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Environmental Impact Assessment Review
23 (2003) 219–244

Environmental Impact Assessment Review

www.elsevier.com/locate/eiar

An environmental impact assessment system for agricultural R&D

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Received 1 February 2002; received in revised form 1 October 2002; accepted 1 October 2002

Abstract

A strategic planning process has been implemented at the Brazilian Agricultural Research Agency (Embrapa) to introduce sustainable agriculture concepts in all steps of Research and Development (R&D). An essential part of the devised mission statement called for the impact assessment of all technology innovation resulting from R&D, under field conditions (ex-post). However, methods for impact assessment of technology innovations at the farmstead level appropriate for the institutional context were lacking. The environmental impact assessment (EIA) system (AMBITEC-AGRO) developed to attend that demand is composed by a set of weighing matrices constructed in an electronic spreadsheet. Impact indicators are evaluated in the field in an interview/survey, and weighed according to their spatial scale and importance toward effecting environmental impacts. The results of these weighing procedures are expressed graphically in the assessment spreadsheets. Finally, the indicator evaluations are composed into an Environmental Impact Index for the agricultural technology innovation.

Keywords: Environmental impact assessment; Project appraisal; Agricultural technology; Sustainability

1. Introduction

The environmental impacts of agricultural activities are a direct consequence of the extensive clearing of the land and the need to keep natural succession arrested

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0195-9255/02/$ – see front matter © 2002 Elsevier Science Inc. All rights reserved.
doi:10.1016/S0195-9255(02)00097-5

in order to maximize net production. The predatory character of agriculture, however, is frequently equated with dependence on external inputs and mechanized operations applied in order to warrant excess growth factors and absolute protection to extended areas devoted to genetically homogeneous organisms. This technological affiliation of agriculture (the so-called Green Revolution) has been severely criticized, while credited by some for the generation of wealth (Borlaug, 1997) and blamed by others for the cycle of degradation and poverty imposed onto large regions of the world (Shiva, 1997).

The challenge of agricultural development is to counteract the dependence on non-renewable resources and environmental services which seemingly unrestrained availability is made apparent by inadequate market forces and economic policies that hinder sustainability (Pezzey, 1992). "Sustainable agriculture is the management and utilization of the agricultural ecosystem in a way that maintains its biological diversity, productivity, regeneration capacity, vitality and ability to function, so that it can fulfill—today and in the future—significant ecological, economic, and social functions at the local, national, and global levels, and does not harm other ecosystems" (Lewandowski et al., 1999, citing the Conference of European Environmental Ministers).

By conveying action (the management) as its essence, this definition underlines the value of environmental impact assessment (EIA) procedures for fostering sustainable agriculture. First, it implies a technology intensive manner of producing, even if resource sparing (Neher, 1992); and second, it emphasizes conservation and regeneration of the rural landscape (Bowers and Hopkinson, 1994), both favored perspectives in EIA.

While entertaining such essential views, an aspect seldom reckoned is that sustainability objectives vary with ecological, economic, social and cultural factors, both at regional and local levels. The context must be set and the sustainability initiatives adapted according to particular necessities and capacities (Brooks, 1992). The EIA of agricultural technologies is, thus, indispensable for sustainable development, because the interaction technology—environment and society, with its multiple interests and objectives, may result in non-intentional, indirect, and delayed impacts (Porter, 1995). It is only by the systematic assessment of these impacts, applying adequate methods specifically designed, and included in an appropriate institutional context, that agricultural technologies may be safely recommended and adopted.

2. EIA of agricultural technologies and the R&D institutional context

The design and systematic application of EIA tools to agricultural technology innovation has received attention in the National Institutes of Agricultural Research (NIARs) of countries in the Southern Cone of South America, as attested by scientific meetings held (Puignau, 1998) and cooperative research developed on the subject (Rodrigues et al., 1998). Recognizing that EIAs should be carried out from project inception and planning on through the implementation steps (Haque, 1991), a method for the ex-ante evaluation of prospective environmental impacts of agricultural technologies was made available and has been applied to a large set of research projects in the NIARs (Rodrigues et al., 2000).[1] This method aims at motivating research scientists to consider, from both conceptual and methodological standpoints (Rodrigues, 1998), all environmental issues related to their research proposals.

The next step for the EIA of agricultural technology innovation at the institutional context of Research and Development (R&D) is the consideration of impacts effectively observed (ex-post) in the field following technology adoption. At this stage, a clear definition of the objective sought out with technology implementation is needed. Ideally, objective definition must find a converging point for the social, economic, and ecological dimensions of sustainability (Tacconi and Tisdell, 1993). The most straightforward approach, well emphasized in the above definition of sustainable agriculture, relies on the concept of “resilience” (the ability of an ecosystem to recover from stress), which ultimately means that the objective of technology implementation in agriculture must be compatible with constancy of the natural capital stock (Barbier et al., 1990).

The simplicity of such an enunciate contrasts with the difficulty of establishing a realistic and operational objective, and of devising an evaluation system applicable to policy formulation and decision-making regarding technology recommendation and regulation (Smith and McDonald, 1998). For instance, relief of environmental degradation pressure often depends, at least partially, on improvements in income and consciousness of local populations about the intrinsic value of the threatened environmental resource (in the words of Poore and Sayer, 1991, to save a forest, it is often better to start with the people rather than the trees). This implies that to comply with sustainability objectives agricultural technology innovation must bring about, besides environmental benefits, quality of life improvements for the users, and hence it must be aligned with plain economic objectives (Warford, 1987).

However, it is hardly possible to obtain consensus about development objectives, especially when seeking to balance environmental, economic, and sociocultural issues, and usually opposite opinions and expectations occur both on assessment procedures and derived policies and recommendations (Morvaridi et al., 1994). These conflicts of interest deepen the weaknesses of conventional approaches for sustainability evaluation, specially the benefit/cost type of analysis that level ‘environmental goods and services’ with purely economic interests and views (Green et al., 1990). The EIA approach, on the other hand, by including indicators of environmental performance and account-

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[1] The file containing this method is available for download from Embrapa Environment at http://www.cnpma.embrapa.br/serv/index.html.

ing for these indicators in their proper measurement units and meanings, facilitates concurrence of objective attainment: the judgement of improved efficiency (better technology) as well as efficacy (better environment) (Girardin et al., 2000).

Value judgments are, thus, intrinsic components in the assessment of agricultural technology impacts and are made through the entire process, from the understanding that technology benefits and impacts are not evenly distributed among social groups, up to the recognition that social groups have diverse values and objectives (Bisset, 1983), all of which interfere with technology environmental performance. With this precept in mind, EIA for sustainable agricultural technology innovation can be defined as the appraisal of changes imposed onto the environment, according to locally delineated development *objectives*, that in turn allow the establishment of a *norm* for judgment (Girardin et al., 1999).

