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Measuring the potential impacts of improved food-feed crops: methods for ex ante assessment

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Abstract

The recent increased emphasis on impact assessment is due in part to the rapidly changing nature of funding for agricultural research and the shifts that have occurred in what is expected of the agricultural research community. The reasons for doing impact assessment are relatively clear: ex post studies can determine the impact of past investment in research on target beneficiaries and are a way to learn some of the lessons of the past. Ex ante studies can provide information to assist in the allocation of scarce research resources to activities that best match donors' development objectives. In practice, impact assessment is often contentious and almost always difficult, particularly when livestock are involved. In this paper, we outline methods that can be used in ex ante impact assessment, and illustrate some of these in relation to three recent studies on improved food-feed crops in different places: improving the quality of millet and sorghum stover in India, using dual-purpose cowpea in West Africa, and alternatives for utilizing maize stover in the mixed systems of East and Southern Africa. Such impact assessments are neither cheap nor quick, and the methods that are most appropriate in any situation will depend not only on the resources and expertise available but most importantly on the exact nature of the questions being asked and the end-users of the results. Much remains to be done to maximize the utility of such assessments, particularly in the areas of quantitative model development, rapid qualitative method development, more effective integration of biophysical and socio-cultural indicators and approaches, and provision of baseline data against which to measure progress. Research resource allocation may well retain its somewhat haphazard nature in the future, but given the challenges facing agriculture in developing countries, a mechanism for attempting to ensure that research and extension really do contribute to widely held development goals has to be based on more than trial and error.

Keywords: Impact assessment; Dual-purpose crops; Sorghum; Millet; Cowpea; Maize; Poverty alleviation; India; Africa

1. Introduction

The next 20 years will see great opportunities for livestock producers in the tropics to meet the rising demand for food of animal origin, with virtually all the increased demand coming from the developing countries (Delgado et al., 1999). The implications for evolving livestock production systems, for the environment and for smallholders' welfare as a result, are largely dependent on the region and systems under consideration.

Mixed crop–livestock systems provide over 50% of the world's meat and over 90% of its milk and are the most common form of livestock operation in developing countries (Von Kaufmann, 1999). In sub-Saharan Africa alone (SSA), 444 million people

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(70% of total SSA human population), 92 million cattle (80% of total SSA cattle) and 194 million sheep and goats (80% of total SSA shoats) are found in these systems (Thornton et al., 2002). In SSA we estimate that 140 million poor livestock keepers are located within these systems (Thornton et al., 2002).

Livestock often fulfill a complex role in smallholder mixed systems, which themselves are often very complex. They are not only used to produce meat and milk, but are used as a store of wealth, for insurance purposes, and often for fulfilling social obligations. Since these aspects of crop–livestock systems arise in part from market failures, valuing them using market prices is difficult if not impossible (Thorne, 1998a).

Within the mixed systems of the tropics, the role of dual-purpose, or food-feed, crops has been, and continues to be, an area of substantial interest. On the face of it, the idea of a crop from which farmers can harvest one product for human consumption and the residues of which they can then feed to their livestock, is a highly appealing one. Of course, farmers have been doing this widely for many years in ‘‘traditional’’ systems. A key issue is how to retain the benefits of multi-purpose use as systems evolve, particularly when market pressures may tend many to increase specialization, for example.

As mixed systems evolve in response to population growth and growing demand for livestock products, there will evidently be increasing integration of crops and livestock over the next few decades (Smith et al., 1997). But there is increasing interest, however, in studying the intensification pathways that different production systems may follow (e.g. McDermott et al., 2001; Staal et al., 2001). Understanding the systems within which small-scale mixed farming households are operating is a prerequisite to measuring impact of any interventions within these systems (Kristjanson and Thornton, 2001).

The objectives of this paper are to present the major tools of ex ante impact assessment and to illustrate the use of some of them in assessing the impact of food-feed crops in various places. We first outline some general considerations regarding impact assessment as applied to smallholder mixed crop–livestock systems, in relation to assessing the costs and benefits of food-feed crops. In Section 3, we provide an overview of many of the tools and methods of impact assessment, with an indication of the strengths and weaknesses of each. We illustrate how some of these tools and methods that have been used at the International Livestock Research Institute (ILRI) over the last few years to assess impact of food-feed crops in three case studies outlined in Section 4: millet and sorghum residues in systems in India, dual-purpose cowpea in West Africa, and maize in East and southern Africa. We conclude with a brief survey of remaining problems and some new approaches that may, in future, better capture the livestock-related impacts at the systems level.

