MAKING SOIL RESEARCH AND DEVELOPMENT RELEVANT AND SENSITIVE TO SOCIO-ECONOMICS IN LATIN AMERICA

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INTRODUCTION

Latin America is a developing area where the prime aim of agricultural research is the alleviation of both rural and urban poverty. This means increasing the productivity of agriculture and particularly of resource poor farmers. Contrary to the situation in the developed countries, where surpluses of agricultural products are so great that land can be put aside for conservation and yields may be curtailed to safeguard the environment, development in Latin America is not a zero sum game trading off productivity for conservation. Agricultural development is, rather, an economic and moral imperative. The challenge is to bring about development without negative or even disastrous consequences for the environment.

We believe this to be possible. A number of CGIAR initiatives show that enhanced sustainability can go hand in hand with increased production and reduced costs. Examples are the application of integrated pest management in rice (CIAT 1991) where marked reductions in the use of pesticides were achieved, the control of the cassava hornworm by a naturally occurring virus (Bellotti et al 1992), and the development of rice/pasture rotation systems (Sanz et al 1993). Each of these innovations decreased cost of the product while protecting the environment. These are early days to say that the systems are holistically benign. Rigorous studies of the implications are planned, for example to monitor the effects of infrastructure development in the Colombian Llanos as the rice/pasture systems are adopted.

Soil science can assist directly at the field level by enabling the farmer to better understand the particular constraints presented by his/her soils (this is purposely in the plural because most farmers have a diversity of resources to contend with). The critical point of all three examples quoted above is that they use knowledge as the main input. They do not involve extra input costs at the farm level. The reduction in cost to the farmer to achieve a more sustainable state is paid for by the research and extension involved. In many cases the benefits to producers and consumers greatly exceeds the research costs.

The development process is far wider than this, however, and soils information is needed for prioritization of research, allocation of resources, and setting the policy framework. Choices have to be made, for example, between recovery of badly degraded lands, increasing productivity to meet the growing requirements of food in the continent, and the protection of environmentally sensitive areas.

In this paper we discuss the relationship of basic soil science research to the farmer in Latin America, to the agricultural researcher, to those who guide the research, and to those who make the policies that guide or distort the use of the land for agricultural production. There appear to be three basic elements to this discussion. Is the relevant soils research being done? If so, does the information get to where it is needed? When it gets there is it in a form that is useful?

Villachia et al (1990) suggest that socio-economic constraints are the main factor preventing full use of technology for sustained systems in the humid tropics of South America. The same could be said of Mexico and Central America (indeed could be said of probably 90% of the developing world). Examples from Tlaxcala, Mexico, illustrate how development of sustainable agroecosystems requires an agroecological approach sensitive to both the agronomic and socio-economic processes governing agricultural production (Altieri et al 1987).

Basoc Soils Reserach

What is the need for Latin America

There will be, for at least the near future, a need to increase agricultural food and fibre production in Latin America. If the development process were to follow that of Europe, Japan or the USA, then we could foresee a diminished role of agriculture in the economies of the region. This is not the reality at present nor, as far as we can foretell, in the next few decades.

42%

Latin America, from the Rio Grande to Tierra del Fuego, covers approximately 2000 million hectares, of which 845 million hectares are truly acid soils. A further 336 million (17%) hectares are soils that can potentially be acid and are so in many cases in Latin America

60% of total
70% of suitable for crops } acid

due to the high rainfalls prevalent throughout the tropical regions (see Table 1). A further 324 million hectares are lands unsuitable for agriculture (although in some cases presently used for grazing or even cropping). This leaves a relatively small percentage (23%) of soils which may be described as potentially useful for high productivity agricultural output. Climatic constraints on many of these soils limit productive potential. (27% of suitable)

Much of the potentially productive land is already in production. On a world scale Brown et al (1992) show that grain harvest area is levelling out and irrigation areas are increasingly difficult to find. The case may not be as dire for Latin America but the end of major production increases on the better lands is surely in sight.

As can be seen from Map 1, most of the acid soils are concentrated in the frontier regions. Ancient civilizations in Mexico and Peru had little use for the acid soils. The present remnants of the preconquest populations make little use of them in the Andes. Small populations of Indigenes in the Orinoco and Amazon owe little to the fertility of the acid part of the terrain but more to their ingenuity in exploiting the varied biosphere.

The acid soils areas will be the obvious targets of agricultural development whether the international agricultural agencies like it or not. They are where the food and fibre will come from to fuel the urbanization and development of the region. Many of these areas are prime candidates for conservation. The tropical forests will undoubtedly spring to mind. Many other acid soil areas, although smaller in extent, may be in even greater need of protection (Robison et al 1993). However, even discounting these fragile and valuable areas, there are many more that can be fruitfully brought into production. Note (Map 1) that the vast majority of the lands with high proportions of acid soils are not the deep Amazon forests but the flanking savanna lands of Brasil, Colombia, Venezuela, Bolivia and Guyana.

A search of the soils literature held at CAB International was conducted and used to construct table 1. The areal extensions of each FAO soil mapping units were taken from the digital version of the FAO soils map of the world at 1:5,000,000. Note that this includes all soils related research throughout the world that made reference to the FAO map legend. Much of the USA soils research will have been missed because of this. The FAO map legend is, however, the only global* reference system that we have at present. As much as it might be wished, there is no comparable US taxonomy mapping.