In the institutional context of R&D, the organization's mission statement can provide the guide for delineating the *objective* to be judged in agricultural technology assessment, e.g., "to promote the sustainable development of agribusiness by generating, adapting and transferring knowledge and technology for the benefit of society" (Embrapa, 1998). Additionally, in order to orient the assessment relative to local constraints, the local social actors and stakeholders must exert active role in the assessment process (Dumanski et al., 1990), thus facilitating the recovery and documentation of hands-on knowledge and expertise of farmers and other users of the technology. These kinds of information are an extremely valuable asset in the R&D institutional context and often prove instrumental when assessments are translated into technology adaptation and improvement.

These premises direct the definition of the scale, delimitation of the scope, establishment of the objective, and outline of the norm for the formulation of an EIA system for agricultural technology innovations in the institutional context of R&D:

(i) Scale—the adoption of an agricultural technology innovation may affect the immediate environment where the activity modified by the technology is carried-out (the near environment), the neighboring area (proximate environment), and the surrounding environment, mainly due to residue emissions. These are, thus, the scales to be addressed by the assessment system.
(ii) Scope—although the social, economic and ecological dimensions are equally essential for sustainability, the EIA system proposed here is restricted to the ecological aspects. The social and economic dimensions are being addressed independently for future integration, due to a particular institutional directive established by Embrapa.
(iii) Objective—to promote rural sustainable development by the adoption of technological innovations that contribute to improve environmental quality as well as ecosystem conservation and restoration.

(iv) Norm—recommendation of agricultural technology is conditioned to improvement of the environmental performance of the activity to which technology is applied, as measured by designed environmental impact indicators.

These definitions of scale, scope, and objective here delineated for the institutional context of R&D under the paradigm of sustainability can be translated into concrete action by value judgements applied to the established norm. When value judgments are systematized, they are called assessment procedures (Bosshard, 2000). In the following section, one such procedure is presented for the assessment of environmental impacts of agricultural technology innovation.

3. Environmental impact assessment system for agricultural technology innovation

3.1. General aspects of AMBITEC-AGRO

The objective of AMBITEC-AGRO is to provide a practical EIA platform, of simple and inexpensive application to the whole spectrum of agricultural technologies in the R&D institutional context. Also, the sustainability horizon of the system calls for the assessment of long-term viability, crystallized by the concept of technological life cycle. Upstream, this means consideration of the resources required for technology development (e.g., raw materials, habitats affected). Downstream, it means consideration of the residuals and effects on environmental quality (Porter, 1995).

The system has a hierarchical structure in which *indicators* of technology environmental performance are constructed by *components* measured in the field and weighed by factors related to the component importance and scale of occurrence (Lowrance et al., 1986). This structure is similar to EIA methods described in the literature, however, instead of exhaustive listings of components and complex indicator constructs that puzzle the evaluations (Rossi and Nota, 2000), the system relies on a previous experience of EIA method applied to research projects in the R&D institutional context (Rodrigues et al., 2000).

The AMBITEC-AGRO[2] consists of a set of electronic spreadsheets (MS-Excel platform) related to the evaluation of four *aspects* of agricultural activity improvement resulting from technology innovation: (i) its magnitude, (ii) efficiency, and contribution towards environmental, (iii) conservation, and (iv) restoration (Fig. 1). Each of these aspects consists of a series of *indicators* of technology environmental performance, constructed by *components* in automatic weighing matrices (Fig. 2). Each matrix has a number of open cells where the

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[2] The file containing the AMBITEC-AGRO system is available for download via internet access to Embrapa Environment homepage at http://www.cnpma.embrapa.br/serv/index.html.

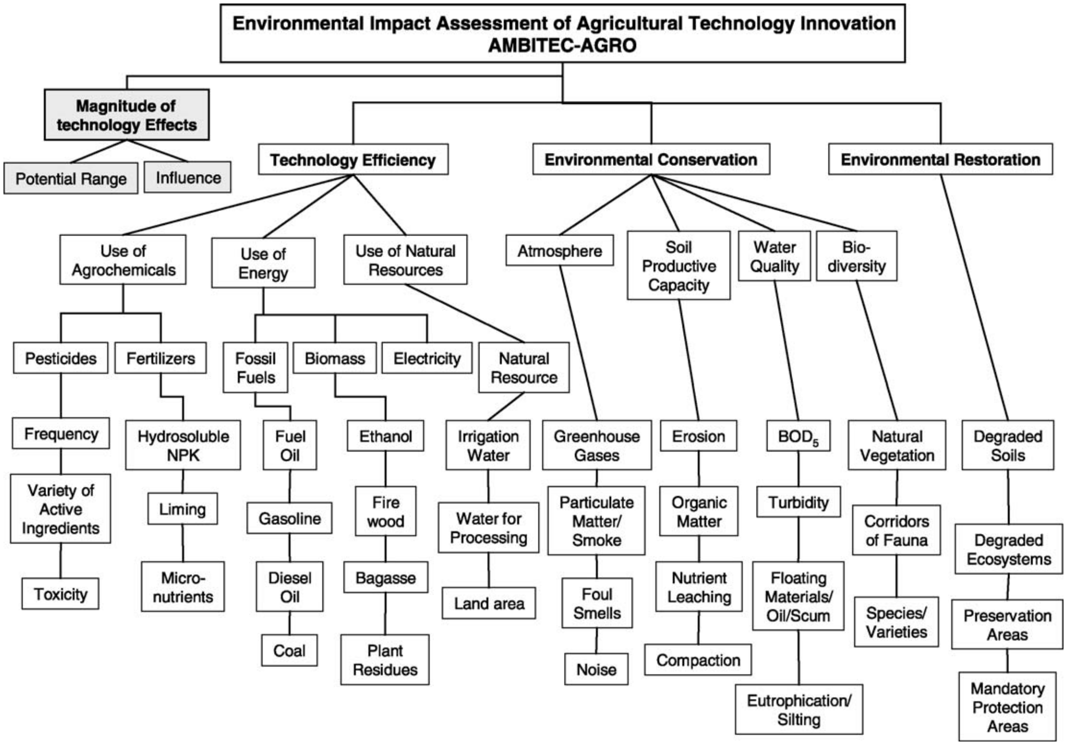


Fig. 1. Diagram for environmental impact assessment of agricultural technology innovation showing the aspects, indicators, and components of the AMBITEC-AGRO system.