2. The nature and role of impact assessment

Impact assessment, in its broadest sense, is the evaluation of the effects of change in agricultural systems. The change may be brought about by indigenous innovation, research, such as a new technology or a new policy, or by other drivers such as population growth or market collapse. The effects that may be assessed include changes in production and productivity, income, food security, social welfare, and the environment (Peterson and Horton, 1993). These different effects may also be assessed at different scales, such as the farm, watershed or nation. Impact assessments may have to take some account of the ecological, economic and social subsystems operating at each scale. Most impact assessments that study change that has already occurred (ex post) and, particularly, change that has yet to occur (ex ante), require mixtures of models and analytical tools to generate appropriate information concerning the effects of this change (Thornton and Herrero, 2001).

Increased prominence has been given to impact assessment in recent years and is a result of various factors. These include the rapidly changing nature of funding for international agricultural research, and the remarkable shifts that have occurred in what is expected of the international agricultural research community on the part of the donors. While international agricultural researchers once focused on increasing productivity, usually of a particular crop, now they are expected to show how their research is leading to improved natural resource management, poverty alleviation, and enhanced food security across the developing world. Ostensibly, the reasons for doing impact assessment are relatively clear; ex post studies can help to determine the impact of past investment in research on target beneficiaries and the adoption of technology by, or shifts in policy on, farmers. Such studies can generate useful information for organizations and donors to understand the lessons of the past, in terms of successes and (especially) failures, in the hope that more of the failures will be avoided and more of the successes repeated. The point of ex ante studies is to help to identify those researchable issues that will, if resolved, produce the most bang for the buck, in terms of impacts on large numbers of poor people. Given often severe funding constraints, donors cannot fund everything, and research and development organizations cannot work on everything everywhere, so investment decisions have to be made on some basis. Ex ante studies aim to offer one logically coherent way of making difficult choices as to where the money should then be spent.

That is the theory. However, impact assessment remains a difficult and contentious area, both practically and methodologically. Severe methodological issues relate to the ‘‘completeness’’ problem, i.e., how can impact assessments deal adequately with both the direct and the indirect effects of research and development activities? In many (if not most) cases, the indirect impacts on human resource capacity or on people’s approaches to problem solving, for instance, may be more far-reaching and profound than the more easily quantifiable impacts at the farm level of uptake of a technology (Thornton et al., 2001; Randolph et al., 2001). While there is little doubt that research that leads to improved policies at various government levels will often have profound, widespread and sustainable impacts, how to quantitatively measure these appropriately remains a very difficult problem.

There are various practical problems with impact assessment. Two in particular relate to the costs involved in looking at complex systems, and to the problem of attributing credit (or blame, for that matter) to the host of partner institutions that are almost always involved in any research and development activity. The attribution problem is generally so thorny that most practitioners would take the pragmatic approach and avoid direct attribution. Even so, costs of research and development activities have to be taken into account, so whose costs should be included in the analysis?

The complexity problem is daunting. Impact assessment of agricultural interventions are, by definition, systems problems, and we generally have inadequate knowledge of the researchable issues for each system that will ultimately lead to increased food security and household welfare. At the same time, given the time delays both in generating agricultural technology and in its being adopted at the farm level, these things must fit into the agricultural systems that will exist in 15 or 20 years’ time. A major question then is, how will the target systems evolve in the future? This necessitates a need to understand what exists now, what the major drivers of change may be, and how these drivers will play out in terms of future system orientation.

Given such problems, it may reasonably be asked, why bother with impact assessment at all? One pragmatic response is that, while the state of the art is currently far from where it needs to be, it is better to think about the issues of impact, past and future, than to ignore them entirely. Tools and methods are improving, and as various practitioners have pointed out, the fact that some of these difficult questions are being asked at all may have far-reaching implications on all sorts of institutions. At least we are starting to ask some of the right questions, even if our current ability to answer them is somewhat lacking.

3. Approaches to impact assessment

There are four basic questions to ask in any impact assessment. First, where is the impact likely to occur? Second, by whom will the impact be felt? Third, which impacts will have an effect? And fourth, what is the value of these impacts? For each of these questions, Table 1 lists typical data requirements, gives an indication of the analytical methods and tools that may be appropriate to answering them, and highlights some key constraints and assumptions that may need to be addressed.

