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SPATIAL ASPECTS OF THE DESIGN AND TARGETING OF AGRICULTURAL DEVELOPMENT STRATEGIES

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ABSTRACT

Two increasingly shared perspectives within the international development community are that (a) geography matters, and (b) many government interventions would be more successful if they were better targeted. This paper unites these two notions by exploring the opportunities for, and benefits of, bringing an explicitly spatial dimension to the tasks of formulating and evaluating agricultural development strategies.

The paper was originally conceived to address the more specific goal of proposing a spatial characterization to underpin deliberations on appropriate development strategies for the "fragile" or "less-favored" lands of Sub-Saharan Africa. In practice, however, we considered that goal to be not only impractical but, perhaps, ill-conceived. The multiple senses in which land may be considered fragile, coupled with the myriad of potential development pathways would result in either an overly complex characterization or, more likely, a need to aggregate and generalize that would render the characterization of little use when confronted with any specific, real-world problem. We first review the lingua franca of land fragility and find it lacking in its capacity to describe the dynamic interface between the biophysical and socioeconomic factors that help shape rural development options. Subsequently, we propose a two-phased approach. First, development strategy options are characterized to identify the desirable ranges of conditions that would most favor successful strategy implementation. Second, those conditions exhibiting important spatial dependency – such as agricultural potential, population density, and access to infrastructure and markets – are matched against a similarly characterized, spatially-referenced (GIS) database. This process generates both spatial (map) and tabular representations of strategy-specific development domains.

While there are many advantages to this tailored approach, it does depend on having access to a modest GIS capacity to re-characterize and re-interpret spatial datasets as the nature and focus of development problems change, and as new and improved data become available. This would be a significant step for many policy analysis units, typically run by economists. However, while acknowledging that not all aspects of strategic analysis necessarily benefit from a spatial perspective, we feel an important additional benefit of a spatial (GIS) framework is that it provides a powerful means of organizing and integrating a very diverse range of disciplinary and data inputs.

At a more conceptual level we propose that it is the characterization of *location*, not the narrowly-focused characterization of land, that is more properly the focus of attention from a development perspective. IFPRI is expanding on these concepts in its work on policy-relevant applications of GIS linked more closely to economic perceptions of space.

The paper includes appropriate examples of spatial analysis using data from East Africa and Burkina Faso, and concludes with an appendix describing and interpreting regional climate and soil data for Sub-Saharan Africa that was directly relevant to our original goal.

CONTENTS

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1. INTRODUCTION

In this paper, we examine how the use of information in a spatial context can contribute to the formulation of policies for improving rural welfare while maintaining the long-term economic potential of the natural resource base. As a first step, the paper reviews notions of land fragility. A purely biophysical perspective is judged to be of limited value; one that links the potential vulnerability of specific types of land to degradation under specific land use practices is considered preferable, although general dissatisfaction with terminology in this area is noted.

Furthermore, the notion of *location* and its suitability for a specific purpose, in space and in time, is proposed as a more useful concept for formulating development strategies. At any particular time, locations can be deemed less suitable for a range of

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biophysical and socioeconomic reasons, including high rainfall variability, low soil fertility, scarcity of drinking water and fuelwood, high incidence of pests, diseases and weeds, poor infrastructure, limited integration with input and output markets, and so on. Across time, the cumulative effect of human action brings about changes in these factors that may alter the suitability of locations; slowly or rapidly, positively or negatively, reversibly or irreversibly. But it is only feasible to identify the particular set of factors that most adequately characterize development constraints and opportunities in the context of a clearly defined problem and specific goals.

In setting out to write this paper we were faced with the task of proposing a spatial schema that would support the evaluation of agriculture-led development options for the “fragile lands” of Sub-Saharan Africa. But given the enormous diversity and site-specific nature of many production system, cultural, socioeconomic, and resource management issues, we consider it impractical, restrictive, and nowadays unnecessary to design a unique spatial characterization schema for all problems and for all objectives. Rather, we opt for developing effective tools to characterize locations based on specific problems and to re-characterize those locations as our understanding and information base improve, and as new problems arise.

Furthermore, we propose that the design of a problem-specific, location characterization framework can be significantly improved by first characterizing the *development strategies* that the location schema will be used to evaluate. Development strategy characterization establishes the critical requirements for successful strategy implementation and, hence, enables selection of the most relevant set of biophysical and socioeconomic factors. Many of these factors will have significant spatial dependencies and, therefore, could benefit from analysis in a spatial context. Once such development strategy evaluation criteria are established they can help identify locations in which each strategy is more likely to be effective.[1] Location-specific data are held in spatial (GIS) databases.

Since direct and feedback effects link welfare impacts in both less- and more-favored locations, we also propose that development strategies for either type of location should not be formulated in isolation. Spatial analysis procedures and databases need, therefore, to encompass *all* locations in which significant impacts may arise as a consequence of a new development strategy, even if the strategy is only directly targeted at a single or specific sub-group of locations.

IFPRI's recent work on development policy issues in less-favored lands has formalized a research framework based on the theories of induced technical and institutional innovation in agriculture and natural resource management (Scherr et al. 1996), and we briefly review this framework from a spatial perspective. The range of factors embodied in this particular formulation are probably typical of many agricultural development stylizations and, from a spatial perspective, can be viewed as those like agricultural production and natural resource stocks that are specific to a location (*intra-locational*), and those that link multiple locations (*inter-locational*), such as measures of accessibility to markets and other services, and natural resource externalities such as river pollution. It is only relatively recently that the development of tools such as geographic information systems (GIS) has made inter-locational analyses tractable.

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[1] And we provide some simple examples of this approach the section "Development Strategy Applications of Spatial Analysis."

To illustrate these notions, and as a practical guide of how spatial analysis can contribute to development planning and policy formulation, we describe some potential applications, and with each provide a specific example using spatial data from East Africa and Burkina Faso. The applications are:

- Diagnosing development problems and pressures;
- Characterizing development strategy options; and
- Transfering knowledge about development outcomes at specific locations to assess potential outcomes at other locations, including the prospects of technology transfer between locations.

In the second part of the paper (presented as an appendix) we review the spatial and temporal variation in climate and soil resources across Sub-Saharan Africa, as these will likely shape the design of agricultural development strategies within the region. The dominant patterns of rainfall quantity and variability, key biophysical determinants of the extent, nature, and year-to-year viability of agriculture, are briefly described. With regard to soils, the evolution of soil mapping and soil databases is summarized, followed by an overview of the type and extent of soil constraints throughout Sub-Saharan Africa. Preliminary evidence of relationships among existing measures of "potential" and "actual" land degradation and population density is also reported; although the aggregated and subjective nature of much degradation-related data is seen to be a major constraint to meaningful analysis and interpretation.

An opportunity is recognized for improved interaction between development analysts working in national agencies, and other specialists in regional and international agencies that build and manage spatial datasets and develop specialized analytical tools.

There is also a need for mechanisms to enable international analysts to tap local information and keep themselves better informed of conditions likely to help or hinder the effectiveness of strategic, international interventions, such as agricultural R&D, that are designed to have positive outcomes spanning national boundaries.