THE SOILS OF SOUTH AMERICA

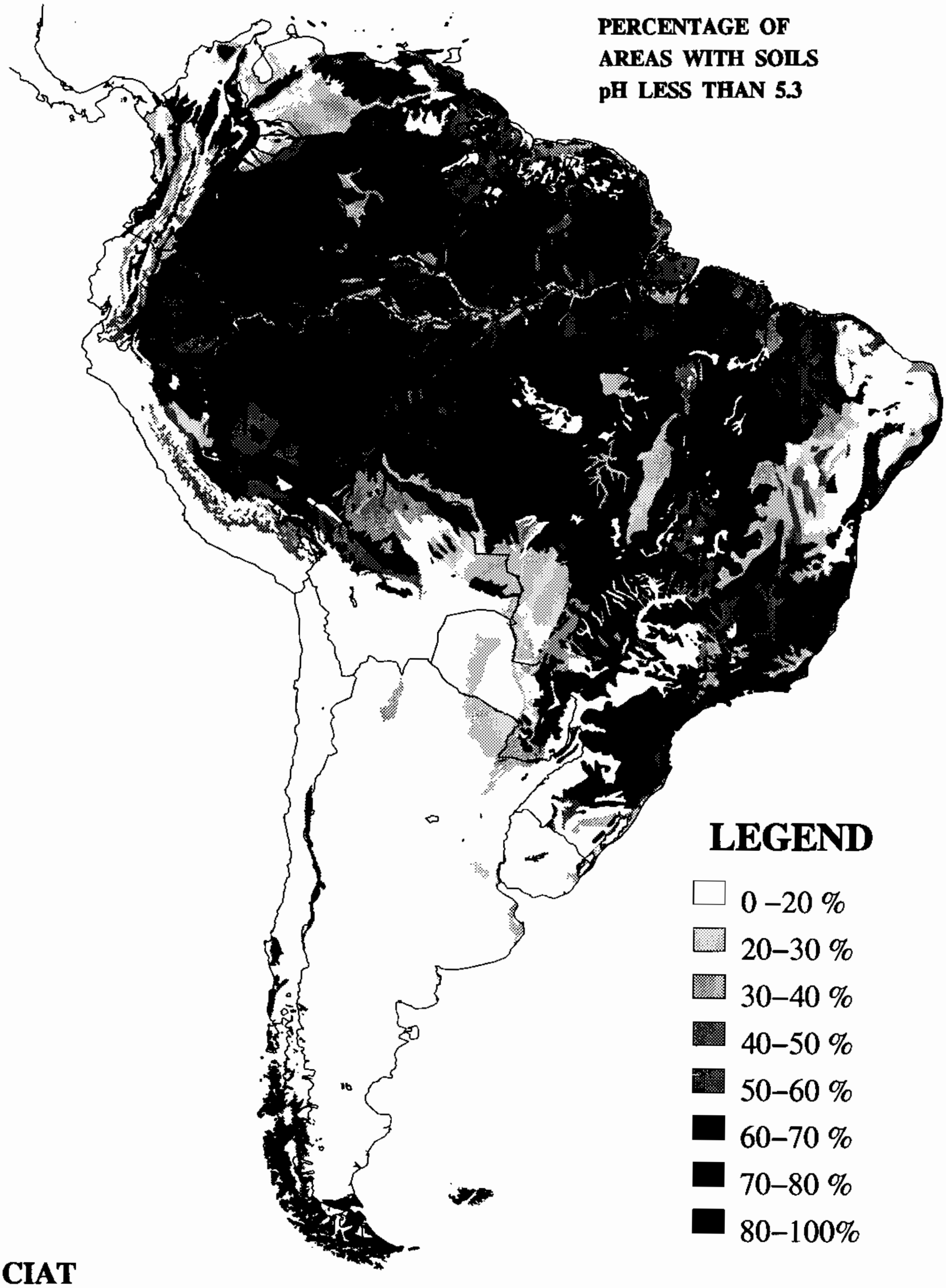

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TABLE 1. The soils of Latin America grouped roughly as to use and major characteristics. With the number of papers published from 1973 to 1991.

Acid agricultural	**Area M ha**	**Papers**	**Papers on Latin America**
Ferralsols	431.1	1010	504
Acrisols	303.6	271	71
Luvisols	110.9	878	39
	845.6 43.2%	2159 11.1%	614 41.3%
Ambiguous agricultural (may be acid)			
Gleysols	122.9	444	29
Arenosols	83.7	48	2
Cambisols	81.9	666	54
Nitosols	47.6	168	13
	336.1 17.2%	1326 6.8%	98 6.6%
Non acid agricultural			
Kastanozems	81.4	149	4
Regosols	56.3	213	29
Planosols	55.9	297	59
Fluvisols	51.3	474	15
Xerosols	50.0	103	4
Andosols	48.7	639	120
Phaeozems	48.2	127	28
Vertisols	37.7	1422	123
Rendzinas	19.4	499	15
	448.9 22.9%	3923 20.2%	397 26.8%
Non agricultural			
Lithosols	169.3	128	31
Yermosols *	78.5	49	0
Solonetz	33.9	748	20
Solonchacks	22.9	297	6
Histosols	7.6	322	16
Rankers	6.4	105	1
Podsols	6.1	5234	295
	324.7 16.7%	6883 35.5%	369 24.8%
Non existent in Latin America			
Chernozems	0	4569	7
Podsoluvisols	0	410	1
Greyzems	0	138	0
	0	5117 26.4%	8 0.5
Grand Total	1955.3	19408	1486

* This includes some irrigation areas

There appears to be a tendency to concentrate basic research on the "interesting soils" at the expense of those of agricultural importance. It is evidently unfair to complain that the research on Chernozems is irrelevant to Latin America as it is obviously of wide interest in Russia, USA and Canada. Nevertheless we can see that as much as 62% of world soil research has no relevance to the agriculture of Latin America. Although a reasonable body of work (over 1000 papers) exists for the Ferralsols, there is a marked discrepancy in the balance between the area under acid or poor soil (60.4%) and the number of papers published (17.9%). When the much smaller subset of papers actually referring to Latin America are considered the proportions are more in line with reality. The fact that eight intrepid researchers could publish on soils not present in Latin America is presumably a reflection on the FAO map and not on their research.