Given the breadth of the realm of impact assessment (the prediction or evaluation of the effects of change in agricultural systems), it is not surprising that there are many approaches that have been and are being used for various impact assessments relating to crop–livestock interventions. We summarize approaches in Table 2 (adapted from Kristjanson and Thornton,

Table 1
Stages in ex ante impact assessment

Questions to ask	Impact where?	Impact on whom?	Which impacts?	Value of impacts?
Information to generate	Potential area (geographical and agro-ecological) of impact or adoption (demand or recommendation domain/target zone)	Potential number of adopters or adopting households; who benefits	Household impacts on income, labor use, production, soil fertility, nutrition, etc.	Gross economic value of impacts compared with the costs of generating them
Typical data required	Crop areas, livestock numbers, human population density, broad climate and soils information	Community and/or household characteristics	Household characteristics	Research and extension costs
	Market accessibility indicators		Marginal changes in enterprise budgets as a result of adoption	Elasticities of supply and demand for commodities affected
			Changes in yield and production distributions as a result of adoption	Input and output prices
Typical analytical methods and tools to use	Agro-ecological characterization (GIS)	Adoption surveys (econometric models)	Household modeling (simulation or mathematical programming models)	Economic surplus methods
	Market surveys	Informal and formal community and household surveys	Formal and informal household surveys (econometric models)	Scoring methods
				Econometric models
Constraints, assumptions and conditions to think about	Sensitivity to environmental variation	Proportion of households susceptible	Robustness of responses	Reliability of data
	Local pricing structure/tariffs	Equity considerations	Alternative avenues (e.g. impacts of off-farm opportunities)	
	Other initiatives (complementary or compromising)	Poverty focus		

2001), and give an indication of the degree of participation and quantification, and the broad disciplinary expertise required for each method. For example, we judge village workshops and stakeholder consultations (number 1 in Table 2) to be highly participatory, they produce mostly qualitative information, and they require social science and economics expertise. One or more examples of recent studies using each method is also given. The main point is that each method in Table 2 will tend to be useful for obtaining particular information. In most cases, an integration of several methods is needed in order to achieve a comprehensive understanding of impact. In addition, many of the approaches in Table 2 contain some participatory elements.

Thus, for example, in determining the spatial domain for a technology, GIS is likely to be particularly useful in delineating appropriate areas. The potential recommendation or ‘‘demand’’ domain for a particular fodder, for example, is clearly limited to the area where the agro-ecological conditions are appropriate for the species. In terms of determining the impact on whom, again GIS may be useful in determining the livestock-keeping populations in the agro-ecological domain identified above, but more information may be needed to pinpoint the types of

Table 2
Impact assessment approaches, strengths and weaknesses (adapted and extended from Kristjanson and Thornton, 2001)

Method	Type[a]	Approach and examples	Uses and strengths	Weaknesses
1	P3, Q1, S, E	Village workshops/discussions, stakeholder consultations, key informant interviews (Kristjanson et al., 2002b; Franzel et al., 2002)	Good for identifying key impacts and indicators and to identify key factors affecting adoption, diffusion and impact; institutionalizing impact assessment in a village	Community leaders can dominate discussions, women are often left out, participants tell the organizers 'what they want to hear'. Lessons may not be applicable across broader areas due to unique characteristics of villages chosen
2	P2, Q2, S, E	Community-level formal surveys (Pender and Scherr, 1999; Okike et al., 2001)	Useful for gaining an understanding of the characteristics of communities that are benefiting from a new technology and village-level factors affecting adoption and diffusion of new interventions	Quality of information can be dependent on relatively few individuals and may vary considerably across communities
3	P2, Q2, S, E	Household-level formal surveys for looking at adoption and impact (Adesina et al., 2000; Baidu-Forson, 1999; Nicholson et al., 1999)	Possibilities for studying: household-level characteristics influencing adoption and impact; farmer knowledge/understanding of new strategies; asset changes; food/nutrition/health impacts; income/expenditure impacts; social/cultural changes; labor/farming strategy changes	Time consuming and relatively expensive; results often not available for some time (and often not communicated back to the participants). Typically targeted towards household heads, whereas resources may be controlled by different household members. Many sensitive and often difficult questions subject to cross-cultural bias. Tend to treat adoption as an event rather than a process of learning/experimenting; most beneficial with a well-defined technology that has been in use for a long time (ex post studies)
4	P2, Q3, E	Financial and economic analyses of the production effects of new technologies (Place et al., 2002)	Monitoring of labor or other resource requirements for a particular integrated crop–livestock system. Analyses of costs/benefits from researcher- and farmer-designed experiments	There will be benefits and/or costs that are not captured in the marketplace (e.g. bank account or insurance aspect of cattle)
5	P1, Q2, T	Transect walks, aerial photography (Reid et al., 1997; N. de Haan, pers. comm.)	Can help estimate the numbers and locations of users/adopters of crop–livestock interventions	Limited area coverage, getting cheaper but still can be quite costly
6	P1, Q3, T	Spatial analysis; GIS; satellite imagery (Staal et al., 2002)	Allows forward-looking approach to understanding systems and impacts of things like population growth, climate change. Also allows delineation of target zones or recommendation domains for specific technologies	Dependent on good spatial datasets; easier to identify crop-based systems than livestock

