–and thus how the research problem is conceptualized–can be illustrated by the issue of management of forest resources. First, there is debate over the system boundary: is it ecologically defined (an agro-ecological region), economically defined (the region serving a timber market), or defined by a land-use system (a managed forest)? Second, what is the output of the system: the alternatives span the range from conservation (non-use) to various logging alternatives (which can be organized for sustainable output but usually entail a loss of ecological diversity)? Both problems suggest a fifth proposition: *sustainability of common resource systems necessarily incorporates value judgements on multiple criteria over how the community wishes to utilize the resource; moreover, sustainability of the system will depend more on social institutions controlling access and use than on production technologies.*

Exacerbation of production externalities–an economic term which signifies a cost or return arising from a production activity which is not borne by the

producer but by other members of society–can also arise from intensification. Soil erosion from upland farming systems that affect irrigation systems downstream or the leakage of agro-chemicals into the environment are classic examples.

Externalities are particularly complex problems arising from three mutually reinforcing aspects of some phenomena: physical, economic and time. As Kneese and Schultze (1975) emphasize, externalities are due in part to the physical conservation of matter. Pesticides applied to a field must go somewhere, usually into the groundwater; even pesticides that break down yield constituent components that go into the groundwater. If enforceable property rights exist for the groundwater, the owner can charge for the disposal of the pesticide and thereby offset its costs (i.e., internalize the costs to the producer). Externalities may also be caused by lack of information. Ignorance of pollution or of the consequences of pesticide pollution is sufficient for that pollution to exist even if a market for groundwater existed. Agricultural production processes require time and the external effects of actions at one point are not known until some later time. If private benefits are realized early and social costs late in time, any positive social discount rate reduces the present value of costs, thereby contributing to the externality. The common property nature of resources also can generate externalities: if one individual owned both the groundwater and the land on which a pesticide was used, decisions would be taken that reflected the effect of the pesticide on groundwater quality.

Resolution of externality problems may involve intervention by the state. Moreover, their effect on a system's productive capacity usually affects several aspects, e.g., value of agricultural production and environmental quality, leading to difficulties in how to evaluate alternative system states, especially where there are trade-offs.[2]

An examination of issues related to agro-chemicals – inorganic fertilizers, herbicides and pesticides – illustrates many dimensions of this conceptual problem, because such input use is at the heart of the debate over alternative agricultural development strategies[3]. The starting point is to recognize that

[2]We would argue that the weights to evaluate such trade-offs should reflect long-term values to society. In a real sense, agreement on the appropriate weights is where economists and ecologists most differ, with the former arguing for weights reflecting prices that would prevail in a well functioning market where the value of every input and output is internalized to the decision maker, and the latter arguing for a set of weights reflecting long-term preservation of an ecologically defined ideal state. This ideal most often is reflected in preservation of the current status quo of an ecosystem. However, neither economists nor ecologists can make a convincing case for the superiority of their set of weights over the other's.

[3]Increased input utilization has been seen as synonymous with agricultural development in some of the development literature. Johnston and Kilby (1975) provide probably the fullest account of this view where agro-chemicals provide a basis for increasing marketed surpluses in the agricultural economy–indeed increased input use is usually first found in cash or export crops, even in peasant agriculture–and in turn provide important backward linkages for industrial development in the economy.

agriculture is an extractive activity (Loomis, 1984) and relies on managing or controlling the crop environment, including maintenance of the soil resource. Increasing productivity, especially crop yields, increases the rate of extraction of soil nutrients at the same time that it involves increased control over the crop environment. The rate of breeding progress is in turn usually linked to these improvements in managing the crop environment. Fertilizers increase plant nutrient availability and with other agro-chemicals provide better control of the crop environment. The enhanced environment provides increased output on intensively farmed land and reduces the pressure to expand to new land.