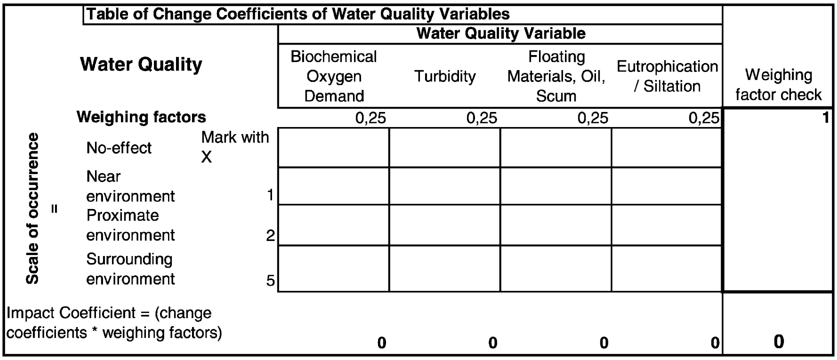


			Table of Change Coefficients of Water Quality Variables				
	Water Quality		Water Quality Variable				Weighing factor check
			Biochemical Oxygen Demand	Turbidity	Floating Materials, Oil, Scum	Eutrophication / Siltation	
	Weighing factors		0,25	0,25	0,25	0,25	1
Scale of occurrence =	No-effect	Mark with X					
	Near environment	1					
	Proximate environment	2					
	Surrounding environment	5					
Impact Coefficient = (change coefficients * weighing factors)			0	0	0	0	0

Fig. 2. Typical indicator (water quality) weighing matrix for environmental impact assessment of agricultural technology innovation of the AMBITEC-AGRO system.

change coefficient obtained in the field for each component is introduced. Also, each matrix has two sets of weighing factors: one related to the importance of the component and the other related to the geographic scale in which the component change coefficient occurred in the case studied.

The component change coefficients are obtained in a field interview/survey addressed to the farmer/manager regarding his/her knowledge about the environmental performance of the technology as applied in the specific activity and management system under evaluation. The interviews are to be applied to a statistically representative sample of farmers from the entire group adopting the agricultural technology under evaluation. It is important to remark that the interviewers should be well trained before going out to the field. In those cases when more than one interviewer is to do the work, it is recommended that, for training purposes, a group of farmers be interviewed by all the interviewers to make sure they obtain similar results for each indicator in each situation.

In summary, the AMBITEC-AGRO procedure comprises three steps. The first step refers to the process of survey and information collection on the technology and the crop to which it is applied, consisting of obtaining data for the magnitude of the technology (potential range and influence), the delineation of the geographic area and the group of farmers that can adopt the technology, and the definition of the representative sample of farmers/managers adopting the technology under evaluation. The second step refers to the application of a questionnaire to selected farmers, that is, the representative sample. The third step consists of entering data into the weighing matrices, followed by the composition of partial and aggregated indices to assess the environmental impact of the selected technology.

Once all change coefficients are inserted in the matrices sequentially for the Efficiency, Conservation, and Restoration spreadsheets, the environmental impact coefficient of each indicator is automatically weighed and the results are graphically expressed. Finally, an *Environmental Impact Index* is calculated for the technology under the specific conditions studied.

Because the active participation of users of the technology in the assessment process is considered crucial in the institutional context of R&D, and due to the variety of technology types and environmental situations evaluated, it is not possible to measure and express indicators and components in their original units. The system then incorporates standardized *component change coefficients* as proxy measures for the indicators. Two important features render objectivity to these measurements: first, components were selected that can be quantitatively evaluated in material, area or proportional units, avoiding biases due to preferences or opinions of the interviewed subjects; second, change coefficients were standardized to reflect the effects of technology contingent to each particular assessment, case-by-case.

The change coefficients were standardized as varying from − 3, meaning a major decrease in the component, to + 3, meaning a major increase in the component (Table 1). The change coefficient of a component is conditioned, on the one hand, by the *comparative* tendency caused by the technology in the particular situation, and on the other hand, by the *relative* character of the activity in the general agricultural context. For example, a technology that recommends nitrogen restocking—only application to pasture soils previously managed without any fertilizer use is to be considered a 'moderate (+ 1) change coefficient' in the 'fertilizer use' component, because even though it represents a major *comparative* increase in fertilizer use in the particular activity (from none to some use), it reflects a small *relative* use of fertilizer in the general agricultural scenario (of large input of nitrogen fertilizer in an area basis).

These considerations belong to the indicator construction step described as 'sensitivity test'—"the weighing of a variable while observing the behavior of the indicator when confronted with simulated variation of an input" (Girardin et al., 1999), and must be exercised for each component in each assessment. More on the objective basis for assigning change coefficients is presented in the description of components and indicators, later in the text.

One last feature of the weighing matrices refers to those components that have no effect relative to a given technology in the situation under study. The

Table 1
Effects caused by the agricultural technology in the studied situation and *component change coefficients* to be inserted into the cells of the weighing EIA matrices

Effect of the technology innovation on the agricultural activity under the management conditions studied	Component change coefficient
Major increase in the component	+ 3
Moderate increase in the component	+ 1
Component unaffected	0
Moderate decrease in the component	− 1
Major decrease in the component	− 3

occurrence of such components is a consequence of the inclusiveness needed for the method to be applicable to any agricultural technology and environmental situation. Every weighing matrix has a line where these cases are marked for expression in the result graphs.

3.2. Weighing for component importance and scale of occurrence

Each component change coefficient obtained in the field interview/survey and inserted into the input cells of the weighing matrices is weighed by two factors: one relative to the importance of the component in the make up of the indicator, and the other relative to the scale at which the change coefficient occurred in the case studied.

The values of the *weighing factors* vary in proportion to the number of components that make up a given indicator and add up to one, thus consisting of normalization factors defined in the sensitivity test (Girardin et al., 1999). The actual values of these weighing factors may be altered by the system user in order to better reflect any specific situation in which given components are to be emphasized, as long as the total value of all components for the indicator equals one.

The *factors for scale of occurrence* are obtained in the field interview/survey, to reflect the local magnitude of the observed component change coefficient in the specific situation studied, as follows:

(i) *near environment* when the technology effects are restricted to the crop area or productive field where the affected activity is being conducted;
(ii) *proximate environment* when the technology effect extends beyond the productive unit, but within the limits of the property or farmstead;
(iii) *surrounding environment* when the technology affects an area or environment beyond the limits of the property or farmstead.

Due to the very localized character of some of the indicators components, some matrices limit the scale of occurrence to the near environment, as is the case for all components in the Efficiency spreadsheet. The factors for weighing the *scale of occurrence* are fixed, as shown in Table 2. These values were assigned to express a proportionally larger impact index when the technology affects an area or environment beyond the limits of the farmstead.