In the past the good agricultural soils have accounted for much of the food and fibre production of the region. As noted above this is changing and the challenge of acid, poor soils is real. It would appear reasonable to trim soils research efforts to reflect the changing emphasis as agriculture expands into the acid soil marginal lands.

Although rarely done, a simple ex-ante evaluation of the benefits flowing to Latin American development from basic soils research could serve to focus efforts on relevant problems. This begs the question, how should basic soils (or any) research activity be evaluated, both before it is carried out and after it has been done? Basic research differs from some other resource allocation issues by virtue of its characteristics. By definition of some (Greig 1981, for example), basic research is that which has no immediate application; it contributes to the store of human knowledge, and after what may be many years, it may (or may not) turn out to be useful. However, most "basic" soil science is not really of this nature, being more applied than this.

The question of what constitutes appropriate R & D will depend to an extent on the policy framework, although this is very much a circular process (i.e. the policy framework should and could be defined on the basis of R & D findings, in part). It is important that some effort should be made to evaluate the likely impacts of a portfolio of competing research activities, not all of which can be funded due to resource constraints. While this might seem obvious, it is not commonly done (or, more to the point, not commonly seen to be done).

There is a growing literature on the evaluation of benefits and impacts of agricultural research, both ex-ante and ex-post. It is not easy; in fact, identifying (let alone quantifying) the social dimensions of R & D is extremely hard. Frameworks have been proposed (Lindner, 1987; Edwards and Freebairn, 1985). While rigorous ex-ante analyses may not often be feasible, there is much value in even simple ex-ante evaluations of proposed R & D activity (Pachico et al., 1987). This forces the evaluator to think about the implications of a particular activity, and it can help in the formulation of an open and transparent evaluation process. Even where data are almost wholly subjective, at least the thinking behind the evaluation is made clear and transparent (Harrison et al., 1991). Anderson (1992) makes a special plea for such activity with regard to uncertainty and risk. Attaching even wholly subjective coefficients of variation to estimated probabilities of research success or wide-spread impact can at least alert decision makers to the fact that some research activities are inherently more risky than others, for example, or that some activities are more likely to have widespread impact than others. There is little doubt that even simple ex-ante evaluations of the benefits flowing to Latin American development from basic soils research could serve to focus efforts on relevant problems.

INFORMATION FLOW

Notwithstanding the apparent imbalance of basic research effort, we argue that the main impact of soil science on the socioeconomics of sustainable development is on the availability and flows of information. No matter how good a soil map or soil profile information may be, it is no good at all if it is not used. Soil managenemt and cropping systems techniques and packages cannot be effectively employed if the basic information on soils is not available. We now look at information uses and flows at various scales. The information flows in various directions within and between scales. We suggest that bottlenecks in these flows are holding up rational use of data that are already available.

Blockage of information flow exists at all scales. The progression 'theory - data - information - knowledge', with a feedback to the theory, is often seen as a paradigm of the scientific method (see Eisgruber, 1973 or Barnard, 1979). This however assumes a uniform population of 'scientists' within which information flows with the *AIM OF PERFECTING A THEORY*. We may view ourselves as this population and in that context might build efficient channels for the information flows. The extension of the concept to 'theory - data - information - knowledge - *ACTION*' involves many actors outside the neat scientific loop of theory proving. This highlights the complexity of the situation. The *ACTORS* include policy makers and farmers who are not interested in proving our theories but have wholly different goals.

Interruptions to the process may be as follows:

1. We do not collect the right data. This is basically the scientist's problem. We should all be trained not to do this.

2. We may not be providing the right tools to turn the data into information. Here we believe we are at fault but are making progress.

3. We may not be getting the information transformed into knowledge for relevant actors. This is due partly to lack of physical dissemination of information but also to lack of tools for turning the information into knowledge, *ESPECIALLY AT THE LEVEL OF ACTORS.*

4. The feedback loop is not now within the community of 'scientists' but must come also from the level of *ACTORS.*

There is nothing revolutionary in this. In fact it is the basis of the drive towards farmer participatory research and community participation. The challenge is to incorporate these things into the standard R&D processes so that we, as the scientific community, can provide and assist these linkages.

A further important point is that information does not necessarily have to spring from completely documented scientific data. There is a large place for softer or 'fuzzy' information based on informed opinion, see Dregne (1989). This type of soft information takes on more and more importance as we consider the data flow between different scales.

Continental and Global scales

At a continental scale, information is needed for research and development planning and prioritization. Small-scale soil maps have been in use for some years as a means of judging research priorities. Only recently have serious efforts been made to put numerical data behind the judgements.

The FAO soils map, with all its faults, has been invaluable in global and regional planning and research priority setting. An early use of it
was in the FAO Agroecozone projects. Subjective judgements based on expert opinion had to be used in fitting the models and constraints to the soils (FAO 1978-81). This

was still hand compiled mapping; at the time GIS techniques were rudimentary and very expensive. These were ground breaking studies, although some discrepancies can be found due to inappropriate models for the lesser known crops, an incomplete climate database, and the misguided assumption that a crop is grown where it is best adapted. The techniques of analysis have advanced considerably since then. Kassam et al (1990) report the case study of Kenya which was the logical successor to the initial studies. The discussion of the paper highlighted the problem of linking the study results to action. It was admitted that there were indeed difficulties linking the smallholder farming population needs with Government policy.