In the late 1980s agro-chemicals are an established feature of the agricultural system of all developing countries, albeit used at widely differing intensities. What then are the disadvantages of a reliance on agro-chemicals and what are the alternatives? By any standard, the post-war record of U.S. crop yields and the post-Green-Revolution rice yields in Asia have exhibited sustained, rapid growth. This growth has been closely linked to increases in the use of agro-chemicals. Concerns about the sustainability of production levels in these farming systems are based on ecological theory about what could happen to output rather than on what has happened and on external costs entailed in some of these. While much of the evidence is marshalled around the not insignificant externality problem, proposed solutions often do not address the externalities but, rather, resort to a theory of 'sustainable agro-ecosystems'. The lack of empirically demonstrated non-sustainability in part results from the time span necessary to measure sustainability. Reganold, Elliot and Unger (1987) could show differences in erosion losses between an organic and a conventional farming system after a 37-year period but they estimated that actual productivity differences would not appear for another 50 years. Theory is thus a necessary part of the sustainability debate, but as Loomis's (1984) critique demonstrates, there needs to be a complementary capacity in place to test that theory–e.g., his discussion of the relation between diversity and stability. The debate is currently polarized because there are not enough data to reject or modify the two competing theories, often verging on ideologies.

The principal alternatives to agro-chemical use that are proposed are improved soil quality and enhancement in the rates and efficiency of existing biological processes that control nutrient cycling and pest populations. This leads to research on topics such as enhanced biological nitrogen fixation, more efficient mycorrhiza strains, ecosystem mimicry in cropping patterns, crop rotations and multiple cropping, and biological control of insects, diseases and weeds–topics which, even in the 1970s and 1980s, formed a considerable portion of the agenda at international agricultural research centers.

There are several large hurdles for technologies based on such a research agenda. First, such technologies are environmentally sensitive and will require in situ adjustment. The demands on research capacity will necessarily be larger than has traditionally been the case.

Second, the demands made on farmer knowledge and management will likely be greater than with high external input technologies. Inputs embody research knowledge and are relatively undemanding of additional farmer knowledge, while highly productive farming systems using few external inputs are labor and management intensive – at least the few that have been demonstrated. To a significant extent this is why agro-chemicals are increasingly being utilized in tropical countries. On the other hand, once an improved agro-ecosystem is in place, it may require less management due to self-regulatory mechanisms. The difficulty is in designing and precipitating the system change.

Third, farmers will decide between using biological technologies or agro-chemicals, decisions influenced by their knowledge, the local market economy and government policies. Even when sustainability is an objective of farmers, the choice of a technology or a change in management practices will largely be determined by its contribution to farmer welfare as reflected in current or near-term future profit or costs. Technologies have to raise profit or the farmer's perceived welfare before they will be adopted and thereby have an opportunity to contribute to system sustainability. Translating the ecological research agenda into adoptable technologies that compete effectively with agro-chemical alternatives will not be easy. These arguments are mustered to support a sixth, and slightly contentious, proposition: *dividing research solutions to the sustainability problem into two distinct and competing strategies is counterproductive; to be successful the biological research agenda will have to complement the continued use of inputs in the intensification of farming systems in the tropics.*

Clearly, intensifying agriculture by high input use is not always the appropriate solution, as illustrated by research on intensification of shifting cultivation by IITA's farming system's program in West Africa and the INIPA-North Carolina State University program in Yurimaguas, Peru. In those projects the objective of sustainable increase in per hectare yields in continuous cropping systems have been achieved through high labor and external input use. Profitability has not been generaly achieved, however. Interestingly, Binswanger (1986) argues that such efforts may be misplaced without a recognition of the effective demand for technology. In particular, he argues that "concentrating research effort on yield increasing technologies makes little sense in the more land abundant environments." Rather he argues that either quality-enhancing or stress-avoiding technologies would be more likely to be adopted. In recognition of these realities, the Yurimaguas group has retreated from its high-input, continuous cultivation system (Sanchez et al., 1982) to a lower input system that uses a kudzu rotation for fertility maintenance and weed control (Sanchez and Benites, 1987). This system, nevertheless, is still labor and input intensive compared to the shifting cultivation system and its prospects for adoption remain undetermined. In such land-abundant conditions, biological technologies would be highly competitive with input-based solutions, if they focused on enhanced stability of the system without increases

in labor requirements. Ruthenberg (1980) and Binswanger and Pingali (1987) document the pattern of intensification in sub-Saharan Africa: in most cases the evolution involves enhanced management of biological processes which requires increased labor. To make the point again, the successful design of technologies to enhance system sustainability will begin with clearly characterized resource, farming and marketing systems. The real utility of agro-ecology will come from its capacity to understand and predict system evolution, a capacity which will require some marriage of agro-ecology and economics.