Table 2 (*Continued*)

Method	Type[a]	Approach and examples	Uses and strengths	Weaknesses
7	P2, Q2, E, T	Market studies (Scarpa et al., 2003; Turner and Williams, 2002; Fafchamps and Gavian, 1997)	For analysis of differences in market conditions; demand studies, determinants of prices and spatial integration of markets	If one-shot surveys, conditional on weather or other circumstances particular to timing of survey; solid time series analysis requires regular market visits over a long period
8	P1, Q3, E, T	Economic surplus methods (Alston et al., 1995)	For investigating the effects of interventions that have measurable impact on the production and price of commodities; both ex ante and ex post	Requires good information on price responsiveness of producers and consumers that often just is not available; non-marketed benefits and hidden costs (e.g. social) difficult to incorporate
9	P3, Q1, S	In-depth anthropological/sociological and characterization studies; farmer assessments (Ashby, 1990)	Good for characterizing major household types; identification of important livelihood strategies of households and pathways for poverty alleviation; processes of testing and uptake of new technologies; more detailed knowledge on resource allocation and investment	Time consuming, relatively expensive and cover a small number of households/area
10	P3, Q1, S, T	Participatory nutrient flow diagrams (De Haan, 2001)	Good for capturing indigenous knowledge; relatively simple methods that involve learning on both sides	Cover a small number of households/area
11	P3, Q1, S, E, T	Follow the technology; participatory technology development (Douthwaite et al., 2001, 2002a)	Useful for gaining knowledge as to complex experimentation, learning and adoption processes, who is adopting (dis-adopting), and why	Time consuming, relatively expensive and cover a small number of households/area
12	P1, Q3, T	Hard biophysical simulation models of component processes and interactions (MacRobert and Savage, 1998)	To assess productivity impacts at the farm level; relatively objective, and can incorporate production risk	Data intensive, time consuming, difficult to calibrate, sometimes incomplete
13	P2, Q2, T	Softer biophysical models of component processes and interactions (Walsh et al., 1998; Tanner and Thorne, 2001)	To assess productivity impacts at farm level; simple to use, can identify broad changes in level and direction of trends	May not have the sensitivity required to assess particular interventions
14	P1, Q3, E, T	Multiple objective mathematical programming models of the household (Herrero et al., 1999)	To assess changes in resource use and trade-offs in objectives at the household level	Data intensive, time consuming, difficulty of eliciting household objectives and representing them appropriately
15	P2, Q2, S, E, T	Rule-based (softer) models of the household (Thornton et al., 2003)	To assess changes in household well-being, in income and nutrition flows, etc; quick to built and test	May not have the required sensitivity; lack of a formal framework may lead to incompleteness

[a] Participatory nature: P1, little or none. P2, somewhat. P3, very. Quantitative nature: Q1, mostly qualitative. Q2, somewhat. Q3, highly. Expertise required: S, social science. E, economics. T, technical biophysical.

household that are really in a position to adopt the new fodder (examples follow in the case studies below). In terms of identifying what the impacts are likely to be, surveys and models may be useful in determining the productivity impacts and the impacts at the household level in terms of resource use, etc. Valuing the impacts may involve aggregating household response using methods such as the economic surplus model to value the gains to both consumers and producers.

As can be seen from Tables 1 and 2, choice of methods will depend on the questions being asked, the time, resources and skills available, and the baseline data that are available. In the next section, we present outlines of three case studies to do with ex ante impact assessment of different food-feed crops, involving different methods to provide information that can help answer the question, is it worth doing this particular piece of research?

4. Case studies

4.1. The case of sorghum and millet residues in India

Sorghum and millet crop residues play a major role in meeting the feed requirements of cattle and buffalo in the smallholder mixed crop–livestock farming systems that are so important across India's semi-arid tropics. These cattle and buffalo provide meat and milk and act as a bank account for many of India's 630 million rural dwellers, three-quarters of whom are estimated to own livestock. Major constraints to increased livestock production efficiency are insufficient and poor quality livestock feed. Researchers at ILRI and the International Centre for Research in the Semi-Arid Tropics (ICRISAT) joined forces with their local partners to develop a genetic enhancement research project in India aimed at identifying existing and developing new higher-yielding millet and sorghum varieties that not only have higher grain yields, but also produce more, and better quality (more digestible) feed for ruminants. The ruminants will in turn convert the improved diet into more milk, meat, manure and draft power.