2. ISSUES, CONCEPTS, AND METHODS

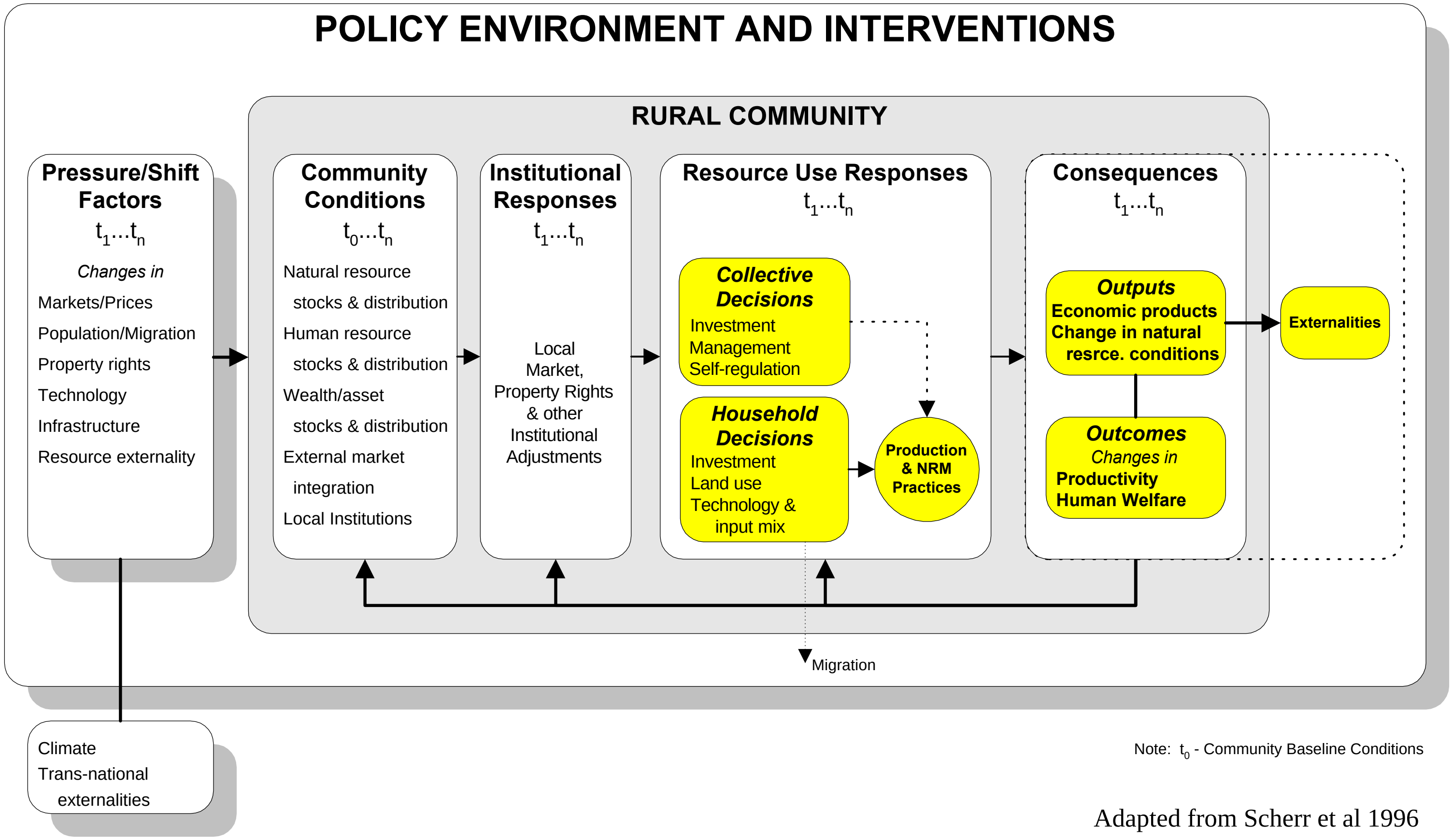
PARADIGMS FOR RELATING LIVELIHOODS AND LANDSCAPES

While the immediate focus of our attention was fragile land, the underlying development concern is the risk of chronic or irreversible loss of economically productive capacity as a consequence of resource degradation, whether or not the land is deemed to be fragile. A particular concern is that poor rural communities may be unable to respond adequately to the pressures they face (population growth being a prime example) and, often having limited access to institutional or infrastructural support, may engage in agricultural production practices that exacerbate the degradation process. This in turn reduces production potential and generates even more pressure to further deplete natural resource stocks and perpetuate the "cycle of poverty." This "downward spiral" is, however, not the only possible development trajectory (Tiffen et al. 1994; Reij 1996; Hassan 1996; and World Bank 1996), and the significant challenge is to identify strategic development choices that can lead to more socially desirable outcomes.

IFPRI's ongoing research on improved policies for "less-favored" land has been formalizing and testing a conceptual framework to describe induced institutional and technical innovation in rural communities with regard to agricultural production and natural resource management (Scherr et al. 1996). A stylized representation of that framework, built around a “pressure-state-response” paradigm, is presented in Figure 1. The figure identifies a range of key factors that research has so far identified as influencing the evolution of rural communities, and hints at the large number of relationships and feedback mechanisms. The figure is a useful starting point for examining the potential relevance of space to the processes involved. Biophysical, demographic, and infrastructure variables clearly have strong location specificity, but other spatial characteristics such as physical accessibility (or remoteness) can significantly influence household, enterprise, and community decisions in a number of ways, e.g., by influencing price formation for inputs and outputs and, hence, the viability and structure of factor and product markets. Thus, we can think about space, or the importance of location, from two main perspectives:

- The *intra-locational* characteristics observable at a specific site, e.g., climate, soils, water resources, human population, flora and fauna, and land use, as well as physical and social infrastructure such as roads, ports, processing plants, health clinics, and banks.
- The *inter-locational* characteristics that determine how variables at one site may influence, or be influenced by, variables at other sites. Such relationships are often assessed in terms of physical distances (by shortest route or via networks such as roads and rivers), perhaps with allowance for the means of transportation and the quality of the surface (Deichmann 1997). Other examples include migration as well as more abstract concepts like market integration and the environmental distance between two locations. These are useful concepts when thinking, for example,

Figure 1 Induced technical and institutional innovation in agricultural production and natural resource research management



Note: t_0 - Community Baseline Conditions

Adapted from Scherr et al 1996

about the transfer of agricultural technologies between locations (Pardey and Wood 1994).

Most studies, even those with an explicit spatial focus, have only paid attention to the intra-locational aspects. However, the rapid expansion of GIS technologies and databases, together with a recognition of the benefits derived from thinking about economics and the environment in a spatial framework to address trade, technology transfer, and environmental externality issues, brings *inter-locational* issues to the fore.

LAND AND LOCATION

The Lingua Franca of Land Fragility

There is an extensive literature on lands variously described as fragile, marginal, vulnerable, problem, and more- or less-favored. Early writers focused on purely biophysical aspects including steep slopes, arid and semi-arid lands with highly variable rainfall patterns, and areas that are poorly drained, too cold, or of low inherent fertility. More recent contributions have recognized that a major development preoccupation is not with the biophysical characteristics of land as such, but the susceptibility of different types of land to biophysical degradation, on a temporary or long-term basis, as a consequence of human activity. In this widely accepted view, at least from an agricultural perspective, “fragility implies a mismatch between human use and biophysical conditions” (Turner and Benjamin 1994, 106). Appropriately matching the use of land with its capacity also underscores FAO’s approach to land evaluation, the first guiding principle of which requires that “land suitability is assessed and classified in relation to particular land uses” (FAO 1976, 3). Thus, a sloping, moderately watered, hillside with light- to medium-textured soils could be extremely “fragile” under one use, but under another, based on better adapted technologies and management practices, could be quite productive, even over the long-term. In the fragile land rubric, inappropriate type and intensity of use, inappropriate technology, the amount, mix, and timing of input use, and other inappropriate management practices can act individually or interactively to produce negative resource impacts. Two recent and fairly extensive reviews of fragile land literature and concepts provide the following definitions:

> "Fragility refers to the sensitivity of land to biophysical deterioration under common agricultural, silvicultural, and pastoral systems and management practices." Turner and Benjamin (1994, 111)
>
> "Fragile lands ... are those that are so sensitive to biophysical degradation that common uses cannot be sustained and the land does not readily recover." Turner and Benjamin (1994, 111)
>
> "Fragile land is land sensitive to land degradation as a result of inappropriate human intervention." TAC (1996, 5)

Confusing Land with Location

While there is some unanimity among natural scientists about the concept of fragile land, the question remains as to how useful these definitions are in designing development strategies. In considering this question some concerns arise:

Land the scope of its meaning. Despite many attempts to broaden the scope of meaning, land is generally interpreted as comprising: soil, terrain, land cover, and, in some circumstances, surface and groundwater resources. FAO's Framework for Land Evaluation (FAO 1976, 9), however, provides a more encompassing definition in which land comprises "the physical environment, including climate, relief, soils, hydrology, and vegetation, to the extent that these influence potential for land use." Most other definitions, and certainly those implicit in the fragile land definitions reported above leave ambiguity, for example, as to the inclusion of climate.[2] In reality, climate variability within and between years is a highly significant factor in determining rural household welfare in most of semi-arid Africa, and needs to be more obviously central to the overall concept of location being developed here. Furthermore, there are other factors that impart significant advantages or disadvantages to a given location; for example, the accessibility of infrastructure and markets, and the incidence and severity of pests and diseases that impact the productivity and general well-being of humans, livestock, and crops. Turner and Benjamin (1994) and TAC (1996) both provide expanded forms of their land fragility definitions that attempt to cover some of these factors. For example, TAC (1996, 5) lists one of the socioeconomic constraints associated with land fragility as "unavailability or high costs of inputs." While recognizing the relevance of this factor, it is more meaningfully conceived as a property of location rather than of land per se, even in the broader sense of that word.