Whether there can be a merging of the ecological perspective with the economic perspective depends, among other things, on the philosophical view of ecologists on the role that markets and social institutions play in system sustainability, from the farming systems level up. Economists believe that today's world is committed to a path in which population growth, resource constraints and human needs and desires lead to market development, which in turn leads necessarily to a division of labor, output specialization, and increased interdependence between economic agents. This implies a loss of crop diversity at the farming systems level (although diversity may be maintained at a national or a regional level) and with the advent of input markets a more difficult environment in which to promote the low-external-input biological alternative. Market development would thus appear to undermine a significant part of the biological research agenda, but viewed slightly differently, increasing market dependence enhances the sustainability of farming systems and regional or national food systems by reducing pressure on some agro-ecologies while increasing output from more robust ones. Recent history, in much of Asia for example, would suggest an imperative toward increased social organization and market development in order to accommodate increasing population pressure on a limited land resource. A division of labor and trade leads to an enhanced productivity of the overall system, even without any necessary change in underlying production technology.

Moreover, trade and institutional development enhance the sustainability of food systems in important ways. As has been noted, institutional and social innovations are key to solving the problem of over-use of common resources. However, probably famine is the ultimate indicator of the unsustainability of a food system. Famines are more common in rural areas than in urban areas and in rural areas they are more likely in those regions not integrated into market systems–certainly this is the case in sub-Saharan Africa. Trade and stock management are buffering mechanisms for marginal agro-climatic regions and in a sense preserve farming systems in regions where they could not exist independently. This observation does not contradict A.K. Sen's (1981) work on famines which suggests the fundamental role of incomes and distributional mechanisms, especially in Asia. But sustainability of food systems also depends on the appropriate design of institutions that correct for 'entitlement' problems. This leads to a rather interesting and perhaps unsettling sev-

enth proposition: *sustainability is first defined at the highest system level and then proceeds downward; and, as a corollary, the sustainability of a system is not necessarily dependent on the sustainability of all its sub-systems.*

Implications for international agricultural research

How should agricultural research, in particular the international centers, respond to the call for sustainable agricultural systems? For a start, they should recognize the value of sustainable cropping, farming, agricultural and national economic systems. Second, they should define appropriate measures of total productivity and establish methods for measuring it for well-defined plant systems, cropping systems and farming systems. Third, they should conduct research with the objective of understanding the likely trend of total productivity in well-defined cropping and farming systems over appropriate time and space dimensions. Fourth, they should identify the externalities associated with such well-defined systems, and finally, they should begin to develop methods to measure such externalities.

The first step, recognition of the issue, probably has been accomplished among all but the most recalcitrant of centers, although there are many individuals at the centers who are more cautious about sustainability than the international trend setters among the donor community. After all, the latter group can simply issue the call for 'sustainability research' and go back to their business of seeing how responsive researchers are. The researchers have to determine how to measure the concept so that the work carried out under the banner adds to knowledge that will enhance food production, small-scale farmers' incomes, consumers' welfare, women's status in development, national research program capacity, stability *and* sustainability of agriculture.

Moreover, it is likely that some agro-ecologies are inherently more suitable for intense use while others can only be used sustainably at low levels of intensity. Successful agricultural research will stratify their target areas accordingly and devise ways to raise intensity levels on the former, thereby permitting the latter to sustain low levels of output. More concretely, agronomic researchers conducting field experiments on production systems and economists who analyze systems research must move from a fixity on yield as the measure of agricultural system 'success' to a measure of total productivity. This implies, as discussed earlier, a definition of total productivity which includes, as much as possible, all costs and benefits, not just those accruing in the immediate time period and to the immediate decision maker. Like all ambitious goals, this objective will not be easy to achieve, but one can approach it incrementally. Comparable total productivity measures require measurement of all inputs and outputs of experimental systems, agreement on weights and computation of comparable total productivity measures for alternative treatments of the system. This is clearly within the reach of the international agricultural research

centers and should be a priority of their agronomic and economic researchers. Identification and costing of externalities is more difficult, requiring specific methodologies which are still being developed (Antle and Capalbo, 1988). It will be impossible, however, unless the first step is initiated.