The Land System study of the tropical lowlands of South America (Cochrane et al 1985) was one of the first to put data into the map database. Its main shortcoming was the coding system. Almost all data were interpreted to simple class limits. This overcame the problems of the user having to interpret laboratory test data from many different laboratories using diverse methods. This was done by throwing the task of interpretation on the database compiler and not allowing the user the option of opinion. Classes are almost always high, medium, or low.

In the mid 80s the Agroecological Studies Unit at CIAT pioneered a table of soil characteristics based on the published tables in the FAO soil map documents (Fairbairn 1993). These were the best available to use the map in mechanized form for some time. The scarcity of data made the use of the table somewhat conjectural. There were insufficient data to include information on the range of values. Thus the pH of, for example, a Dystric Fluvisol was registered as a single value, whereas only a little reflection would show that since this characteristic is not used in the classification of this mapping unit, it could take a broad range of values. The same could not be said of a Ferric Acrisol.

The tagging of actual values from profile information to a soils map in machine readable form is only just starting. The SOTER initiative of ISRIC to form a soils and terrain database of the world at a scale of 1:1,000,000 has been underway for some years and has constructed some pilot sheets. An excellent procedures manual is now available (Van Engelen et al 1993). However, as good as this project is, the final world coverage is not envisaged for many years as the project will proceed piecemeal as the funds become available.

What is evidently needed for many applications is a stopgap until a full world coverage of the SOTER class becomes available. At a meeting of the International Geosphere

Biosphere Program last year (IGBP-DIS 1992), global modelers originally thought that a database of soil profile data could be simply interpolated. Disabused of this idea as inappropriate for the rapidly changing qualities of soil in the spatial dimension, the only alternative was to tie the soil characteristic values to a map. The only available world wide map at a reasonable scale is the FAO 1:5,000,000 map. FAO assures us it will be updated as it moves into readily available digital form (Brinkman,R., pers. comm. 1992). The meeting recommended that a start be made to produce a standardized soil profile database that could be linked to the map.

A number of other initiatives are presently underway. ISRIC is producing a standardized database of soil profile information for the study of soil emissions, WISE (Batches 1993). A compilation of histograms of phosphorus data by FAO soil legend is underway at Penn State University (Lynch, J. pers. comm. 1992). Webb et al (1993) have produced a global study of soil water holding capacities derived from soil profile data linked to the FAO map. It is evident from this short list that there is duplication of effort in this vital task. The problem is that everyone needs the data *NOW* and cannot wait for a major international program to provide everything for everyone. The least that we can hope for is that duplication is minimized by clear communications between groups. The INTERNET electronic mail system could provide such a channel. Unfortunately INTERNET communication in many of the developing countries is rudimentary, if it exists at all.

There is no lack of soil profile data but many are simply not in a useful form. The difficulties of making it available to the user of a GIS based soil map cannot be overemphasized. Cochrane et al (1985) ducked the issue by entering simple codes, but even this simple system is difficult to implement in a database tied to a GIS coverage. We have been attempting this recently at CIAT. The main problem is that all mapped polygons in a land system coverage, or any soils map, are complex entities. They are made up of a range of landscape facets or soil associations. When developing user interfaces to the tables it is therefore meaningless to allow simple boolean operators without taking account of the proportion of the polygon area covered by soils with the particular characteristic. As such it is not possible to ask for a map of, for example, the acid soils of Latin America. It has to be a probabilistic map of the proportion of the area covered by such soils (this is a key point). Thus the graded areal percentage shown in Figure 1 is the best representation that can be made. This is based on the table of assumed proportion originally used for the AEZ studies (FAO 1978-81).

As the soil profile databases are developed the specifications of soil characteristics will improve. Individual profiles can be referenced to specific mapping units and not to the generic classification unit. There will undoubtedly be holes left which must be filled with generic data.

The multiple links to all soils in the association with their areal coverage will be more complicated by the inclusion of these surrogate data. We will soon have a system that is user friendly and does not tell lies, but it needs a lot of dedicated work to bring it about.

International information services play a large role in this support capacity (Nowland et al in press), providing information in the form of printed and electronic journal, on-line hosts, magnetic tape, CD-ROM, books, newsletters, conferences and training workshops. To improve dissemination of information, international information organizations should re-examine and re-evaluate the content and quality of the information they provide, the needs of users, and technology and formats improving accessibility of the information (Nowland et al in press).

A CD-ROM of the FAO soils map, for example, can be distributed to any number of decision makers but in many ways it is not useful information. It is still 'raw'. Unless the data, the tools and the expertise to make sense of it are available then it is largely no more use than the paper maps that preceded it. The information bottleneck relates not only to the physical dissemination of information but also to our seeming inability to provide the right people with the right tools to interpret it. This is obviously a case where we need to turn information into knowledge.

At the other end of the scale the farmer must use soils information to make the best use of available resources in a rational production system. Local knowledge of both soils and production systems are an overriding influence in farmers' actions and are extremely important in 'bottom up' development planning.

In between these two extremes lie the national research agencies and the regional and local NGOs. All use soil data in rather different ways. We indicate some of these data usages and identify constraints to information flow and effective data use at the various levels. Some of the tools necessary to overcome these constraints already exist, some are in development, but some are still lacking. In the next section we illustrate some of the problems at this scale with examples and try to elucidate just where the problems lie.