It may be preferable to reserve the word *land* as a shorthand descriptor of the prevailing range of biophysical attributes of a given location, and that, ceteris paribus, broadly circumscribe the (biophysical) potential of that location for specific economic uses.[3] Other attributes can be summarized as expressions of human action and can be grouped, somewhat arbitrarily, as *socioeconomic* factors. In any particular location,

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[2] Because it is highly improbable that climate *at that location* is degraded by inappropriate land use practices.

[3] Acknowledging that, as this definition proceeds to suggest, prevailing biophysical attributes of the location are often conditioned by the cumulative impact of prior human intervention.

biophysical, and socioeconomic factors interact in ways that can alter the inherent physical production potential of the land. Our primary concern here is with locations at which human welfare and its supporting natural resource base may be at risk; whether that be primarily as a consequence of biophysical or socioeconomic factors.

Opportunities for mitigating natural resource degradation. The land fragility literature appears to take land as variable and land uses as fixed. Thus, the possibility that "common practices" or "inappropriate human intervention" could evolve so as to reduce, and perhaps even negate, resource degradation is missing from many definitions. In reality, it is precisely this ameliorating outcome that most development strategies are designed to bring about. There are three primary, and often simultaneous, sources of mitigation:

- ***Induced Innovation*** the local adaptation, experimentation, and technological innovation by individuals, communities, and societies as a response to external and internal pressures, e.g., the processes of induced innovation hypothesized by Boserup (1965 and 1981), primarily as a response to population growth.
- ***Formal scientific research and development (R&D)*** that identifies new policies, practices and technologies, and that has been highly successful to date in improving agricultural productivity. With increasing concerns about the rate of consumption of natural resources, a significant share of public R&D investments is now being targeted to the development of so-called "win-win" technologies that seek both to improve productivity and

to reduce pressure on the natural resource base. However, we must recognize that in many instances there are tradeoffs involved.

- ***Market integration*** integrating previously isolated communities into regional and broader markets brings net economic benefits by stimulating the generation of marketable surpluses using higher input production systems. In addition to increasing income, market integration usually brings other forms of institutional support, and a set of conditions is brought about that tend, over time, to be land enhancing.[4]

Based on these considerations we conclude that the generally accepted concept of land fragility is of limited use in a development policy context. From a development perspective we prefer, and recommend, a spatial framework based on a broader consideration of *location* rather than land wherein:

> The capacity of a location to support a specific economic activity[5] depends on both *biophysical factors* such as climate, terrain, soil, hydrology, land cover, fauna, as well as s*ocioeconomic factors* such as demography, income and technology constraints, physical and institutional infrastructure, and market integration. It is recognized that the nature of the activity, as well as human-induced and natural changes in these location-related factors, can bring about positive or negative changes in the location's capacity to support this (or an alternative) activity over time.

This seems a more meaningful framework for designing strategies that foster human-induced improvement. It does not exclude the possibility that short-term degradation could be an optimum land management strategy (e.g., as found in fallow-based rotations), nor that degradation can occur on "non-fragile" land if it is cultivated excessively (e.g., the

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[4] Although some would argue that the absence of markets for many environmental goods and services leads to aggregate over-exploitation of land for the production of "economic" goods and services.

[5] or development strategy.

Argentinian Pampas, or Machakos or the U.S. Dust Bowl in the 1930s), nor that degraded lands can be rehabilitated (e.g., Machakos or the U.S. "Dust Bowl" in the 1990s). Furthermore, it embraces the notion that, for example, markets and other institutions, and not just technologies, can all play a role in influencing the extent to which land is degraded or conserved.[6]

Location and Time

Another key issue is the temporal nature of the pressures bringing about change in resources conditions. There are chronic pressures including: climate change and population growth (and consequent changes in livestock and crop production), along with improvements in infrastructure and technology, and other short-term or episodic pressures such as: droughts, floods, disease epidemics, and pest outbreaks. From a development perspective it is useful to separate these as requiring different, though possibly complementary, strategic responses. Long-term pressures may best be addressed through policies related to structural and incentive issues, while short-term pressures require some capacity for crisis response and relief. One of the important policy challenges is to better integrate interventions, particularly in the Sahelian countries, where short-term climatic uncertainty and extremes need to be addressed as the long-term issues they clearly are.

Many of the concepts discussed in the previous sections are synthesized in Figure 2. The figure highlights the complexity of land-use decisions in much of Sub-Saharan Africa, where a range of dynamic pressures (both short- and long-term), and limited capital and other

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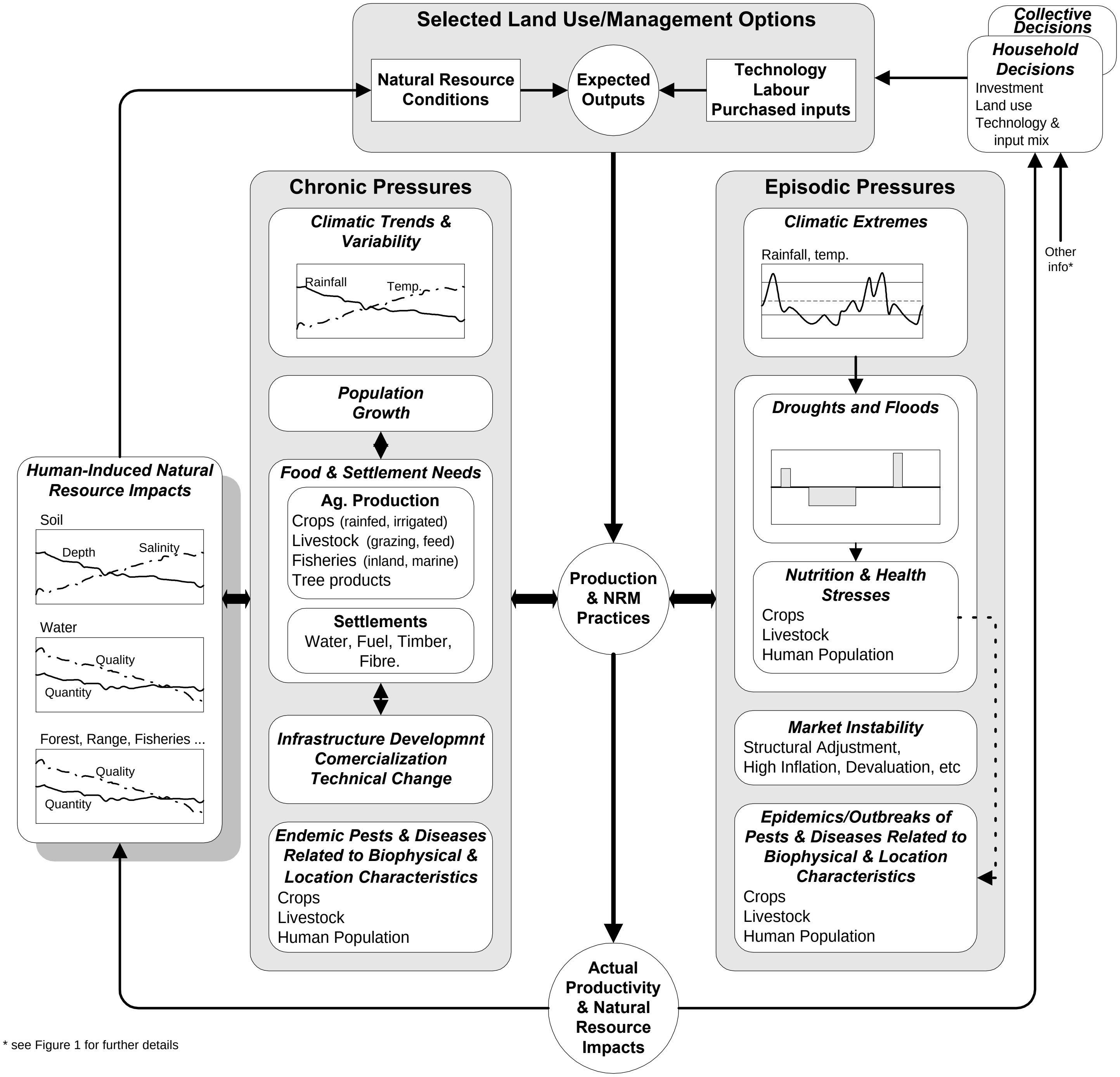
[6] While there is no shortage of concepts and empirical work on the economics of land and location, from the works of von Thunen (1842) to those of Krugman (1998), there is much to be done to wed this body of work to broader development issues of the type we are addressing.