The third step that international research centers could take is to institute a set of long-term cropping or farming system experiments in a limited number of agro-ecologies typical of their mandate responsibilities. These would have to be carefully designed to provide useful information in the short run as well as over the long term. They would have to contain a sufficient range of treatments of a system to provide a set of comparisons that would be useful as economic and weather conditions changed. Plots would have to be large enough to reflect what might happen under farmers' conditions and to permit the possibility of future modification of treatments. One might build in flexibility, by designating certain treatments as the 'best commercial practice under current prices', or 'most promising new cultivar', or 'integrated pest management'. A careful advance assessment of the likely sources of perturbation will be necessary if the experiments are to be useful in making judgements about sustainability and stability. And, one must recognize that the experiments, however carefully designed, will be inadequate for many purposes. They will not necessarily identify sustainable systems, but at the end of 10 or 20 years a great deal more information and a great deal more insight will be available to examine the issues of sustainability *and* productivity *and* stability *and* input use and much else that is now unknown.

The fourth step links directly to the third–scientists should examine the experimental systems for all possible externalities and identify them. The fifth step, that of developing methods to measure and value such externalities, then follows directly. These efforts will require new skills and techniques, and hence may take most agricultural research organizations some time to accomplish, but they should be started now.

While the above may be viewed as the necessary first steps to addressing sustainability as a research objective, they do not grapple with the issue of how international agricultural research adapts or organizes programs so that sustainability is addressed. The alternative approaches are three; namely (a) a recasting of existing commodity research programs, i.e., a continued focus on plant breeding research but an incorporation of the five additional steps outlined above, (b) organize research around resource management, e.g., around soils, irrigation, or forestry, and (c) organize research around 'solutions', for example, agro-forestry, tropical soil biology, and insect physiology. There is an emerging structure in the form of international research networks or centers organized around these latter two disparate approaches. Moreover, CGIAR centers are adding or adapting research programs along similar lines. These are in most cases independent efforts, which leads to the natural question of whether there is an emerging order in this 'rush' to sustainability.

This emerging order will have to resolve two fundamental difficulties that characterize sustainability research, namely (a) how to organize research on problems whose solutions are very location-specific and, (b) how to organize biological research where the focus is on the whole agricultural system rather than individual components. At issue is whether some integration of the three above approaches can overcome or accommodate these difficulties.

Researching whole agro-ecosystems is not practical. First, it is not clear how to select and evaluate alternative states of an agro-ecosystem, so that the biological performance of the whole system is examined under alternative treatments that can be compared and evaluated. Second, the number of agro-ecosystems in the tropics is essentially infinite, precisely because these managed biological systems are so finely tuned to the great variation in soils, climate, pest complexes, resource availability and output markets. System definition to focus the research under such circumstances becomes impossible. Alternatively, sustainability research can be structured around components within an integrating framework, even when the broad objective is commodity improvement. Agro-ecology provides a theoretical framework for selection of these components and a number of research groups, and some commodity research programs, are working on biological nitrogen fixation, integrated pest management, biological pest control, agro-forestry, tropical soil biology and multiple cropping.

Alternatively, a significant amount of applied biological research has been organized around management of natural resources, for example, in forestry and fishery management. Such research focuses on the management of a single natural resource system where the biological yield of the system largely coincides with the economic yield. However, agriculture, soils, water and forests are managed as part of farming systems and there is often a disjunction between management of the sustainable productivity of a single resource and organizing output and input mix so as to optimize income. The difficulty for organizing sustainability research – if not the organizational paradox – is suggested by the example of hillside maize systems: the erosion problem cannot be solved by a singular focus on the maize system and in turn a singular focus on erosion control technology without consideration of the maize cropping system is impossible. Equally, research to optimize management of Vertisols or acid soils cannot be done without considering alternative cropping systems to be grown on those soils. Research on resource management is, in reality, component research. The difference is in the definition of components and their coincidence with farmer objectives.

Thus, the systems problem inherent in sustainability research is being addressed by organizing research groups that focus on components defined as sub-systems, resources, or commodities. Such component research faces the challenge of developing solutions of general applicability which meet the individual requirements of particular systems. This problem is usually resolved

through adaptive research that integrates components into systems, taking as its research the long-run trend of total factor productivity. The basic and applied research objectives that underlie the development of sustainable systems are met by focusing on sub-systems. Nevertheless, it is incumbent on researchers in these programs to be informed about research on other components and how the sub-systems might interact. That is, they should be doing component research with a sustainability perspective.