Table 2
Weighing factors relative to the scale of occurrence of a component change coefficient caused by an agricultural technology innovation

Scale of occurrence	Weighing factor
Near environment	1
Proximate environment	2
Surrounding environment	5

4. AMBITEC-AGRO indicators and components

4.1. Magnitude of technology innovation effects

The Magnitude Aspect expresses the overall geographic scale in which the technology influences the activity or product, as determined by technology *potential range*—the total area occupied by the crop or activity to which the technology may be applied; and *influence*—the extent in which it may be applicable to the crop or activity. This is a general aspect of the technology, independent from its local use; hence it is not included in the system weighing matrices and should be obtained from the technical specifications of the technology, provided in its development project.

All other aspects considered in the technology EIA (efficiency, and environmental conservation and restoration) are characteristic of its local use, and must be obtained in the field interview/survey, with respect to the activity and specific management situation in which the technology is effectively being applied. The text that follows presents all components and indicators for the environmental impact assessment of agricultural technology innovation used in AMBITEC-AGRO.

4.2. Technology Efficiency Aspect

This aspect refers to the upstream contribution of the technology to sustainability of the productive process, by altering the dependence on inputs, both technological and natural. The indicators of technology efficiency are (I) use of agrochemicals, (II) use of energy, and (III) use of natural resources.

4.2.1. Use of agrochemicals

Agriculture depends on soil nutrients that are depleted and exported in the production process, and must be replenished by fertilizer application. On the other hand, any organisms that reduce productivity by competing with or predating on the crops are controlled with pesticides. These products used in soil fertilization and pest control are generically called agrochemicals. In general, agrochemical use is inversely proportional to agricultural sustainability for two main reasons: first because they are external inputs of a high relative cost, imposing a considerable capital drain to the farm; and second, because they are important environmental pollutants when inadequately used or overused. Due to the specific impacts caused by fertilizer and pesticide use, each is evaluated by a separate set of components.

4.2.1.1. Pesticide use. The enormous diversity of existing chemical classes and the countless possible physico-chemical interactions with water, soil, and biological matrices make the study of pesticide environmental behavior extremely complex. This complexity is resolved for impact evaluation in AMBITEC-AGRO by the consideration of three components descriptive of the effect of technology innovation on pesticide use: (i) frequency, (ii) variety of active ingredients, and (iii) toxicity.

(i) Frequency: refers specifically to the number of pesticide applications, disregarding compound type or potential effect. Variations above 50% in the number of applications compared to the situation previously to technology adoption are considered major changes in this component (± 3). Therefore, variations below 50% in the number of applications are considered moderate (± 1).

(ii) Variety of active ingredients: refers to the number of different pesticide compounds used in the production process, and reflects the dependence on pesticides caused by the technology. It is important to separate this case from the alternating use of pesticides used as a management strategy to delay the onset of resistance to those chemicals. Variations above 50% in the number of active ingredients needed in the activity are considered major changes (± 3).

(iii) Toxicity: expresses the potential environmental hazard of the pesticides used in the production process. This is an extremely complex component, dependent on the physico-chemical character of each compound, its specific formulation and use situation, and the numerous possible combinations of these factors. This complexity is resolved by consideration of the toxicity categories expressed in pesticide labeling—for example, in the USA and Brazil pesticides are categorized in four toxicity levels as follows: I—extreme, II—high, III—moderate, IV—low toxicity. Because similar labeling categorizations are compulsory in many countries, it is possible to check the change coefficient for this component directly in the field interview/survey. A major change coefficient (± 3) should be assigned when two or more toxicity category levels (from I to III or vice-versa, for example) result for the comparison of active ingredients before and after technology adoption. When the balanced toxicity categories of this comparison results in only one level, the change should be considered moderate (± 1).

4.2.1.2. Fertilizer use. Soil management for sustainable agricultural production involves two main goals, to avoid physico-chemical–biological degradation (included in the Environmental Conservation Aspect of the EIA system), and to warrant replenishment of nutrients exported or depleted in the production process, which is normally accomplished by the regular application of fertilizers. The technological efficiency related to soil fertilization is assessed by the need for three input categories: (i) hydrosoluble NPK, (ii) liming, and (iii) micronutrients.

(i) Hydrosoluble NPK: the main soil macronutrients needed for plant growth are phosphate, potassium, and nitrogen. These nutrients are applied to agricultural soils as chemical fertilizers formulated from phosphatic and potassic rocks obtained in mining, and by fixing atmospheric nitrogen in highly energy intensive industrial processes. Therefore, fertilizers are non-renewable resources that impose a capital drain on the farm. Also, the highly soluble form in which nutrients are formulated in fertilizers facilitates their leaching from soils, causing pollution problems downstream. For these reasons, changes in fertilizer dependence represent important contributions for the environmental impact and sustainability of agriculture. Variations above 50% in NPK use caused by technology innovation should be considered major change coefficients (± 3) for this component.

(ii) Liming: a consequence of soil exposure to weathering promoted by the removal of vegetation and the tilling operations commonly performed for cultivation is the oxidation of soil organic matter and reduction of the cation exchange capacity. The succeeding preferential leaching of hydrosoluble compounds result in chemical unbalances, among which soil acidification due to H^+ build up. Electrochemical interactions are modified in acidic soils, causing on the one hand, loss of particle structure and water retention capacity, and on the other, increased solubility and activity of toxic elements such as aluminum, resulting in severe agricultural limitations. The periodic application of lime reverts soil acidification and greatly improves soil physico-chemical characteristics, being considered a beneficial management practice when carried out at adequate time intervals. However, increases in the need for liming indicate improper soil management practices and impose a capital drain on the farm. Variations above 50% in the time interval between liming operations should be considered a major change coefficient (± 3) for this component.

(iii) Micronutrients: another common unbalance caused by inadequate soil management is leaching of minerals and micronutrient depletion. Replenishment of micronutrients is relatively costly and must be performed with caution, for many of these elements are toxic when present in high levels. Measurement of this component is carried out also according to periodicity, and variations above 50% in the time interval between micronutrient applications should be considered major (± 3) change coefficients.

The weighing matrix for the Use of Agrochemicals indicator limits the scale of occurrence to the near environment, for the inputs are applied within the field or productive field in which the technology innovation is adopted. Relative to the importance of the components, the pesticide use receives 70% of the total weight, with toxicity representing 30% and frequency and variety of active ingredients 20% each. The remaining 30% of the weighing factor are equally distributed in the components of fertilizer use.

4.2.2. Use of energy

The second indicator of Technology Efficiency considered in the proposed EIA system is the use of energy. Even though energy use is essential in all steps of agricultural production, and involves natural (e.g., solar and hydraulic) and manmade (fuels and industrial inputs) sources used directly as well as indirectly, in order to avoid double counting only the direct uses of fuels and electricity are included in this indicator. The use of energy is assessed by accounting for fossil fuels, biomass, and electricity.