Figure 2 Location specific development dynamics in sub-Saharan Africa



* see Figure 1 for further details

inputs, result in high production variability and significant risk of natural resource degradation.

GENERIC CHARACTERIZATION: PROBLEMATIC, RESTRICTIVE AND UNNECESSARY

We have established that the scope of spatial interest, from a strategic perspective, is location, and that location comprises both biophysical (e.g., land, broadly defined) and socioeconomic factors. This begs the question of the feasibility of devising a practical, generic schema for those biophysical and socioeconomic factors that might guide the design of development strategies targeted to poverty alleviation and improved natural resource management in Sub-Saharan Africa.

The design of any characterization schema should be based on several key principles, including clear objectives of use, relevance to a known set of problems, and reliance on a feasibly measurable and manageable set of characterizing variables. Even these, seemingly trivial, requirements provide sufficient grounds to believe that a generic schema would be impractical. For example, since poverty is a key concern we might want to include the incidence (and, likely, severity) of poverty in any geographic area as a key characterization variable. First, we must define a poverty metric, for which we will need to obtain data of sufficient time and space resolution. Shall that metric be average per-capita income, or household income—in total or by gender, or something else? And to what extent would this metric capture other important poverty dimensions such as health and nutritional status, and access to land, credit, and education? Even having settled on a set of indicators, the generic, somehow-critical values of those poverty indicators need to be defined.[7] Natural resource issues are no less complex, including soil erosion and soil fertility loss, water resource problems associated with over-extraction, pollution and insecure access, the loss of genetic biodiversity, depletion of fuelwood resources, and the growing complexity of pest and disease management.

One strategy is to aggregate characterization variables in an effort to devise a pragmatic characterization schema, for example, to move away from direct measures of soil organic matter, through indices of soil fertility, to soil classification. However, each aggregation loses specificity that may, in truth, best describe the binding constraints to development; unstable soil structure, failing property right arrangements, endemic whitefly, fecal pollution of drinking water sources, or a host of other factors for which we possibly have, or could assemble, data, or could make reasonable proximate estimates. Such important details could “fall through the cracks” of a generic characterization schema that would need to trade-off breadth (coverage) for depth (precision). Until the scale and objectives of each development initiative are known, and until the critical development constraints are diagnosed, we have little notion of the most relevant variables, nor of the critical ranges of those variables, that may prove central to the design of relevant and feasible interventions. Conversely, we maintain that predetermined (i.e., preselected and preaggregated) generic schema are likely to impose unnecessary restrictions of analytical scope and geographic scale.

Why may a generic schema be unnecessary? Because, without wishing to minimize the real challenges of developing even a modest spatial analysis (GIS) capacity,

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[7] For a contemporary review how the spatial dimensions of human welfare and poverty have been, and could be handled see Henninger (1998).

the techniques of building *problem-specific* characterizations in a dynamic and cost-effective way are now little more complex, and little more expensive, than using other large Windows-based software packages.[8] Some types of data problem are also reducing as high-resolution remote sensing data (e.g., USGS 1996), international compilations of data (e.g., WRI 1995), and helpful analytical tools (e.g., Corbett and O'Brien 1997) are beginning to provide solid, low-cost, start-up information on biophysical (and to a lesser extent, socioeconomic) factors at the national level. Within most countries, other publicly available datasets can add more spatial detail, as well as a wider range of thematic variables, in a cost-effective manner.

Our council, then, is not to allocate scarce resources in attempting to devise a generic classification schema, that may never properly fit any real-world problem. Rather, we propose that the goal should be to *foster the development of human, physical, and information resources to build problem-specific characterizations as an integral part of the strategy formulation process*. The iterative nature of that process, in and of itself, would also best be served by a capacity to quickly re-characterize and test the spatial implications of alternative interventions. As the scope of geographic or other issues surrounding each development problem and each intervention become better understood, more refined characterization can be made. In this way, problem-oriented spatial characterizations can be developed that, over time, improve the knowledge and data bases for creating new problem-specific schema. In all cases the two dimensions of characterization are:

- Characterization of *development strategies*—identifying the locational and

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[8] Bearing in mind that we are proposing spatial analysis capacities built around secondary data collected and pre-processed by specialized agencies.

other attributes that would contribute to the success or failure of a specific strategy. This is an essential step in identifying spatial domains within which a given strategy is more likely to be successful.

- Characterization of *locations*—structuring the key spatial attributes of land, infrastructure, demographics, poverty etc. This is important for such tasks as problem identification, development strategy evaluation, and technology transfer, and provides a basis for mapping locations based on their similarity or dissimilarity. [9]

By matching development strategies with locations, the improved ability to diagnose problems and evaluate strategies, should make it possible to design interventions that are both more effective and less costly to implement.

SPATIAL ANALYSIS TECHNIQUES

There are many potential applications of spatial analysis in the process of designing development strategies. In the next section we will focus on just three strategy formulation activities and, for each, illustrate a single analysis technique that is relatively straightforward to describe and implement. However, to lay some groundwork for the description of those applications, we will first make a brief review of the most common spatial analysis techniques. While GIS technologies may differ in the way they represent spatial objects and their associated properties, practically all GIS technologies support the following:

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[9] When location characterization is performed only to assess the suitability of a specific development strategy (e.g., locations are characterized using only the development strategy characterization variables) then these components are perfectly complementary.

Visualization

The mere visualization of information in its proper spatial context can foster an understanding of some types of problems and opportunities. At the lowest level is the presentation of different indicators using a single, fixed spatial configuration, e.g., using district boundaries as a basis for displaying district-level statistics of population density, crop production, average yield, head of livestock, and so on. At another level, different types of map elements, with different boundary configurations can be precisely overlaid for on-screen presentation or printing. This enables population density, road networks, rainfall isohyets, soils, and other factors to be superimposed and visually examined in a search for spatial patterns or anomalies.

Intersection

Beyond simple visual overlay of map elements, intersection supports the analytical combination of digital maps to generate a new set of spatial (map) units as well as cross-tabulations that summarize the spatial correspondence between values shown on the original maps. For example, a watershed map depicting three elevation ranges, when intersected with a population density map depicting four population density ranges, will create a cross-table of area extents, and a corresponding spatial distribution map, of twelve elevation-by-population density classes.

Spatial Characterization

Inductive – To identify locations having a desirable set of characteristics, relevant characterization themes and key threshold criteria are first specified. A spatial search is then performed across an appropriate GIS database to identify all locations satisfying the specified criteria, e.g., show all areas with population density less than 50 persons per square kilometer, river valley soils, annual rainfall of less than 500 millimeters, and elevation ranges from 500 to 800 meters. *Deductive* – Here a specific location is identified and the value ranges of variables from that location are abstracted from a user-specified set of related maps, e.g., for a selected watershed, extract the representative ranges of elevation, rainfall, population density, slope, and land cover that are encountered within that watershed. Wood and Pardey (1998) provide a much more detailed review of these methods applied to issues of agricultural research and development, and the targeting and spillover of technology.

Distance and Network Functions

These functions allow distances between points to be calculated, as well as buffer zones to be defined, and all objects within a certain distance to be located, e.g., find all towns of more than 1,000 people within a radius of 50 kilometers. More sophisticated network functions are able to recognize and manipulate points lying on the same network, e.g., on the same road, river, and railway, and support queries such as, “find the closest three villages by road from the current location.”

Spatial Relationships

The techniques described above take little or no account of relationships among adjacent spatial units, but for some applications these relationships are critical. Applications include slope determination (e.g., the relative elevation of adjacent points), and identification of water flow pathways to the nearest river. These are relevant in hydrological, soil erosion, and pollution studies. Similar algorithms support spatial diffusion analysis, e.g., for modeling groundwater flow, or to represent diffusion of technologies among farmers.