An ex ante impact assessment indicated high potential returns (over 30%) to the proposed investment in the genetic enhancement of feed quality of crop residues research (Kristjanson and Zerbini, 1999). While this assessment was limited to India, it was also pointed out that the potential returns to this research area could be significant in West Africa as well. There are several reasons to believe that the adoption potential of the new varieties developed through this area of research is high in West Africa as well as India: farmers are already using dual-purpose cereal and legume varieties; the new varieties involve little or no added inputs or changes in management; the ongoing shift from extensive to intensive crop–livestock systems means increasing demand for stover for feeding animals (as demonstrated in the active crop residues trading seen throughout the region).

Assessing the potential returns to genetic enhancement of feed quality of crop residues research involved various components. Firstly, it was necessary to determine *where* these productivity gains were likely to occur, and *to whom*. This involved identifying the recommendation domain, the likely regions and farming systems where the new varieties were most likely to be adopted. Spatially referenced secondary data allowed us to map out the districts in India where millet and sorghum cover a reasonable proportion of total cropped area, and their residues contribute a significant proportion of the estimated total roughage available to livestock in the district. The primary farm-level data collected in a sample of the districts verified the importance and uses of dual-purpose varieties within these districts. This component thus made use of methods 1, 3 and 6 (Table 2).

Secondly, it was necessary to determine *which impacts* the research was likely to lead to. Since this involves estimating the productivity increase of crop residues fed to livestock, this required the use of a simulation model to translate increased availability of inputs (i.e. feed) to system outputs (milk, meat) that could be valued, as well as likely environmental and/or social impacts. Expected increases in milk, animal growth and draft power of ruminant livestock to be obtained from increased digestibility of sorghum and millet residues were estimated using the JAVA feed-animal performance simulation model developed by Brouwer (1991). This model simulates the production performance of ruminants, given animal live weight, maintenance requirement and diet inputs associated with feeding practices during different seasons of the year. The output is a value of surplus (or deficit) energy available for each animal in the herd at the end of a defined period. Starting herd composition and feed allocation strategies used in the model came from a farm household survey of 160 households. This component made use of method 12 (relatively simple simulation models), with input data derived from primary and secondary household data (Table 2).

Thirdly, we needed to determine *the value* of the potential impacts identified. An economic surplus model (Alston et al., 1995) was used to measure the potential returns to the research on genetic improvement of dual-purpose millet and sorghum. A partial-equilibrium, comparative static model of a closed economy was used in the analysis. Outputs from the feed simulation model—the percentage increase in milk and meat output resulting from improved quality straw—were converted to gross proportional reductions in cost per tonne of output, which were valued in the model and translated into net annual research benefits. The model incorporates estimated research and adoption lags (from survey results), probability of research success (from interviews of a broad panel of scientists, not just those involved in the research), and an estimated ceiling level of adoption (again, as suggested by the farm surveys as well as the literature). This is method 8 in Table 2.

All the steps involved the collection and analysis of a considerable amount of data, from field trial results to price data, as well as carrying out formal and informal surveys by a multi-disciplinary team that included a crop breeder, an animal nutritionist/scientist, an economist, and a GIS specialist.

Farmers are already using dual-purpose varieties of sorghum and millet, and crop residues in general provide around 50% of total cattle and buffalo feed; sorghum residues make up around half of this, millet around 10% (although it varies by region). The analysis assumed scientists could increase the quality/digestibility of sorghum and millet residues by between 1 and 5%, with impacts on milk and meat production dependent on baseline levels and the importance of these residues in the original diet. The feed model assumed that the same feeding patterns as those observed in the farm survey would be followed, but that the digestibility of the residues would be improved. Thus the analysis did not go into possible alternative uses of additional feed. Assuming that only 10% of the farmers in the recommendation domain—that is, in the regions where sorghum and millet crop residues are already important sources of animal feed—adopt the new dual-purpose varieties developed using marker-assisted selection, the returns to the research investment are substantial. Assuming a 10-year research and development period and a 6-year period to reach the ceiling adoption level, the results indicate an NPV of US$ 42 million, an IRR of 28% and a benefit–cost ratio of 15. The analysis only included the direct benefits of more milk and meat, and only for cattle and buffalo in India.

4.2. The case of dual-purpose cowpea in West Africa

The application of genomics has also been applied to cowpea (*Vigna unguiculata*) for improvement of residues as livestock feed. A recent ex ante impact assessment of this research shows that higher yielding (and low purchased input) food-feed cowpea varieties will improve the nutrition and incomes of at least 30 million poor people in the dry savanna areas of West Africa alone by 2020 (Kristjanson et al., 2002c).