4.2.2.1. Fossil fuels. Because fossil fuels are non-renewable resources obtained outside and imposing a capital drain on the farm, and represent sources of pollution, it is recommended that alterations above 25% in fossil fuel use due to technology adoption be considered a major change coefficient (± 3) for these components.

4.2.2.2. Biomass. A substantial portion of the energy in rural areas is normally supplied by biomass. Besides being a renewable energy source obtained locally, when well planned and executed according to production levels, biomass combustion represents a valuable application for plant residues that otherwise have no alternative use. However, firewood extraction above renewal capacity is responsible for extensive habitat degradation around the world, and must be avoided. Alterations above 50% in biomass energy consumption due to technology adoption should be considered major change coefficients (± 3) for this component.

4.2.2.3. Electricity. Electricity represents a higher quality source of energy and usually must be obtained outside the property at relatively high costs. Variations above 25% in electricity consumption due to technology innovation should be considered major change coefficients (± 3) for this component.

Energy use is restricted to the near environment in the weighing matrix because the EIA is directed towards the demand relative to the particular activity modified by technology adoption. Fossil fuel use responds for 40% of this indicator (10% for each fuel type), 30% is due to biomass (7.5% for each type), and electricity use responds for the remaining 30%.

4.2.3. Use of natural resources

In addition to the inputs provided by the economic system discussed above, agriculture relies on natural resources taken not only as the location and support for productive activities considered ahead in the Environmental Conservation Aspect, but also directly as inputs. The use of natural resources as production inputs is an important aspect of Technology Efficiency as regarded by the need of water for irrigation and processing, and of land area.

(i) Irrigation water: although restricted to irrigated agriculture, this use of water responds for the largest demands of water in rural areas. Because good quality waters are a dwindling resource in many areas, volume alterations above 25% should be considered major change coefficients (± 3) for this component.

(ii) Water for processing: this use of water is mainly related to post-harvest processing and in most cases is non-consumptive. Frequently, however, this use results in depreciation of water quality, an effect that is assessed later in the Environmental Conservation Aspect, and should not be accounted here, in order to avoid double counting. Similarly to the previous component, alterations above 25% in water needs resulting from technological innovation should be considered major change coefficients (± 3).

(iii) Land area: relative to agricultural technology efficiency, land area use can be equated with productivity. The larger the productivity gain rendered by a technological innovation, the smaller the area needed for the same production volume, hence the smaller the pressure on new land areas. Considering that in most cases these new areas consist of marginal low quality soils, or natural habitats on the frontier of agricultural expansion, any alteration above 25% in the demand for land (translated by corresponding alterations in productivity) should be deemed major change coefficients (± 3) for this component.

By equating use of natural resources with input consumption, the Technology Efficiency weighing matrix limits the scale of occurrence of these components to the near environment. The components related with water use make up 60% of this indicator (30% for each type of water use), while the remaining 40% refer to demand for land area.

4.3. Environmental Conservation Aspect

Once the Technology Efficiency Aspect of input requirements has been considered, representing the contribution of technology innovation to sustainability upstream to the productive process, the downstream effects of the technology are to be considered. These impacts are represented by environmental contamination with residues of production, and the effects on natural habitats and biological diversity due to technology adoption. The Environmental Conservation Aspect is assessed by indicators of technology innovation effects on the quality of the atmosphere, the productive capacity of the soil, the water, and biodiversity.

4.3.1. Atmosphere

Besides being an important source of greenhouse gases, agricultural activities frequently generate particulate matter and smoke, foul smells, and noise. These are the components used in the assessment of effects of agriculture on the quality of the atmosphere.

(i) Greenhouse gas emissions: some of the main gases associated with the greenhouse effect and global warming, such as carbon dioxide (CO_2), methane (CH_4), and nitrogen oxides (NO_x) are generated in large quantities by the agricultural activities. CO_2 emissions are related to combustion processes, both from fossil fuel use and the burning of crop residues, pastures, and vegetation in general, such as practiced in slash-and-burn agriculture. CH_4 is emitted from anaerobic metabolism, such as occurs in ruminant digestion and organic matter decomposition in inundated soils. Thus, cattle raising and flooding irrigation (very common in rice production) are considered important methane emission sources. NO_x emissions from agriculture are associated mostly with microbial denitrification processes in soils, whereas nitrogen fertilizer use and nitrogen fixing leguminous plant cultivation are sources of this gas. Due to the complexity and variety of these processes, and the controversial role of agricultural activities as sources and sinks for these gases, parsimony must be exercised in this assessment. For the simpler case of combustion emissions, only large-scale operations should be considered as causing major change coefficients (+ 3). In the opposite direction, only extensive permanent carbon fixation processes, such as definitive reforestation, should be considered as major changes (− 3). Relative to methane and nitrogen oxide emissions it is recommended that only with direct and documented evidence major change coefficients (± 3) should be assigned. Otherwise, and when applicable, the change coefficients should be considered moderate or unaffected.

(ii) Particulate matter and smoke: these emissions represent a nuisance to neighboring populations and also have a negative effect on domestic animals and plants. Particulate matter and dusts reduce photosynthesis and act as abrasives on the membranes of plants, making them susceptible to insects and diseases. Smoke results from incomplete combustion and usually indicates the presence of toxic levels of carbon monoxide, but can also include considerable quantities of hydrocarbons, which are the precursors of highly damaging tropospheric ozone. Assessment of this component is carried out according to emission periodicity, considering alterations above 50% in emission periods as major change coefficients (± 3).

(iii) Foul smells: the impact caused by foul smells is essentially related to discomfort of exposed people, and is assessed by sensorial evaluation. When applicable and affected by technology innovation, the intensity of this component is qualified by the farmer/manager in the interview/survey as weak, moderate, or very strong discomfort. Also, and similarly to the previous component, the periodicity can be considered. The change coefficient is considered major (± 3) when a two-level change of intensity or discomfort (from weak to strong or vice-versa) result from technology adoption, or when a 50% variation in occurrence period is observed.

(iv) Noise: the same considerations of the effects and the same reasoning applied to the previous component are valid for noise generation. The change coefficient due to technology innovation is considered as major

(± 3) when a two-level change in comfort level, or a 50% or larger variation in the noise generation period occurs.

The weighing matrix for this indicator emphasizes greenhouse gases and particulate matter/smoke emissions as the most important components of the indicator (40% each). Foul smells and noise respond equally for the remaining 20%. These components can be associated with the three scales of occurrence (Table 2), according to the spatial distribution of the emission changes caused by technology adoption.