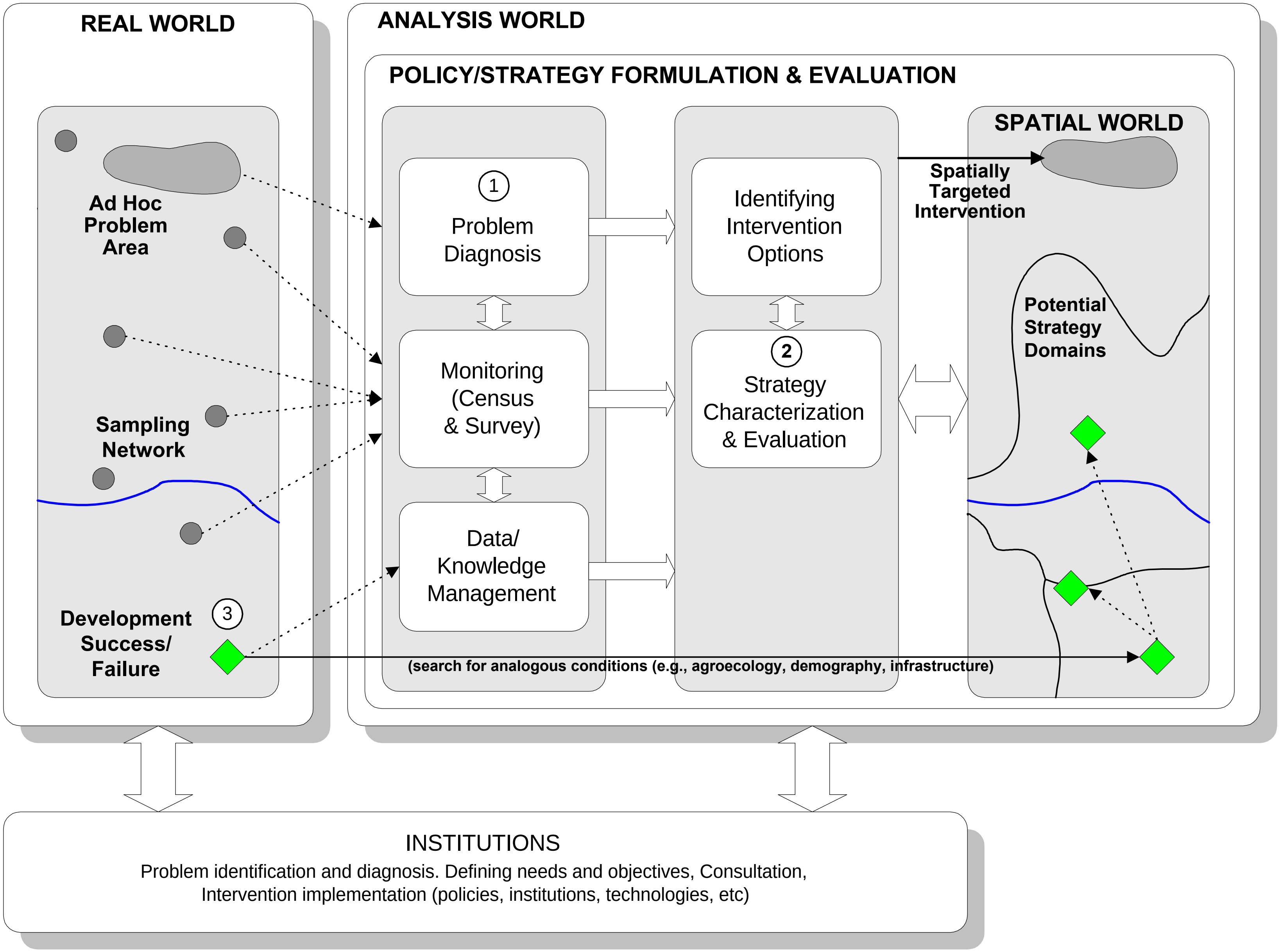
DEVELOPMENT STRATEGY APPLICATIONS OF SPATIAL ANALYSIS

Figure 3 presents a stylized view of the development strategy process into which a spatial (GIS) representation of the real world has been inserted. This section will describe how just three stages of that process could be facilitated by spatial analysis. They are indicated on the figure by the numbers 1 to 3, and comprise: *problem diagnosis*—a straightforward application of the *intersection* of two related themes as a means of highlighting significant departures from an expected relationship; *development strategy characterization*—a concrete example of the approach proposed in this paper - to enable the delineation of locations appearing more or less suited to the successful implementation of specific development strategies; and *spatial extrapolation*—the characterization of locations having some desirable feature (e.g., where a specific strategy or technology is known to have been successful) in order to find similar locations elsewhere.

Problem Diagnosis

A classic means of establishing the well-being of an entity or process is to observe its identifying characteristics and compare those observations against norms established by empirical evidence or theory. The process may not provide major insight into

Figure 3 Spatial analysis as a component of development strategy formulation and evaluation



causality, but it does at least identify the potential existence of a problem. Thus, if actual crop or livestock yields, or water table levels, or fish stocks, are significantly different from those expected, production or resource problems could be to blame. However, these anomalies may also be due to data or method problems, issues equally worthy of investigation. This type of comparative analysis is fairly standard even in a non-spatial setting. Table 1 shows the format of simple cross-tabulations that a GIS could generate by intersecting the two input maps. The table lays out the possible combinations of the classes defined in each map, and the GIS calculates the area extent (or area proportion of the total map area) of each combination encountered. Table 1(a) compares the area correspondence of observed farmer yield classes (e.g., low-medium, medium-high) against those obtained either from yield potential modeling (from a biophysical or economic perspective) or from experimental yield data. It is essentially a spatial "yield gap" analysis. For those combinations that warrant further investigation (high observed-low potential, low potential-high observed) the table highlights some possible explanations. Other combinations are considered unremarkable.

The advantage of performing this analysis in a spatial domain is that it produces not only a table, but also a map, of the potential anomalies. This map can be visually overlaid with other variables: rainfall, soils, and the yields of other crops to see whether any spatial patterns emerge that help in explaining the phenomena (or in confirming data problems). On the same basis, Table 1(b), relates potential soil degradation, (e.g., estimated by the USLE approach, Wischmeier and Smith 1962, or the Fertility Capability Classification, FCC, Sanchez et al. 1982 and FAO 1997) to estimates of actual degradation (based on empirical data or, as in the case of GLASOD, on expert

Table 1a & 1b Problem diagnosis by the spatial intersection of maps

a. Comparing Potential and Actual Yields

	Potential (modelled or experimental) yields	
Actual yields	Low to medium	Medium to high
Low to medium	Unremarkable	a) Degrading/degraded land b) Less effective or appropriate technologies and practices than assumed c) Limited market integration (high relative price of inputs, low relative price of outputs) d) Resource constrained production e) Method/data limitations
Medium to high	a) Over intensive land use (high degradation potential) b) Better technology/ practices than assumed (e.g., irrigation) c) Method/data limitations	Unremarkable

b. Comparing Potential and Actual Estimates of Land Degradation

	Potential degradation	
Actual degradation	Low to medium	Medium to high
Low to medium	Unremarkable	a) Better technology/ practices than assumed b) Method/ biophysical data limitations
Medium to high	a) Inappropriate land use/ technology/ practices b) Resource “mining” c) Method/ biophysical data limitations	Unremarkable

consultations with some field validation). This is an altogether more uncertain exercise but could serve, at a minimum, to reveal any systematic biases in the potential assessment methods, such as the improper accounting for sediment deposition when modeling soil erosion over larger areas.

One of the significant data errors that may confound this simple type of analysis is a mismatch in scale, or level of aggregation, between the two sources of data being compared, and attention should be given to select or build data sets so as to minimize this problem.