A similar approach to the one outlined above for the ex ante impact assessment of genetically improved sorghum/millet residues was taken for the cowpea assessment. Once again, a multidisciplinary team integrated multiple approaches, combining GIS, a crop model, and household, community and participatory research approaches in northern Nigeria, to answer questions as to *where* are the impacts likely to be felt, *by whom*, and *which* impacts are involved. Since the adoption issue is such a critical one in this type of assessment, considerable effort went into both community-level and household-level surveys in order to be able to realistically predict uptake rates of the new varieties which are only just beginning to reach farmers in northern Nigeria (Okike et al., 2001; Kristjanson et al., 2002a). Who is using the new varieties (e.g. men or women, poor or rich households), why, and how they use them (e.g. cutting and feeding the residues to sheep at home, or leaving them on the field to be grazed), are all issues that were explored in these surveys, and will continue to be monitored as uptake of the new varieties spread. This provides important information for researchers who are continuing genetic cowpea enhancement work, and those interested in extension of the new technologies. It also allowed us to explore some of the issues research investors are particularly interested in, such as 'what is the impact of this new technology in terms of poverty and women?' For example, the results of the household-level survey showed the following:

- The intensity of adoption (the proportion of total cowpea area planted to improved varieties) was strongly influenced by the importance and density of livestock, human population density and degree of market access, supporting similar evidence elsewhere that markets and roads are important drivers of change.
- Gross farm income, gross revenue from cowpea grain and fodder, gross revenues from other crops, and number of wives were significantly *larger* for improved dual-purpose cowpea adopters compared to non-adopters.
- The improved varieties enhance food security, as the number of months a house was deficit in grain was significantly *less* for adopting households.
- Improved dual-purpose cowpea adopters had significantly more assets than non-adopters.
- While the richer households had more people, plots, much larger farms, more labor, used more animal traction and credit and had more livestock and wives, there was not a statistically significant difference between the ratio of improved dual-purpose cowpea varieties to local varieties—in other words, this is not a technology being adopted by the wealthiest households alone.

GIS was used to extrapolate the findings to similar socio-economic domains (defined in terms of human population density and degree of market access) and physical environments across West Africa. Thus while the intensive survey work covered a relatively small area, the results could be cautiously extrapolated to much wider areas, because the survey areas were well characterized first. These components of the work thus used methods 1, 2, 3 and 6 (Table 2).

To *value* the impacts, productivity changes were simulated using a computer simulation model that could predict grain and forage yield of cowpea as a function of weather and soil conditions and crop management inputs. The generic crop model CROPGRO (Boote et al., 1998) was adapted for this purpose. To generate the data with which to adapt, calibrate and validate CROPGRO-Cowpea, various pot and field experiments were conducted in the USA and Nigeria. The model is now a component of the DSSAT (Decision Support System for Agrotechnology Transfer) version 3.5 (Hoogenboom et al., 2001; see http://wwwicasanet.org), an integrated software package with many models and databases. The simulated productivity changes were used in the economic surplus model to estimate the total value of adoption of improved dual-purpose cowpeas (methods 8 and 12, Table 2).

In the study, the rate of return to this joint ILRI-IITA (International Institute for Tropical Agriculture)-Nigerian NARS (National Agricultural Research System) research investment was estimated to be 71%, assuming a 20-year adoption lag, with ceiling adoption rates varying by socio-economic domain. The net present value of the research and extension investment in improved dual-purpose cowpea was predicted to be US$ 606 million, with a benefit–cost ratio of 63.

4.3. The case of maize as a food-feed crop in East and Southern Africa

In conjunction with the International Maize and Wheat Improvement Centre (CIMMYT), we recently carried out an ex ante impact assessment to generate information to help guide future research activities concerning the maize crop in the mixed systems of East and Southern Africa. Maize is the staple food for perhaps 25 million households in the region, and is planted annually on more than 15 million hectares of land, and contributes at least 25% of the calories to the diets of more than 80 million people. Much of this maize is grown in the mixed systems of the region, which contain 170 million people in total. This is expected to grow to 266 million people by 2020, so the issues of food security and sustainable livelihoods for this burgeoning population are of great importance and concern (Thorne et al., in press).