Putting improved systems together relies on two hopefully complementary approaches. These are system simulation models (Dent and Thornton, 1988) and adaptive research, organized around agro-ecosystems (Conway, 1985). Much like farming systems research (FSR), the application of agro-ecosystems as a research methodology has most utility at the adaptive research level. Whether it also can be a bridge to problem identification for applied research remains to be seen–FSR has in practice not performed as well as was originally conceived as a vehicle for information feedback to basic and applied research programs (Lynam, 1986).

The CGIAR system is now assessing how it can best implement sustainability as a research objective. Two distinct but not necessarily contradictory approaches are emerging. The TAC, in its policy paper (CGIAR, 1988), has delegated responsibility to each of the centers, in the sense that each has to incorporate the sustainability objective into its work. How this will be done is, given the autonomy of the individual centers, left to their strategic decision process. However, the TAC paper recognizes, in a vague way, that such an incorporation will require some reorganization and a reallocation of staff to what is termed resource management. This reorganization is a tacit admission that the sustainability problem must be broken down into a set of researchable component areas that complement the commodity research programs. What those areas are and which centers will adjust their programs so as to include them are issues which are left in abeyance.

Another proposal (Colmey and Schuh, 1988) suggests that the CGIAR could meet the sustainability objective by incorporating additional centers that address resource management. Such an expansion would ensure the CGIAR were addressing the sustainability objective only to the extent that centralized resource allocation also results in better inter-center collaboration, a more rational division of labor, and more effective priority and program definition. Such coordinating mechanisms presently exist only weakly within the CGIAR system. A concerted move to allocate the various dimensions of sustainability research among (existing and additional) centers would require a radically stronger coordination mechanism. Most observers agree that one of the strengths of the CGIAR system is its relatively unstructured nature. Must the organization of the CGIAR become more complex to deal with the sustainability problem, leading to the danger that what it gains in coordination of activities, it will lose in bureaucratic rigidity and information management costs?

Summary and Conclusions

We agree with those who are concerned that agricultural production systems should be sustainable, and further believe that technology can be designed to contribute toward increasing the sustainability of systems. We have developed the following propositions which provide a framework in which international agricultural research centers can empirically address sustainability:

(1) Sustainability is a relevant criterion for evaluating agricultural technologies only when a system using a technology has been well specified, and therefore, in most cases, the criterion cannot empirically be applied above the farming system level.

(2) The appropriate measure of output by which to determine sustainability at the crop, cropping or farming system level is total factor productivity, defined as the total value of all output produced by the system during one cycle divided by the total value of all inputs used by the system during one cycle of the system; a sustainable system has a non-negative trend in total factor productivity over the period of concern.

(3) Sustainability of a system cannot be feasibly measured without a prior determination of the factors likely to make that system unsustainable.

(4) Whether sustainability should be a criterion of research programs depends on their target area; unsustainability is often locally or regionally defined and depends on such factors as the rate of increase in exogenous demand on the system, agro-climatic environment, and the relative intensity (generally in land use) of existing systems.

(5) Sustainability of common resource systems necessarily incorporate value judgements on multiple criteria over how the community wishes to utilize the resource; moreover, sustainability of the system will depend more on social institutions controlling access and use than on production technologies.

(6) Dividing research solutions to the sustainability problem into two distinct and competing strategies is counterproductive; to be successful the biological research agenda will have to complement the continued use of inputs in the intensification of farming systems in the tropics.

(7) Sustainability is first defined at the highest system level and then proceeds downward; and, as a corallary, the sustainability of a system is not necessarily dependent on the sustainability of all its sub-systems.

The minimum steps that international agricultural research centers should take to address agricultural system sustainability are to (a) recognize the need for sustainable agricultural systems, (b) define appropriate ways to measure sustainability, (c) empirically examine the sustainability of some well-defined cropping or farming systems, (d) define the externalities that exist in such systems, and (e) develop methods to measure those externalities. Even while recognizing that sustainable agriculture requires more than sustainable farm-

ing systems, we believe that these steps will begin to generate knowledge that will lead to that larger goal.

The supposed advantage of organizing research with a sustainability objective around resource management or 'solutions' instead of around commodities is not at all evident. Organizing multi-disciplinary, agricultural research along commodity lines has been successful in producing new technologies principally because of the correspondence between researcher and farmer evaluation criteria. How resource management and 'solution' centers will organize their research and interact with commodity research programs to produce 'sustainable' technologies is something which will be determined as all these centers implement research programs that measure the sustainability of various agricultural systems.

Note

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