Intermediate scale information

In Guatemala, soils are mapped at a scale of 1:250,000, in a study carried out by Simmonds et al (1959), since which there has been little further advancement (Rosa Maria de Barrio. Pers comm 1990, ICTA). While the individual series were described in detail and based on extensive fieldwork, the map is, in comparison, very generalized and does not effectively communicate the data collected. This is one block in information flow. The Guatemalan NARS, ICTA also has a great deal of information on soil fertility status, the result of hundreds of analyses carried out on request of individual farmers throughout the country. At present the results of each analysis are sent back to the client and filed on hard copy. This information is dormant. However, collectively, the information could be used much more effectively, particularly if incorporated into a spatial database. Whilst resources are not available in ICTA, it should be the responsibility of international organizations to identify such blockages of existing information across the Latin American continent, and to target them for external funding.

In Mexico, use of the modified FAO legend enhances the use and flow of the information. The availability of soils information is relatively good, with many regional information centres of INEGI (Instituto Nacional de Estadistica, Geografía e Informática) across the country. The central office in Aguascalientes is now equipped with the Laser-Scan Automated Map Production System (LAMPS) - a suite of software for production of digital and paper maps using digital mapping technology with the accompanying hardware.

Soil maps and soil use maps are available from INEGI at 1:50,000, 1:250,000 and 1:1M. The evolution of the mapping has resulted in gaps. The first maps to be produced were at 1:50,000. Before complete coverage, the soils office was asked to produce a more general map of the whole country - the 1:1M map, based on the completed 1:50,000 maps and remotely sensed images and aerial photography. To fill the gaps missing at the detailed level, production of a middle scale coverage of 1:250,000 was proposed and commenced. The need to react to immediate requirements has inevitably resulted in inconsistencies in the information. In the case of Mexico, therefore, whilst the flow and availability of the information is very good, and the mapping in many areas accurate, the actual quality is variable.

Because of the varied quality of the information, Mexican planners are at a disadvantage. This is a fault of information flow upwards, which unfortunately reverts to the strategic planning institutions and to their short term budgets.

Information flow at the farmer level

The success or failure of projects almost always depends on communications. Cases from farm irrigation projects in Peru and Mexico (Lees 1987) show how problems in information flow caused waste and damage due to the lack of an effective repair mechanism, experts ignoring local knowledge (see also Hogg 1990, Warren 1991), and excessive paperwork. Pitfalls abound. Technical solutions to problems unperceived by the farmers are not readily adopted (a clear failure of transforming information into knowledge). New technologies duplicating indigenous ones are superfluous , a failure of feedback (Warren 1991). Ease of flow of information at the farmer level may also help prevent ecological disasters. In Costa Rica, lack of information from chemical suppliers caused toxicity and abandonment of banana soils (Thrupp 1991).

Soils research and soil projects should therefore consider socio- economic factors and information flow at all scales, but particularly at the farmer level, since these factors are the most difficult to predict from more general scales (Fairbairn 1993). This general need in tropical soils research has been recognized for some years (Moran 1987, Latham 1987), and it is encouraging that a standard handbook of tropical soil methods (Anderson et al 1993) has a section on rural farmer survey techniques. However, recognizing the need is only the start and opens up a whole new spectrum of problems for soil scientists.

Farmer Knowledge

The literature shows that farmers have a great deal of knowledge about the soils they manage. This could be inferred from first principles without difficulty, except where immigration from a different agroecosystem renders farmers' knowledge inappropriate. Dent and Young (1981) state that many farmers have a far better knowledge of their own soils than a soil surveyor is likely to acquire during a soil survey, particularly regarding management characteristics, whose variation may be known between and within fields. Many authors give examples of soil types identified by farmers, based on such criteria as fertility by colour, mineralogy, slope categories, texture, soil-vegetation associations, susceptibility to wind erosion, colour of drainage waters, etc. (Conklin 1957; Netting 1968; Chambers 1969; Chambers et al 1991; Weinstock 1977; Nations and Nigh 1980; Acres 1984; Tabor 1992; Fairbairn 1993). There is also evidence to suggest that farmers can adopt their soil knowledge quickly, when innovation or utilization of new crops is required (i.e. when the economic incentive exists for them to do so). The Shipibo of Peru, for example, changed land use patterns after pressure to change from staple banana and plantain cropping for subsistence to rice for cash cropping (Behrens 1989).

Proportionally less use was made of soft sandy soils suitable for bananas and more use made of harder clayey soils for rice.

Farmers know how soils change on their land and we have been slow to realize the potential of these mental maps. Information concerns soil distribution and, in addition, empirical observations of the responses of crops to different soils and conditions. The interest in indigenous soil knowledge is clear, but there continues a reluctance to incorporate this knowledge in current research initiatives (Reij 1991). This is in part due to the lack of communication between soil scientists and farmers, who do not understand each other's jargon. Talking to farmers to establish their terminology allows farmer soil descriptors to be related to those of pedologists, and local nomenclature can be compatible with national or even international soil classification systems (Acres 1984). An example of a farmer conceived soil classification from Durango, Mexico, is shown in Table 2.