The key elements of the approach used in this study were similar to those outlined above in relation to sorghum and millet in India and cowpeas in West Africa. The study started by considering *where* potential impacts of research on maize-based mixed farming systems are likely to be felt, and *by whom*. The process involved a set of country studies conducted in

Kenya, Tanzania, Malawi, Zimbabwe and the Republic of South Africa, to characterize the maize-based mixed systems in the region (these countries were chosen for pragmatic and logistical reasons). From this work, four systems were identified: small-scale intensive, medium-scale intensive, medium-scale semi-intensive, and medium-scale extensive. These were defined in terms of human population density and maize cropping density, and subsequently mapped for the five countries. The case-study countries account for some 32% of the land area in maize-based mixed systems in East and Southern Africa as a whole. They also account for 73% of the maize grown, 40% of the population, and 48% of the cattle. This work used extensive spatial analysis (method 6, Table 2) coupled with rapid country case studies carried out using key informant interviews and secondary data (method 1).

The next question to answer was, *which* impacts? From the many crop and livestock management options that could be explored, information from the country case studies and the literature was used to define baseline conditions and a subset of alternatives that either are in use in some of the systems and countries of the region but not in all, or show particular promise, given smallholders' constraints and attitudes, for increasing incomes and productivity. These were as follows:

- Use of collected weeds of the maize crop for livestock feeding.
- Improved management of green maize stover (thinnings, strippings) for feed use.
- Improved feeding systems, based on more effective integration with complementary feed resources, incorporating dry maize stover.
- Chopping/soaking of dry maize stover to increase acceptability and/or digestibility.
- Use of replacement fodder crops such as Napier grass.
- Intercropping with grain, dual-purpose or even forage legumes.
- Improved manure management strategies for more effective nutrient retention and transfer amongst system components.
- Selection and/or breeding for improved digestibility of maize stover.

The impacts of these options on grain yield, fodder quality and quantity, milk and meat production, and soil fertility trends were assessed by system using crop and livestock simulation models. CERES-Maize and CROPGRO, components of the DSSAT (see above, Tsuji et al., 1994) were used to evaluate grain and forage production from the maize crop and, where appropriate, an associated bean intercrop. Fodder quality was estimated from nitrogen contents predicted by these two models. DRASTIC (Thorne, 1998b) was used to examine the impacts of changes in forage quantity and quality on milk and meat production under smallholder management. ANORAC (Thorne and Cadisch, 1998), incorporating a soil organic matter model based on CENTURY (Parton et al., 1987), was used to indicate likely changes in soil nutrient and organic matter status following adoption of the various interventions. Where input data were judged to be insufficiently reliable for a modeling approach to be applied, values were estimated from extrapolations of information contained within the literature. This part of the work used method 12 (Table 2).

To *value* these impacts, the household-level impacts by system within the various countries were aggregated, using a set of spatial data layers on human population, cattle and maize density derived in the characterization stage. Each intervention-by-system combination was then assessed, using the economic surplus model, in relation to the potential impacts that could arise as a result of resource expenditures on research and extension to develop and disseminate the particular intervention, and in relation to specified ceiling adoption levels for each intervention in each system and country. Details and data sources are given in Thorne et al. (in press). This valuation used methods 6 (spatial analysis, Table 2) and 8, the economic surplus model.

The results of the economic surplus modeling contain some interesting indications as to where potential impacts of research and extension on maize in the mixed systems of the five countries might be appropriately targeted. Improved feeding systems appear to offer substantial potential for smallholders, particularly those in the more intensive systems. We judged that there are significant research and extension costs associated with these, but the potential benefits far outweigh these costs. Promoting the use of intercropping in the more extensive systems where this is not already practised also offers substantial net benefits.

The extension effort involved may be considerable, but again the potential impacts at the household level are such as to outweigh these costs. Improved green stover management has very modest research and extension costs, but could provide some net benefits in the more intensive systems. The case of improved manure management is less clear-cut. In the medium-scale intensive systems, there may be substantial benefits to be reaped, but less so in the small-scale intensive systems, although the results are highly sensitive to the assumptions made. This suggests that research and extension on this intervention would need to be very well targeted for appropriate societal benefits to accrue. Little evidence could be found of net benefits for treating dry maize stover (high research and extension costs coupled with limited benefit at the farm level), or breeding/selection for improved stover digestibility (in contrast to the results of the millet/sorghum residues assessment for India). Current price regimes are not conducive to replacing maize with fodder crops in the small-scale intensive systems, and are not likely to become so in the future.

5. Discussion

The three case studies outlined above followed similar patterns and made use of similar methods. The recommendation domains for the various interventions were generally identified using a mix of spatial analysis and secondary data. Identifying the value of the interventions involved using simulation models to generate plausible productivity change, which were then valued using an economic surplus model together with information on likely adoption rates from primary or secondary information. The cowpea study was different, in that considerable effort was put into household and community survey work. As a result, there is now a considerable bank of information available concerning the adoption of improved dual-purpose cowpeas and what the impacts at the household and community levels really are.