Example 1: Problem diagnosis (Yield comparison in East Africa). This example is based on climate and yield data for Ethiopia, Kenya, and Uganda. Firstly, monthly mean average temperature and a monthly mean aridity index[10] were used to generate a map of the potential suitability for maize production under low levels of input. Assuming that an aridity index greater than 0.5 qualifies a month to be part of the growing season, the Corbett and O'Brien (1997) dataset includes an estimate of the total length of growing period (LGP) of any location. Although the Corbett and O'Brien definition of LGP is a simplification of that used by FAO we applied the FAO's LGP (and temperature) crop suitability rules (Kassam et al. 1991) using the LGP and temperature variables from the Corbett and O'Brien dataset to obtain an agroclimatic suitability map for low input, rainfed maize production. Suitabilities were assigned to one of five levels; S1—very suitable, S2—suitable, S3—moderately suitable, S4—marginally suitable, and N—not

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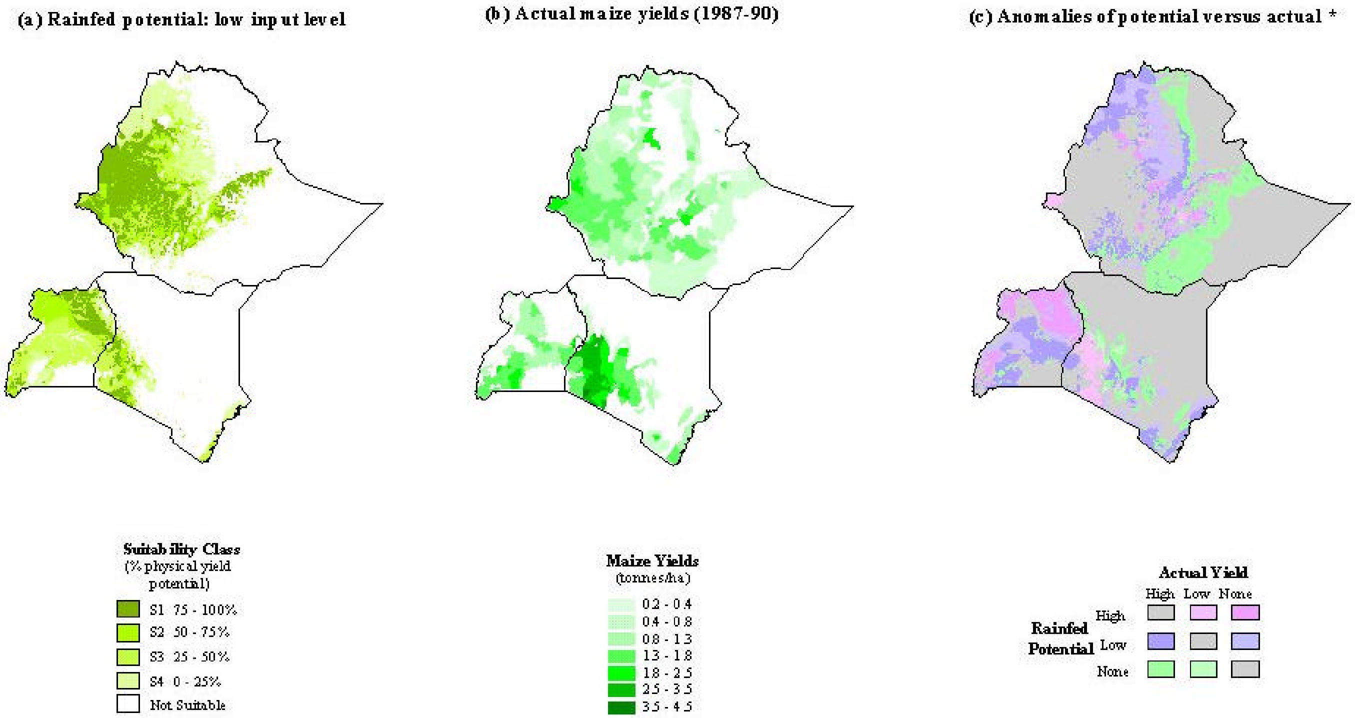
[10] Aridity index is the ratio of monthly rainfall to monthly potential evapotranspiration. The climate surfaces underlying these measures were calculated by Corbett and O'Brien (1997) and are available as digital images with a spatial resolution of 3 arc minutes.

suitable. The S1-S4 levels represent quartiles of the potential (biophysical) yield, i.e., S1 represents an expectation that 75-100 percent of the maximum yield could be attained at that location. The results of this analysis are shown in Figure 4(a). With regard to actual yield, data were generated by a joint Intergovernmental Authority on Drought and Development (IGADD) and FAO study (van Velthuizen and Verelst 1995), in which some 1,220 crop production system zones were delineated throughout the IGADD countries: Sudan, Eritrea, Ethiopia, Djibouti, Somalia, Kenya, and Uganda. For each zone a wide range of production related variables were measured and estimated, including maize yield (see Figure 4(b)). The yield data correspond to the period 1987-90, although the exact period varies by country. The two separate images were reduced to just three classes, high-to-medium, medium-to-low, and not grown (actual map) or not suitable (potential map). These maps were then intersected to produce the map shown in Figure 4(c) and Table 2. For about 61 percent of the area there is correspondence in terms of classification group of the two input maps. However, a significant proportion of the area, 12.9 percent, is judged to be highly suitable, yet no actual yield is reported– while about 5 percent of the area is considered “unsuitable” and yet produces maize in the high yield class. The map clearly shows the large tracts where these differences occur and Table 1 provided some suggestions as to how these differences could be interpreted and further investigated. In this specific case the omission of soil constraints results in an over-optimistic assessment of agricultural potential. Taking soils into account (a general, but spatially variable, limitation) there would likely be a significant reduction of the 31.6 (0.5 + 12.9 + 18.2) percent of area in which potential yield levels appear to be overstated relative to actual yields.

Figure 4 : Spatial Data in Problem Diagnosis : Potential versus Actual Maize Productivity



(a) Rainfed potential: low input level

(b) Actual maize yields (1987-90)

(c) Anomalies of potential versus actual *

Source: (a) and (b) - Authors' estimates based on Kenya rule set (Kassam et al. 1991) and SCT Database Corbett and O'Brien 1997)
(c) CPSZ (IGADD and FAO 1995)

* See Table 1a and text for discussion of some possible causes

Scale: 1:30,000,000

Table 2 Agricultural potential rating versus actual yield maize (Ethiopia, Kenya, Uganda)

Actual yield	Agricultural potential rating[a]					
	None		Low-medium		Medium-high	
	Area	Share	Area	Share	Area	Share
	1,000 km²	*%*	*1,000 km²*	*%*	*1,000 km²*	*%*
None[b]	721.6	43.6	9.0	0.5	212.6	12.9
Low-medium	131.8	7.0	18.2	1.1	181.5	18.2
Medium-high	81.1	4.9	31.9	1.9	265.4	16.1

[a] Based only on agroclimatic suitability—ratings would be downgraded after allowance for soil conditions.
[b] No production in these areas.

Development Strategy Characterization and Evaluation

This technique can be used to address several related questions: How suited would a specific development strategy be for a given set of locations (including an entire country)? Which of the identified development strategy options would be most suited to a given location? What mix of development strategy options would be needed to achieve a particular goal, and how would they be targeted to match the most suited strategies to the most appropriate locations?

In the ex ante sense used here, strategy evaluation is an iterative, two-stage process.[11] In the first stage, problem diagnosis together with a broader understanding of the current and likely macro context, identifies some preliminary intervention possibilities. In the second stage, these possibilities are evaluated in desk and field studies, the outcome of which often calls for further refinement of promising strategy

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[11] And one that should be properly linked to the problem diagnosis and stakeholder consultation mechanisms depicted in Figure 3.

options. This process is repeated until options that appear most attractive to stakeholders, and feasible and cost-effective from an implementation standpoint, have been identified.

Our concern here is with the potential role of spatial analysis in this evaluation process, and one possibility is to provide analysts and stakeholders with a visual and statistical view of the geographic scope, and a qualitative feel for the intensity, of the impact of a given strategy option. Table 3 presents a structure for characterizing strategy options by identifying conditions that would significantly promote or hinder the implementation of the strategy. The characterization data in such a table is of general utility, but some aspects, e.g., development strategy requirements regarding agricultural potential and physical infrastructure, would be of particular relevance for testing the viability of the strategy from a geographic viewpoint. By building such a table we can identify those variables (or proxies thereof) that have significant spatial dependency, and that can be incorporated into the spatial development strategy characterization schema. This approach focuses the search for appropriate spatial information, and requires analysts to be specific about variables (and appropriate value ranges of those variables) that are most likely to influence the outcome of a proposed strategy. Table 3 suggests that agricultural potential is an important variable conditioning development strategy options for any geographic area. Furthermore, it is often necessary to be specific about the nature of the potential, e.g., upland crops, cash crops, irrigated or rainfed production. Table 4 presents a matrix of the type required (for each location or area) as a reference source when considering the range of agricultural options that could form the basis of a development strategy initiative. The data for such a table can be obtained by a range of methods, from informed expert judgement through to formal modeling. It is important

Table 3 Example framework for characterizing development strategies

Development strategy option	Development strategy requirements/tolerances (e.g., enabling/negating conditions)					
	Agricultural potential	Infrastructure		Demography	Complementary Policies (E, O)[a]	Etc.[b]
		Institutional	Physical			
Low external input	Cassava Maize	Research Extension NGOs		Low population densities		
High external input (intensification*)*	Maize	Extension Short-term credit Land titling	Good market access	Medium-high population densities	Liberalized input markets (E)	
Commercialization (cash crops)	Coffee Citrus	Land titling Long-term credit	All-weather roads Ports	Migrant and seasonal labor	New quota agreement	
Rural non-farm industry		Credit	Roads Education Electrification			
Etc.						