4.3.2. Soil productive capacity

The contribution of a technology innovation to environmental conservation cannot be directly equated with soil quality indicators, for these are all defined according to fertility parameters that, although valuable for the agricultural use of soils, have little correspondence to environmental quality per se. This is true because soil fertility is not necessarily equivalent to the quality of the environment, and in fact fertile soils are normally inserted in highly occupied and degraded environments, while many highly valuable natural ecosystems occur on extremely poor soils. Nevertheless, soil quality is essential for sustainability, and must be considered in the EIA of agricultural technology innovations. Soil quality indicators are assessed according to time dependent alterations in productive capacity due to technology adoption, rather than soil genetic characteristics of fertility. The components for evaluation of soil productive capacity alteration are erosion, organic matter, nutrient leaching, and compaction.

(i) Erosion: being a function of natural soil erodibility, rain erosivity, slope length and gradient, plant cover, and land use, erosion rates may vary enormously. This complexity is resolved in the EIA system by the relative consideration of three increasingly damaging processes, sheet, rill, and gully erosion (Cox and Atkins, 1979, pp. 277–284). A major change coefficient for this component should be assigned when the technology adoption causes erosion intensity to vary over two levels of damaging potential (i.e., from sheet to gully or vice-versa), while changes involving one level of damage can be considered moderate (± 1).

(ii) Organic matter loss: oxidation of soil organic matter (SOM) ensues as soon as natural vegetation is cleared and tillage is carried out to prepare the land for cultivation, causing soils to lose structure and water and nutrient retention capacity. SOM content in soils is extremely variable according to soil genesis and occupation history. This component can be assessed indirectly by influence of the technology innovation onto the managing practices adopted, such as low-tillage planting, soil incorporation of crop residues, composting, etc. A major change in the OM content refers to effective practices being used to increase or decrease its amount in soils (± 3). Another way of assessing OM in soils is by comparison of historical data if quantitative analyses are available: variations above 25% in its content over a period of 5 years is considered major (±3).

(iii) Nutrient leaching: this component is dependent on erosion, SOM, and fertilizer input assessments, and some double counting may be committed in its consideration. The operational evaluation of nutrient leaching must rely on historic data or knowledge of the farmer/manager on fertilization needs, and variations above 25% the historic requirements of fertilizer application due to technology innovation should be considered major change coefficients (±3) for this component.

(iv) Compaction: the intensive use of heavy machinery and overgrazing are the main causes of soil compaction and plow pan formation. Assessment of this component relates the relative change of compacted soil surface in the area occupied by the activity modified by technology adoption. Alteration above 25% in compacted soil area should be considered major change coefficients (±3).

Similarly to the indicators of Technology Efficiency, changes in soil productive capacity occur in the particular cultivated area or productive field, hence the components of this indicator are restricted to the near environment scale of occurrence. Because complete independence among these components cannot be assumed, the relative weighing factors for composing this indicator are equally distributed (25% to each component).

4.3.3. Water

Water quality is possibly the most sensitive general indicator of the environmental impacts caused by agricultural activities, because practically any management inadequacy will result in water quality degradation, both in the immediate and in the surrounding environments. Therefore, this indicator always exhibits a certain degree of dependence relative to others, implying that some double counting is inevitable, given the systemic character of EIAs. Another aspect to be kept in mind when considering water quality issues is the existence of separate but interrelated surface and groundwater compartments. Due to the difficulty to obtain reliable information regarding groundwater quality and quantity at the farm level, and assuming the systemic continuity between these compartments, this EIA system addresses specifically the quality of local surface waters. The assessment involves biochemical oxygen demand (BOD_5), turbidity, floating materials/oil/scum, and water body eutrophication/siltation.

(i) Biochemical oxygen demand: BOD_5 refers to water organic content, and as little as 5 mg/l may cause severe oxygen depletion in certain conditions, impairing respiration of aerobic organisms. Assessment of this component is carried out analytically (through lab analysis or a field oxymeter). When these analyses are not possible, the presence of aquatic fauna can be used as a proxy, according to farmer/manager knowledge expressed in the field interview/survey. A major change coefficient (± 3) should be assigned when anoxia episodes start to occur (or stop occurring for decreases in BOD_5) after technology adoption.

(ii) Turbidity: represents the presence of suspended matter (particulate or colloidal, organic or inorganic), and causes photosynthesis impairment and difficulty for water filtration and disinfection, as well as aesthetic depreciation. Assessment of this component relies on farmer/manager knowledge of the site, and changes in periodicity of occurrence. A major change coefficient (± 3) should be assigned when turbidity is increased (or decreased) over 50% of the time due to technology adoption.

(iii) Floating materials/oil/scum: these pollutants impair all uses of water, and cause complete aesthetic depreciation. Similarly to the previous component, the assessment must rely on the farmer/manager knowledge of the site, and changes in periodicity of occurrence. A major change coefficient (± 3) should be assigned when presence of floating materials/oil/scum is increased (or decreased) over 50% of the time due to technology adoption.

(iv) Water body eutrophication/siltation: this component represents the composite result of long exposure of an aquatic environment to low quality waters, hence it depends on all previous components and may imply certain double counting. Its inclusion is justified, however, to express the effects at the ecosystem level. This component reflects the alteration caused by the technology in the natural succession rate that occurs in all aquatic ecosystems, and because it is a long-term process relative to the EIA of a technology innovation, it must be assessed by the historic knowledge of the farmer/manager. The change coefficient of this component should be considered major (± 3) when there is alteration in water surface area in any extension of the water body margins. The change coefficient should be considered moderate (± 1) when the siltation causes only volume loss, due to bottom deposition.

The water quality weighing matrix distributes the weighing factors of these components evenly, each responding for 25% of the indicator, recognizing their interdependency. Given the pollutant carrier character of water, the scale of occurrence of these components usually extends beyond the limits of the farm, influencing the surrounding environment.

4.3.4. Biodiversity

Biodiversity conservation is an essential objective of sustainable development, and especially for the multifunctional role of agriculture, for most of the existing stock of biological and cultural diversity occurs in areas under some level of agricultural or forestry management (Pimentel et al., 1992). Conversely, biodiversity contributes for agricultural sustainability by providing genetic and managerial alternatives that improve resource use efficiency and production security (Campanhola et al., 1998). Three components are included in this indicator of the Environmental Conservation Aspect of technology innovation: changes in natural vegetation, corridors of fauna, and local occurrence of species and varieties.

(i) Natural vegetation: this component addresses the conservation of all forms of natural vegetation locally influenced by technology innovation, especially those present in marginal areas such as mountain tops, steep slopes, paludal and riparian vegetation. Due to similarity with the indicator of Permanent Preservation Areas included in the Environmental Restoration Aspect presented later, this component must include only natural vegetation effectively present in the area, and which conservation status is changed by technology adoption. The component change coefficient should be considered major (±3) when the technology innovation directly contributes to vegetation conservation (or degradation); or moderate (±1) when such contribution is indirect, due to reduction (or increase) in occupation pressure or predatory exploitation, for example.