While scientists have the advantage of understanding in detail the direct effects of soil properties on crops, farmers have the advantage of being able to see the effects of soil conditions on the efficiency of the system as a whole, since it is their livelihood. They have strong opinions on the relative advantages and disadvantages of different soil types for their crops for each range of conditions. Measurements may be quite indirect, but relevant to farm management, e.g. time taken to plough a field; time for soil to become trafficable after rain; risk of frost in different topographic positions. The challenge is to design methods to incorporate this information. Local knowledge should be legitimized without romanticizing its potential (Thrupp 1989). The strengths and weaknesses of indigenous knowledge should be understood. Work in Honduras (Bentley 1989) and Mexico (Fairbairn 1993) illustrates that farmers are good at some things and poor at others. In the Mexican example, while farmers were good at relating soil factors to crop management, terms for texture were confused. Is this a failure of the farmers to understand the concepts of texture in terms of particle size, or is it a failure of a soil scientist to recognize a useful observation of another aspect of soil at the field level?

TABLE 5.6: FARMER CONCEIVED SOIL CLASSIFICATION SYSTEM IN DURANGO, MEXICO			**EQUIVALENT FAO SOIL UNITS**	**FAO-AEZ SUITABILITY FOR BEANS (LOW INPUT)**	**OBSERVATIONS**	
					PERCEIVED BY FARMERS	**FAO VOLUMES, USE/SUITABILITY**
TIERRA NEGRA (BLACK EARTHS)	**Plana Baja** (Bottomland)	**Profunda Migajon** (DEEP LOAM)	Pelic Vertisol (Vp) Mollic Planosol (Wm)	Marg/Not Marg	High Fertility. High Risk (Frost, poor post- storm trafficability, weeds, too much vegetative growth).	High Fertility (Vp), little response to fertilisers, low porosity during rains, v.erodable, management only difficult with extensive mechanisation. (Wm) flood risk, lower soil fertility, little success with crops..
		De Grano (Granular)	Pollic Vertisol (vp) -Gravelly Phase	Marg/Not	As above but lower risk due to limestone grave)	
		Sarteneje (Sticky Clay)	Pellic Vertisol (Vp) (Extremely Clayey)	Marg/Not	High Fertility, Weeds Difficult Management	
	Ladera (Slopes)	**Caliche**	Rendzina (E) Lithosol (I)	Marg/Not Not	High Fertility & Warm Quickly, Depth Restriction	High chemical fertility (E) on slopes, risk of soil erosion, often excessive internal drainage. Drought Risk.
		Suave Prieta (Soft Dark Earth)	Rendzina (E)	Marg/Not	High Fertility, weeds Good Workability Occasional Depth Prob.	
TIERRA COLORADA (RED EARTH)	**Plana Baja** (Bottomland)	**Migajon** (Stoneless Loams	Phaeozems (Hh.H1) Xerosols (Hh.X1)	V.Suit/Suit V.Suit/Suit	Lower Fertility Lower Risk Dependability	(Hh) and (Hl) high fertility. (Hl) better due to higher water holding capacity than (Hh). Wind & water erosion hazard. (XL) & (Xh) not used for crop agriculture, great drought risk.
		De Grano (Granular Loam)	Phaeozems (Hh.H1) Xerosols (Xh.X1) -Gravelly Phase	V.Suit/Suit V.Suit/Suit	Lower Fertility Lower Risk Gravel Extra Advantage	
		Pegregosa (Stony Loam)	Phaeozems (Hh.H1) Xeroxols (Xh.X1) -Stony Phase	V.Suit/Suit V.Suit/Suit	Lower Fertility Depth Restriction Still low risk	
	Plana o Ladera (Flat or Sloping)	**Migajon** (Loam)	Phaeozems (Hh.H1) Xerosols (Xh.X1)	V.Suit/Suit V.Suit/Suit	Low Fertility Low Risk, Reliable. Quick post-storm trafficability	
		De Grano (Granular)	Phaeozems (Hh.H1) Xerosols (Xh.X1) -Gravelly Phase	V.Suit/Suit V.Suit/Suit	As above, but preferred due to limestone fragments	
		Pedregosa (Stony)	Phaeozems (Hh.H1) Xerosols (Xh,X1,Xk) -Stony Phase	V.Suit/Suit Xk - Marg	Lower Fertility Depth Restriction Still low risk	
TIERRA JOSCONA (BROWN/DUSKY EARTH)	Undifferentiated		Calcic Kastanozem (Kk)	V.Suit/Suit or Marg	Intergrade between red & black soils. Combine quick wetting of red soils with higher fertility of blak soils.	Potentialy Fertile, little fertiliser required, yields depend on rainfall.
TIERRA BLANCA (WHITE EARTH)	Undifferentiated		Pellic Vertisol (Vp) Mollic Planosol (Wm) -Sodic Phase	Not Not	Almost unworkable, beans die, maize possible but low yields. Hard when dry, sticky when wet.	—

Adapting soils work to include local knowledge

Farmers' preferences and decision making processes are the key to the problem and must be understood. Many factors enter into farmers' decision making processes, and farmers' attitudes and objectives vary widely; in fact, our understanding of these factors is at best rudimentary. However, risk management plays a critical role in determining farming practices, as the farmer attempts to dampen down fluctuations in production levels and household income from one season to the next (which, after all, is really the final arbiter of "sustainability" in the long run). Conclusions from work in semiarid Durango in Mexico showed that the assessment of soil types by dryland bean farmers was not in terms of fertility alone, but of risk reduction factors (Fairbairn 1993). The less fertile red soils (Phaeozems and Xerosols) were preferred overall, being less risky, since they are quick to wet (allowing prompt sowing and reducing frost risk towards the end of the season) and become trafficable quickly after heavy rain (allowing quick removal of weeds, which can destroy the entire crop). The more fertile black soils (Vertisols) are slower to wet, delaying sowing and increasing frost risk before harvest. The preferences also change from year to year depending on rainfall. In considering farmer decisions, therefore, temporal variability must be considered.