[a] E—essential; O—optional.
[b] See, for example, table 5.
Shaded groups of development-related variables can exhibit high levels of spatial variability.

Table 4 Example framework for rating (biophysical) agricultural potential[a]

Crop	Production system (technology, input mix, management intensity)			
	Low input (Subsistence)	Medium level (Smallholder)	High level (Smallholder)	Commercial
Cereals				
Maize	S3[b]	S2	S1	S2
Millet	S2	S2	S2	n/a
…….				
Livestock				
Rangeland/Grazing	S2	S2	S1	S1
…….				
Perennials				
Coffee	N	N	N	N
…….				
Etc.				

[a] For a given location or specified area.
[b] Suitability Rating: S1–very suitable; S2–suitable; S3–moderately suitable; S4–marginally suitable; N-Unsuitable.

that the agricultural potential be assessed for specific types of land use, that is, specific combinations of products and production systems, since there can be significant differences between the geographic extents not only of areas most suited to the production of, say, sorghum, coffee, and potatoes, but also between areas most amenable to say, predominantly manual versus predominantly mechanized production regimes (e.g., the difficulties of manual cultivation in vertic soils and of mechanization in steeply sloping land). Such data on agricultural potential are often obtainable from ministries of agriculture as a lot of emphasis was given to land evaluation in Sub-Saharan Africa in the 1980s (e.g., national studies supported by FAO in Ethiopia, Kenya, Mozambique, Botswana, and Malawi).

With regard to likely natural resource requirements and impacts, Table 5 presents some ideas about the type of information that would be required in order to bring an explicit resource dimension to development strategy characterization. The table identifies the resource inputs that would be needed if a particular strategy were to be adopted, as well as the potential resource threats the strategy may pose.[12] As with Table 3 (to which Table 5 represents a resource-specific extension), the expectation is that several of the important factors identified will have a spatial component, and therefore, could become part of the spatial (location) evaluation for that specific strategy.

Table 5 Example framework for characterizing resource aspects of development strategies

Development strategy option	Natural resources requirements/impacts	
	Resource needs[a]	Potential resource impacts
Low external input	Organic fertilizer Fuelwood	Soil fertility loss (OM, N, P) Soil erosion on steeper land Forest degradation
High external input (intensification)	Irrigation water	Salinization Fertilizer/pesticide leaching
Commercialization (cash crop)	Irrigation water	Pesticide leaching Pesticide-related health problems of farm workers
Rural non-farm industry		Wastewater quality
Etc.		

Note: This table represents a simple extension of table 3.
[a] Additional to the biophysical factors considered in assessing agricultural potential (e.g., temperature, rainfall and soil).

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[12] Development strategy resource requirements and potential impacts are here considered separately from the use of resource data as a means of estimating agricultural potential.

Summarizing, when designing and evaluating agricultural development strategies, spatial analysis can play an initial role in assessing agricultural potential (as in the first example, in which agricultural potential was proxied by the agroclimatic suitability of maize at low input levels). Agricultural potential and other broader development factors, including those specific to natural resource requirements or impacts, can then be used to characterize each development strategy. Subsequently, these strategy-specific characterization variables and value ranges are matched against location-specific values held in a GIS database and, by this process, a set of strategy “domain” maps can be generated. The geographical scope of each development strategy domain may overlap with those of other strategies, thus delineating geographic areas where a range of strategies may be feasible. After examining these results, each strategy can be accepted, modified, or rejected, in order to build a portfolio of strategies likely to maximize positive outcomes for specific target groups and regions. Within the spatial domains delineated by any selected combination of development strategies, it would be necessary to proceed with more detailed evaluation studies user higher resolution information and related socioeconomic fieldwork, that may well modify initial assumptions made at the macro level.

Example 2: Development strategy characterization and evaluation (East Africa). In this characterization example, three hypothesized development characterization variables; agricultural potential, population density, and a potential market integration index (PMI) are overlaid to delineate a configuration of mutually exclusive geographic domains. These three variables (each in two broad ranges – high and low) were proposed by

Pender, Place and Ehui (1999) as stratification criteria for targeting a range of agricultural development strategies considered appropriate for Ethiopia, Kenya, and Uganda. While Pender et al.'s criteria had been tabulated (see Table 6), they had not been fully quantified nor translated into a spatial (map) representation.

The geographic scope of the spatial dataset compiled for this example encompasses all of Kenya and Uganda, northern Tanzania, and southern Ethiopia. The selection of this coverage was conditioned by the desire to use a new road network database prepared by the World Resources Institute. In keeping with Pender et al., only two classes were defined for the agricultural potential and population density maps (i.e., low-medium, medium-high), but three classes were defined for the PMI map (that was used instead of their "market access" variable). The agricultural potential map was based only on a single agroclimatic variable—water availability—proxied by a length of growing period variable (LGP, one of the two variables used for the agricultural potential map developed for example 1). In this case, an LGP of six months or more was classified as high agricultural potential, and an LGP of five months or less as low (see Figure 5(a)). The cut-off value was selected by visual comparison with a rainfall map since the objective was to match the LGP variable with the 1,000mm rainfall cutoff variable specified by Pender et al. (we preferred to use LGP as a water availability proxy since it takes better account of seasonal rainfall distribution). It is possible, and almost certainly desirable, to significantly improve this agricultural potential definition, both by being more specific in terms of production systems, as well as by including additional conditioning variables and more discriminating value ranges.

Table 6 Possible pathways of development in the East African Highlands

Agricultural potential	Market access	Population density: High	Population density: Low
HIGH	High	*Central Kenya, parts of Western Kenya, Eastern Uganda* - High input cereals - Perishable cash crops - Dairy, intensive livestock - Non-perishable cash crops - Rural nonfarm development	**???**
	Low	*Southwestern Uganda, parts of Western Kenya* - High input cereals - Non-perishable cash crops	*Southwestern Ethiopia* - High input cereals - Non-perishable cash crops - Livestock intensification; improved grazing areas
LOW	High	*Parts of Central Tigray* With irrigation investment: - High input cereals - Perishable cash crops - Dairy, intensive livestock Without irrigation investment: - Low input cereals - Rural nonfarm development	*Parts of Northern Ethiopia* With irrigation investment: - High input cereals - Perishable cash crops - Dairy, intensive livestock Without irrigation investment: - Low input cereals - Livestock intensification; improved grazing areas - Woodlots - Rural nonfarm development
	Low	*Parts of Northern Ethiopia?* - Low input cereals - Limited livestock intensification - Emigration	*Much of Northern Ethiopia* - Low input cereals - Livestock intensification; improved grazing areas

Source: Pender, Place and Ehui (1999).