(ii) Corridors of fauna: Many productive areas managed with various degrees of intensity are crucial for the movement of fauna, favoring the genetic flux and thus exerting the role of corridors of fauna. To avoid double counting due to the overlap between corridors of fauna and natural vegetation considered above, only these managed areas should be included in this component. It is recommended that major change coefficients (±3) be assigned to managed areas that effectively favor (or restrict) fauna movement between existing natural vegetation areas. The change coefficient should be considered moderate (±1) when these managed areas favor (or restrict) the movement of fauna between other managed areas that consist themselves corridors of fauna.

(iii) Preservation of species and traditional varieties: the technological development of agriculture must take precaution to avoid the homogenization commonly mistaken as an inevitable consequence of modernization. Many dimensions of diversity conservation must be included in this precautionary principle, from habitats, landscapes, species, and rustic plant and animal varieties, to tools, construction materials, management practices, traditional foodstuffs and medicines, and ways of life. With such a broad range of considerations, it is suggested that this component be assessed subjectively, offering opportunity to the farmer/manager to express his perception of the effects of technology innovation, and documenting these effects. The alteration may be considered major (±3) when the technology directly affects the component, whereas a moderate alteration (±1) refers to an indirect effect.

The weighing matrix for Biodiversity Conservation allows consideration of effects beyond the area occupied by the agricultural activity modified by technology innovation, for this influence frequently affects neighboring ecosystems and properties. The importance of natural vegetation for biodiversity conservation as a whole (fauna and species in general) is recognized by a larger weighing factor (40%), while the other two components respond equally for the remaining 60%.

4.4. Environmental Restoration Aspect

An advanced state of environmental degradation is currently observed in agricultural areas throughout the globe, imposing the need for ecosystem restoration as a common objective for technology innovation in sustainable agriculture. This aspect refers to the effective contribution of technology innovation to promote natural resources improvement through recovery of degraded soils, degraded ecosystems, preservation areas, and mandatory (legal) protection areas.

4.4.1. Environmental restoration variables

(i) Degraded soils: the intensive and frequently inadequate patterns of soil exploitation of conventional agriculture in the last decades have caused the continuous expansion of chemically impoverished, physically degraded, and biologically barren soils. An important research effort has been directed to soil reclamation techniques, such as microbial inoculation and minimal tillage, and every agricultural technology innovations should include this concern. It is recommended that a major change coefficient (± 3) be assigned to innovations that directly improve (or reduce) soil quality related to at least two parameters of soil fertility (physical, chemical or biological).

(ii) Degraded ecosystems: this component addresses the recovery of productive capacity of those marginal areas effectively inserted in the productive context of the farm, but frequently exposed to fire, overgrazing, and other forms of degradation pressure. The assessment of this component should refer only to improvement of the productive insertion of these areas, because the recovery of natural areas is considered in the next component. The change coefficient for degraded ecosystems is considered major (± 3) when the productivity of the area is increased by at least 25% relative to the situation without technology adoption.

(iii) Preservation areas: natural habitats and areas of mandatory preservation such as mountain tops, stream buffer zones, steep slopes, among others, are generally defined in the legislature of many countries. When no such formal provisions exist, general habitat and marginal land conservation recommendations are in place, and generally enforced by agricultural extension services. It is recommended that these provisions for preservation be included in this component, and that the change coefficient be considered major (± 3) when, as a result of technology adoption, the farm status, as regarded by compliance with such legal instruments or provisions, is altered (from non-compliant to compliant or vice-versa). The change coefficient is moderate (± 1) when the alteration in preservation areas is larger than 25%, but is not sufficient to change the compliance status of the farm.

(iv) Mandatory protection area: in addition to the preservation areas defined above, many legislatures include a minimum protection area, normally defined as a fixed proportion of the property total area. The distinction between this component and the previous one is of an inclusive order, that is, if the preservation areas in the farm are sufficient to comply with Mandatory protection area this component should be considered as having no-effect. Otherwise, when in addition or alternatively to the Preservation areas, technology innovation contributes to compliance with Mandatory protection bills that may be in place, this component should be assessed, in the same basis as the previous one.

The weighing matrix of the Environmental Restoration Aspect emphasizes compliance with Mandatory protection areas (which is legally regulated in the institutional context of development of this EIA system), with a 40% importance factor. Each of the other components responds with a 20% importance factor. As this aspect reflects local legal provisions that may vary considerably, these weighing factors may be altered accordingly. The scale of occurrence for these variables extend from the near to the surrounding environment, for in many cases, technology adoption may interfere with neighboring natural habitats and protection areas.

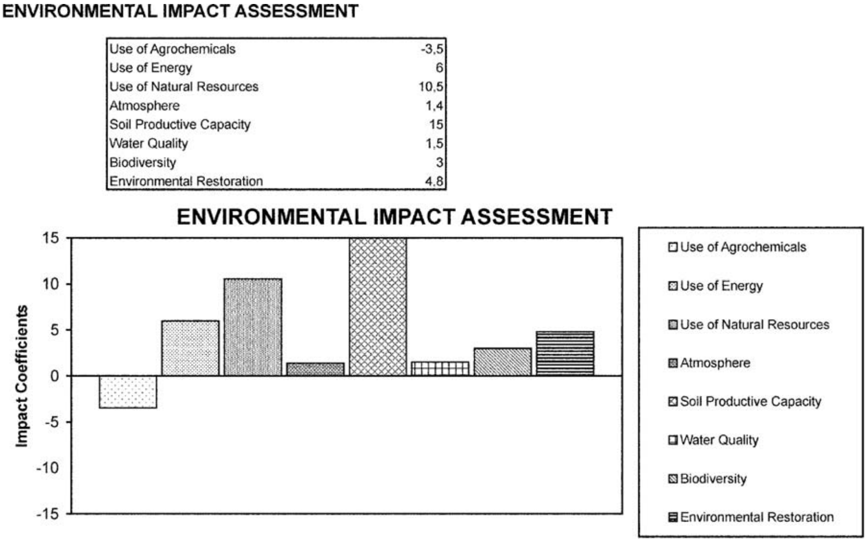
5. Technology environmental impact assessment

Once the assessment is completed and the change coefficients for all components are inserted in the corresponding weighing matrices, the environmental impacts associated with technology innovation in the studied situation are automatically expressed graphically in the Technology EIA spreadsheet (Fig. 3). The graphs are sequentially composed for each aspect, first showing the components that eventually had no effect on the specific situation studied, followed by the numeric Environmental Impact Coefficient result of all components and by a summary graph for the aspect considered.