Another example from Mexico highlights how farmers did not adopt recommendations to increase the number and change the timing of fertilizer applications, since it was more profitable on one type of soil 'the traditional way', but more risky on another type of soil (Gladwin 1980).

Such examples can give insights into the critical soil factors in the particular farming system. Much time and effort may be saved by recognizing which factors are relevant. Much is known about the behaviour of soil taxonomic units, but the suitability of soils for the crops in the farming system can only be accurately assessed by asking farmers about the relevance of differences in their soils on their crops. Assessment of the ability of the soil to produce high yields should therefore not be the only, or even the primary, concern.

Considerable effort continues to be made to model the way in which farmers make decisions and to isolate the important factors that determine such decisions. Perhaps the most basic model is the one that assumes the actors are maximisers who attempt to obtain the greatest return on an investment. Modifications of this basic model to account for risk have resulted in a voluminous literature (see Binswanger (1980) for work on risk attitudes; Davenport (1960) and the critique by Read and Read (1970) for the use of game theory in analysing decisions). Alternative models include the mini-max optimising farmer, who minimises the risks of disaster and tries to ensure the survival of his family. Once done, the mini-max optimiser will attempt to maximise his return on what is left (if anything) of his available resource investment.

Work still continues on profit or expected utility (or its variants) maximisation models, but whether such models are really able to account for human behaviour is in some doubt; their predictive ability is not particularly good. Other types of decision modelling have emerged in recent years. For example, one possible solution to modelling farmers' decisions in response to change in Latin America is spelled out by Gladwin (1980, 1989a, 1989b). Cognitive science is drawn largely from anthropology and agricultural economics, and involves a 2 stage process: understanding the rational reason why farmers farm the way they do, and describing the knowledge systems and logic to scientists. Survival strategies should also be understood (Jodha 1991).

One other type of decision modelling is being explored, largely in response to the emergence of artificial intelligence and expert systems. Preliminary work towards the modelling of socio-economic as well as biophysical data using crop simulation models and rule-based systems has been undertaken, in which farm household decision models specify the details of cropping system, sowing, crop husbandry, harvesting and post-harvesting processing in response to a changing environment (Dent, 1993). Although such work is in its infancy, there would appear to be much potential for modelling soft data in this way. As in all modelling efforts, the critical test is the predictive ability of such models, and the specification and testing of these types of models will be key activities over the next few years.

Increasing scientists' understanding of the processes whereby farmers make decisions is important, but equally the infrastructure has to exist to allow information to be exchanged at the farm level between the various actors. Traditionally, the provision of information to farmers is the preserve of extension services, whereas the movement of information in the other direction (from the farmer to the researcher) has been much more restricted. Extension theory and practice have evolved substantially over time, as has the concept of applied agricultural research itself. We should now be in a much better position for setting up appropriate knowledge and information systems to facilitate this exchange than formerly (see Roling, 1988).

Agrarian knowledge networks allow informal exchanges and generation of information, as illustrated in the Dominican Republic (Box 1990). Countries may develop national strategies for the effective flow of agricultural information (Houng 1989, Ballantyne 1991). In order to have equal accessibility of information at all levels in rural development, it may also be necessary to set up local information centres.

To offset the apparent lack of available information covering indigenous knowledge, the Centre for Indigenous Knowledge for Agriculture and Rural Development (CIKARD) was set up at Iowa State University, U.S.A. in 1987 (Warren & Cashman 1989, Rajesekaran 1991). CIKARD collects published and unpublished material, develops approaches to integrate indigenous knowledge into agricultural research and extension, and conducts training courses of techniques for documenting and using indigenous knowledge.

While many developments have taken place, there is still far to go in institutionalizing the two-way linkages between farmer and researcher for maximum benefit. On the one hand, it must be recognised that temporal and spatial variability in the performance of agricultural systems will often militate against the possibility of static, blanket-type recommendations being entirely appropriate. On the other hand, local knowledge has to be 'internalized' in the research and extension processes, if profound understanding is to be gained of the way in which farmers operate their systems. While these demands are undoubtedly onerous for any agricultural science, they must be dealt with if the goals of relevance and sensitivity are to be attained.

Soil measures as indicators of sustainability

Sustainablity is fashionable, particularly since UNCED. To dyed-in-the-wool agriculturalists it sounds very much like 'good husbandry', the meaning of which we knew intuitively many years ago. Sustainable development, however, implies much more. It implies that information on system performance and the quality of natural resources is freely available and that it flows in both directions from the poorest farmer to the policy makers. Soil scientists may be intermediaries and promoters of this information flow.

Indicators of sustainability have recently become a major industry; Manuel Winograd (pers comm 1993) has recently reviewed approximately 1500 papers. Seeing the wood for the trees is, in this context, rather difficult. Harrington et al (1993) have identified characteristics required of an efficient indicator of agricultural sustainability. The following is based on their list.

1. It should be easily measurable.

2. It should feature relevant, complete geographic coverage.

3. It should be cost effective. taking advantage where possible of available information. The cost of an efficient indicator should ideally be born by the economic output of the system, unless it is being used as a diagnostic from a higher system level.

4. It should change as the system moves away from sustainable equilibrium.

5. It should clearly distinguish between causes and effects. Effects (system state variables) should not be confounded with causes (system parameters) that make the system vulnerable to decline.

6. It should give warning of degradation processes that are irreversible. That is to say where the cost of reversing the process cannot be born by the economic potential of the system.