There are some obvious limitations to the studies outlined above. Firstly, as with any impact assessment, there are considerable sources of uncertainty in various parts of the analysis, particularly relating to realistic levels of adoption. This underscores the importance of sensitivity analysis to determine whether results are robust or not. Extensive sensitivity analysis was carried out for all three case studies outlined above, and the results are reported in Kristjanson and Zerbini (1999), Kristjanson et al. (2002c) and Thorne et al. (in press).

Secondly, it is unlikely that all the impacts of the various interventions have been adequately captured in the analyses above. These mixed smallholder farming systems are highly complex, and there are limits to what was included. In the cowpea study, for example, direct impacts of improved cowpeas on sheep and goat production was handled using market prices of sold fodder. In the maize analysis, the long-term impacts of incorporation of maize stover into the soil and subsequent effects on crop yield and soil fertility were not included.

Thirdly, such studies are neither quick nor cheap to carry out. Each study involved at least two scientists working part-time for between 6 months and 1 year. For many impact assessments, there will be neither the time nor the resources for such relatively in-depth analysis. Options do exist for using off-the-shelf software to perform impact assessments (an example is the DREAM package of Wood et al., 2000), but much care has to be exercised in parameterising these programmes if credible results are to be produced.

Despite these and other limitations, the studies outlined above have provided some insights into the nature of the interventions that could assist in improving the livelihoods of smallholders who operate mixed systems and depend on food-feed crops. They have also provided information that can help to prioritize research and extension activities that should be able to contribute to widely held development goals. The India case study has already led to donor-funded research activities to look at genetic enhancement of sorghum and millet residues. The cowpea study is currently helping to orientate activities of national and international research institutes working in West Africa. It is hoped that the maize study will help to define parts of a research agenda for the coming years for national and international partners concerning maize in the mixed systems of East and Southern Africa.

6. Conclusions

Impact assessment of research is carried out for a number of reasons: to determine if the science is on target, to see what results have been achieved, and to provide donors and other interested audiences with information that can be used to help justify their research investment. Impact assessment of mixed crop–livestock systems in the tropics is challenging because of the complexity of the systems themselves. It is evident that there is no one approach that is sufficient for measuring the impacts of interventions in these. It is necessary to take a broad, integrated look at the systems themselves and the processes going on within them. Models will continue to be important and relatively low-cost tools that allow us to do this. Even if the biophysical models are presently lacking or incomplete, it is possible to use a mixture of 'hard' and 'soft' models to deal with the lack of a generic crop–livestock model (Thornton and Herrero, 2001). Participatory approaches are likely to become even more important in impact assessment in the future. These can provide a great deal of information relatively inexpensively, concerning household- and community-level impacts that are vital for credible results.

With any impact assessment challenge, having the foresight to collect baseline data from which to gauge relative change is critical. Furthermore, if we want to maximize the value of impact assessment, asking the question 'Who is this information for, and what are their needs?' should always be a key step. There are indications that donors and institutions may not always want complex impact assessments, but that rapid, qualitative approaches may be more appropriate in certain situations.

We also need to continue to try new approaches and develop new tools that increase the efficiency and lower the costs of undertaking such assessments. We still have not done a good enough job, for example, at including measurements and valuations of environmental impacts associated with new interventions (on the crop side, approaches are summarized in Maredia et al., 2002). The need for assessments such as those reported above is minimized (or greatly assisted) if projects and programmes build in, right from the outset, rigorous monitoring and evaluation plans. Since adoption of a new technique, technology, strategy or policy is typically a process, not an event, this should include monitoring how different people and communities react to, and use, new technologies. Recently, Douthwaite et al. (2002b) have noted that:

> "once one accepts that users are modifying technologies, and their own systems to accommodate new technologies, and these adaptations affect adoption rates and who benefits and loses, then one must also accept that technological change is an immensely complex process, with a high degree of non-linearity. Current 'best practice' economic evaluation methods commonly used ..., which attempt to establish a linear link between a project's outputs and wider level impacts, struggle in this complexity."

A key strength of the approaches to impact assessment that have evolved over the last few years is the integration of multiple methods. This has led to a more comprehensive understanding of the links (and gaps) between researchers and beneficiaries. Credibility is increased greatly as the recommendation domains for the interventions being assessed become more tightly defined. At the same time, this places a burden on the provision of the higher-resolution databases that are then necessary. There is clearly a need for more investment in, and coordination of, the development of improved spatial and other databases. This is a case where collaboration between national and international institutes has large payoffs, as there are common data needs between a wide variety of institutions.

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