All indicators are then normalized and shown in a final weighing table, where an importance factor is attributed to each indicator to compose the Environmental Impact Index of Technology Innovation. The results of each indicator are also presented in bar graphs where the user may find which specific changes brought about by the technology caused major impacts. The Environmental Impact Coefficients for the indicators are computed as:

$$\mathrm{EIc}_i = \sum_{j=1}^{n} C_{ji} S_{ji} I_{ji}$$

where EIc_i = environmental impact coefficient of the indicator i; C_{ji} = change coefficient of component j of indicator i; S_{ji} = scale of occurrence factor of



ENVIRONMENTAL IMPACT ASSESSMENT

Use of Agrochemicals	-3,5
Use of Energy	6
Use of Natural Resources	10,5
Atmosphere	1,4
Soil Productive Capacity	15
Water Quality	1,5
Biodiversity	3
Environmental Restoration	4.8

Fig. 3. Summary graph showing the Environmental Impact Indices for all indicators considered in the AMBITEC-AGRO system. The particular example refers to a technology directed at the "reclamation of mined areas with plants associated with nitrogen fixing bacteria."

component j of indicator i; I_{ji} = weighing factor of component j of indicator i; n = number of components of indicator i.

The individual environmental impact coefficient for each component is calculated with the multiplication of the change coefficient by the scale of occurrence and by the weighing factor. Then, the environmental impact coefficient for each indicator is obtained with the summation of the environmental impact coefficients for all components of that indicator.

The Environmental Impact Index of Technology Innovation is computed as:

$$\mathrm{EIIti}_t = \sum_{i=1}^{n} \mathrm{EIc}_i I_i$$

where EIIti_t = environmental impact index of technology innovation t; EIc_i = environmental impact coefficient of the indicator i; I_i = weighing factor of indicator i for the composition of the Environmental Impact Index of Technology t; n = number of indicators.

The aggregated Environmental Impact Index of an agricultural technology is calculated with the summation of the environmental impact coefficient of each indicator multiplied by its respective importance factor. In this version of AMBITEC-AGRO, we consider the same weighing factor (composed importance 1 divided by 8 indicators = 0.125) for all indicators.

Based on the resulting graphs and indices, the system user proceeds with a contextual analysis of the agricultural technology innovation, according to the environmental performance observed in the specific case studied. An indispensable approach at this point is to go back to each spreadsheet to interpret and describe the particular results for each indicator. That is, it is necessary to understand each particular result obtained. With this analysis at hand, the system user should return to the farm, first to discuss the results with the farmer/manager and make any corrections that might be deemed necessary to ensure the adequacy of the results. Second, and most important, to comment on problems and advise on alternatives that may contribute to improve the environmental performance of the technology in the specific context of environment and production system of the farm.

6. Discussion

The AMBITEC-AGRO consists of a practical EIA system of agricultural technology innovation, ready for field application through an interview/survey directed at the farmer/manager responsible for the agricultural activity modified by the adoption of the studied technology. The system relies on a computational platform readily available and easily applicable at low cost, and facilitates the storage and communication of information regarding environmental impacts.

Regarding the computational structure, the system is simple and transparent, unveiling to the user all operations performed with the data. Also, while fairly standardized relative to measurements, the system is malleable, allowing the user to adapt for specific use situations, by changing the weighing factors of indicators and components when appropriate. Components marked as having no effect are clearly shown in the Tables accompanying each graph, allowing the user to better evaluate the appropriateness of the system for the particular technology and situation considered.

There are other limitations of the proposed system. One is the exclusive consideration of the ecological aspects of sustainability. The integration of social and economic dimensions is fundamental for the impact assessment of technology innovations, especially when sustainability objectives are defined, as is true for the present case (Barbier, 1988; Corkindale, 1993; Pinho and Pires, 1991). However, an important theoretical gap still exists between social appraisal and environmental impact assessment, making the development of a truly integrated system a difficult methodological challenge (Azqueta, 1992).

The ecological-only basis of AMBITEC-AGRO reflects a specific demand for technology innovation assessment at the institutional context of R&D, in which policy definitions direct each dimension, ecological, economic or social, to be addressed from a departmental viewpoint. This limitation, however, is outweighed by the opportunity of introducing the praxis of performing EIA in technology development, adoption, and extension. The system proposed is applicable to this end both in the internal and external institutional contexts of

R&D. Internally, it favors awareness of researchers and administrators regarding the environmental implications of agricultural technology development and adoption. Externally, it introduces EIA at an operational level into agribusiness, offering farmers and managers a chance of understanding the environmental interface of technology innovation.

The other limitations of the system are: it is a relatively simple system, with only eight indicators and 34 components; it does not quantify parameters, but is based on the experience and observation ability of the farmer/manager; and is restricted to agricultural technologies with spatial dimension, that is, those affecting land areas. In this case, agroindustry technologies and confined animal husbandry, for example, are not suitable for assessment with this system. The simplicity of the system leads to a certain bias related to individual value judgement, but has the advantage of being performed at low costs.

The acceptance of simpler systems such as AMBITEC-AGRO is an important step toward more complex methods that require a stronger analytical basis and involve a more complex theoretical foundation. In effect, a multi-attribute EIA system integrating dimensions related to Landscape ecology, Environmental quality, Sociocultural values, Economic values, and Management values has been formulated and is currently been validated in field trials (Campanhola and Rodrigues, 2001). In this sense, AMBITEC-AGRO is a contribution to the stepwise process of sustainable agricultural technology development and appraisal.

Acknowledgements

The authors thank their colleagues Mariza M.T.L. Barbosa, Antônio F.D. Ávila, Morsyleide de F. Rosa, Odo Primavesi, and Sérgio Ahrens (Embrapa, Brazil); André T. Furtado, Claudenicio Ferreira, Débora Mello, José Maria da Silveira, Marcelo Valle, Marco Polli, Maria Beatriz Bonacelli, Maria Ester dal Poz, Mauro Zackiewicz, Mirian Hasegawa, Rosana Corazza, Sérgio Salles, Solange Corder and Sônia Paulino (GEOPI/Unicamp, Brazil); Roberto Bochetto (PROCISUR, Uruguay), Roberto Díaz and Ana Berretta (INIA, Uruguay); Ernesto Viglizzo, Guillermo Huerta, and Celso Giraudo (INTA, Argentina); Emílio Ruz and Silvia Gálvez Anastassiou (INIA, Chile); and Renato F. de A. Veiga (IAC, Brazil) for many contributions to this work. Geraldo thanks professors Mark T. Brown and H.T. Odum, from the Center for Environmental Policy, University of Florida, Gainesville for the warm welcome. This work is supported by Fundação de Amparo à Pesquisa do Estado de São Paulo (FAPESP) and by Empresa Brasileira de Pesquisa Agropecuária (Embrapa).

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