7. It should take account of the full cycle through which the system moves in time.

8. It should highlight links to other system levels at which degradation processes might be more readily addressed.

9. It should have the capacity to be used to monitor and forecast future trends in resource quality and agricultural system productivity, as well as tracking corresponding trends from the past.

It is obvious from this list that an indicator is not a measure that governs the initial state or the potential of a system. Those are system parameters which are fixed; examples could be soil texture, depth, clay mineralogy, rainfall variability etc. In other words, things that the farmer and farming practice cannot change, even though they are of prime importance in deciding what can be done with an agricultural area.

The indicator should change, reflecting an underlying system variable, as the system progresses towards system failure. (Sustainability is the null hypothesis and therefore cannot be proved). In workshops and conferences one frequently hears that measures on the soil are prime candidates for the elusive indicators of sustainability. We often hear that soil pH, organic matter content, compaction and many more are critical indicators of sustainability. They are not so in most cases. They are management variables set within a hierarchic system. Letey (1985) states clearly that soil physical properties are what set the management practice that is appropriate. The important point, noted in the list above, is, can they be managed within the economic constraints of the system?

Let us take the case of soil organic matter. As an example, we have before us a Maize/Bean relay system on one of the poorer volcanic soils of the Andes. Little weed regrowth is expected during the dry season. The maize stover is carted off for fodder or roofing material. The organic matter of this soil will inevitably decline to unsustainable levels and surface erosion will occur during the onset of the rains when maize growth is slow due to the lack of nutrients.

Embed this system (field) in the larger context of a farm or community and the solution becomes obvious. Up to sixty percent of the area under consideration is under pasture. Farm yard manure should be available (we are not saying that it is). The deficiency of organic matter can be corrected from a higher level of the system - be it farm or community.

Soil compaction in an oxisol should be no problem if the production system can afford to incorporate sufficient crop residues and to deep plough when necessary. The secondary structure of an oxisol can be readily recovered, if the organic matter content is not too low, by the normal wetting and drying cycles of these soils (Buol, S. pers. comm. 1992).

In both of these examples, the critical point is the economic ability to manage the system. Conway & Barbier (1990) identified much of the problem of agricultural development thus: 'mismatching of technologies is particularly apparent where technological packages are applied on a large scale; in the belief that the natural resources they are intended to manage are uniform'. We would go further than this and include the economic variability and capacity to cope with the management of the system that exist between the agriculturalists of the developing world.

Thus simple measures of variable soil characteristics are not generally good indicators of the sustainability of a system, or even the unsustainability of a managed agricultural practice. The capacity to manage the system would be a much more compelling indicator. This brings us back to the examples given in the introduction. The knowledge necessary to handle the system is the critical point. It may cost almost nothing to the farmer who applies it, but it does have a cost in the research process.

There is one obvious case where this is not true, where irredeemable soil damage is occurring through soil erosion. Erosion at a faster rate than the soil forming processes is obviously unsustainable. A good example is that of the Fen soils of East Anglia. The tilling of the Fen peat soils inevitably results in the depletion of the peat horizon. This seems to have been accepted by the farmers of the region and they generally accept that this is a cost that future generations will have to pay. Where obvious soil erosion is taking place in Latin America, the same sort of mentality seems to hold sway.

If this really is the case, and farmers recognize the damage they are doing to the land (and we are fairly sure that in most cases they do), we do not need sophisticated measures of soil depletion or degradation to highlight the fact. We simply have to ask the farmers why they have to pursue the course they are following. The answer will be economics. The solution will almost always be sociological. The needs of future generations will have to be safeguarded by convincing the present generation that it is in their best interest. This is completely outside the realm of soil science and, we suspect, of any science.

In essence, then, sustainability is a *WHOLE SYSTEM* characteristic. The system includes the soil, the farm, the farmer and the relationship of the farmer to the community and to the rest of the world. To look for simple soil measures as indicators of sustainability is fraught with all the above problems. What happens on an experimental plot is not real life. As a community of agricultural scientists we have to come to terms with the reality of the agricultural process as a whole.

Conclusion

The move to sustainable agriculture in the developing nations implies an increase in agricultural production. This is particularly the case with small farmers. Increased productivity will allow the management practices that protect the environment. There is not necessarily a tradeoff of production for conservation and sustainability, as there appears to be in the developed nations.

The productivity increases which are most cost effective in enhancing sustainability are most likely to be applied on the acid lands of the agricultural frontier. These lands are not the deep Amazon rainforest but the legally accessible land in the forest margins, the savannas and the hillsides of Latin America.

The balance of basic soil research still reflects the academic or production interests of the developed world. While redressing this imbalance of basic research would obviously be a good thing, the main constraints to progress are the information flows within the agricultural production and policy communities of the developing world. The world soil science community can contribute to the alleviation of these restrictions.

Information for planning policy at a national or regional level is still far from complete. This can result in the distortion of production and trade policy decisions and in poor priority setting for research. There is a need for tools that are more easy to use for major decision makers. The development of major soils databases now in hand must include efficient user interfaces for non-soil scientists.

There is a major deficiency in the flow of information back from the farmers to the soils research community. More attention should be paid to farmers' knowledge of their soils,in particular their variability in cultivation characteristics. Farmers' decision making processes are a key to the application of innovative soil management practices.

Agricultural system sustainability, while often based on careful analysis of soil characteristics, is a whole system characteristic. The analysis of this depends heavily on the joint efforts of the farmer, the soil scientist, the agronomist and the social and economic scientist.

We conclude that while basic soils research is still required, it should be done in response to highly specific and well-focused needs. A major effort is needed to collate and articulate the application of already existing information. The impetus for this effort should come from the formal research community, but its details should be driven by end users.

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