Agricultural potential: High ≥ 1,000mm per annum, Low < 1,000m per annum rainfall
Population density: High ≥ 175 persons/ha, Low < 175 persons/ha
Market access: High > 100km, Low ≤ 100km distance

Figures 5(b) to 5(d) illustrate crop-specific, agroclimatic suitability maps (based on an interpretation of temperature and LGP variables). Figure 5(b) presents an aggregated map for all maize ecotypes, while figures 5(c) and 5(d) show the sub-areas within which lowland and highland ecotypes have high production potential.[13] If commodity-specific strategies were being evaluated, such more detailed interpretations could be substituted for the generic agricultural potential map (5(e)) used in this example. The population map (Deichman 1998) depicts population density for 1990 by third level administrative unit. The map shown in Figure 5(f) was reclassified for the purposes of this analysis into only two classes; low to medium population density (less than 175 persons per square km.), and medium to high population density (175 or more persons per square km). This corresponds exactly with the Pender et al. cutoff for this variable. The final variable, PMI, is based on an algorithm reported by Deichmann (1997), and has been previously used in the generation of regional population density maps (Tobler et al. 1995). For any location the PMI represents an accumulated index of the travel time to the nearest n target locations (markets), weighted by the population of each market location. “Nearest” is assessed in terms of lowest travel time across a transport network (including off-road travel time to reach the closest network point), and in this example the nearest three target locations were used to build the index. Market locations were defined as gazetted settlements having a population of greater than 5,000 inhabitants. Travel times along any segment of the transport network depend upon travel speed, and speed is conditioned by the nature of the surface, e.g., 60 km/h on a surfaced road, 25km/h on a dirt road,

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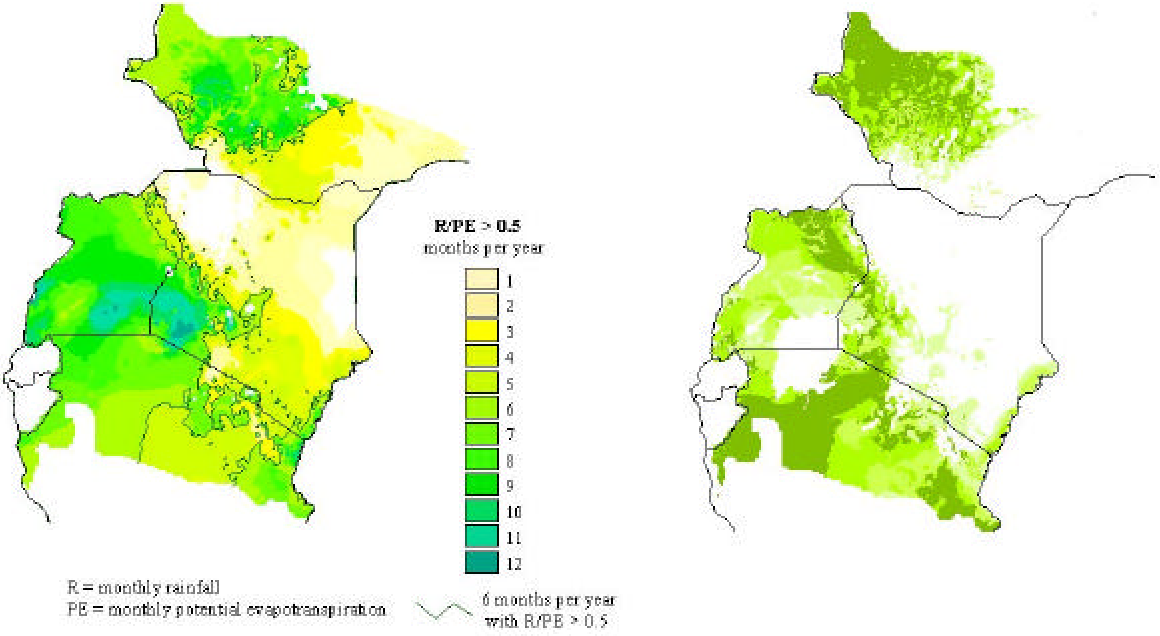
[13] And Figure 13 in the Appendix describing the use of soil information in Sub-Saharan Africa shows a complementary interpretation of the agroedaphic suitability of maize.

Figure 5 : Spatial Data in Strategy Characterization and Evaluation

Options for Representing Rainfed Agricultural Potential

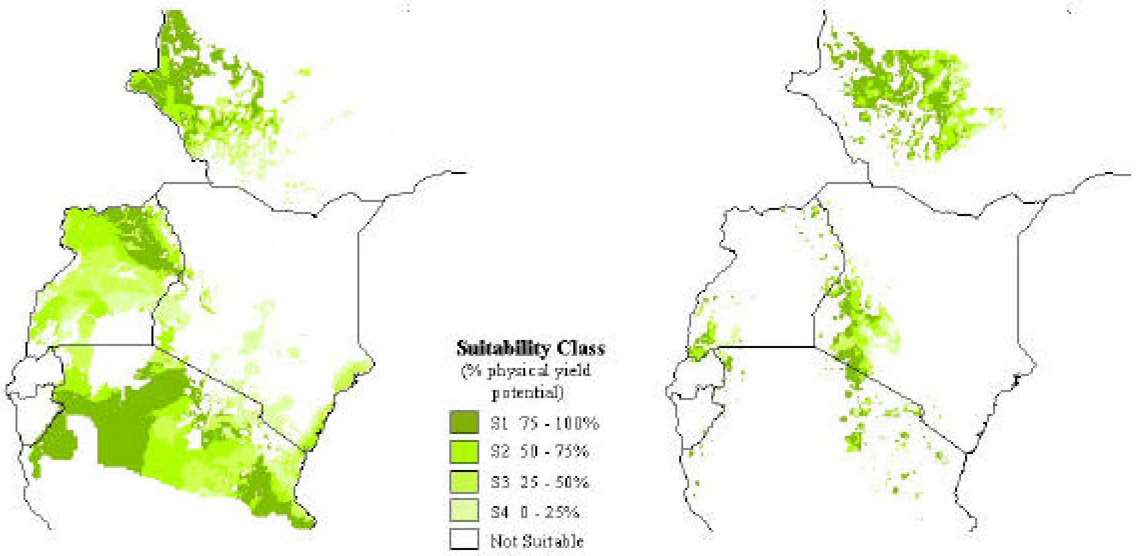
(a) Length of growing period

(b) Maize agroclimatic suitability



(c) Lowland maize agroclimatic suitability

(d) Highland maize agroclimatic suitability

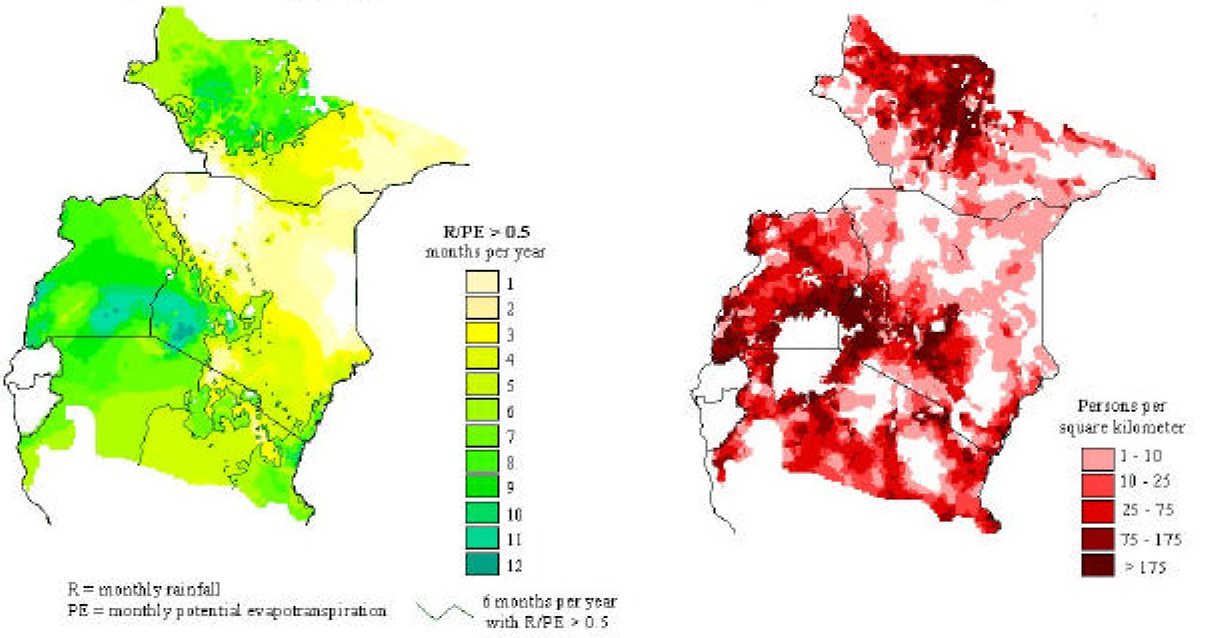


Source: (a) - based on SCT data (Corbett and O'Brien 1997); (b,c & d) - authors' estimates based on Kenya rule set (Kassam et al. 1991) and SCT Database (Corbett and O'Brien 1997)

Scale: 1: 26,000,000

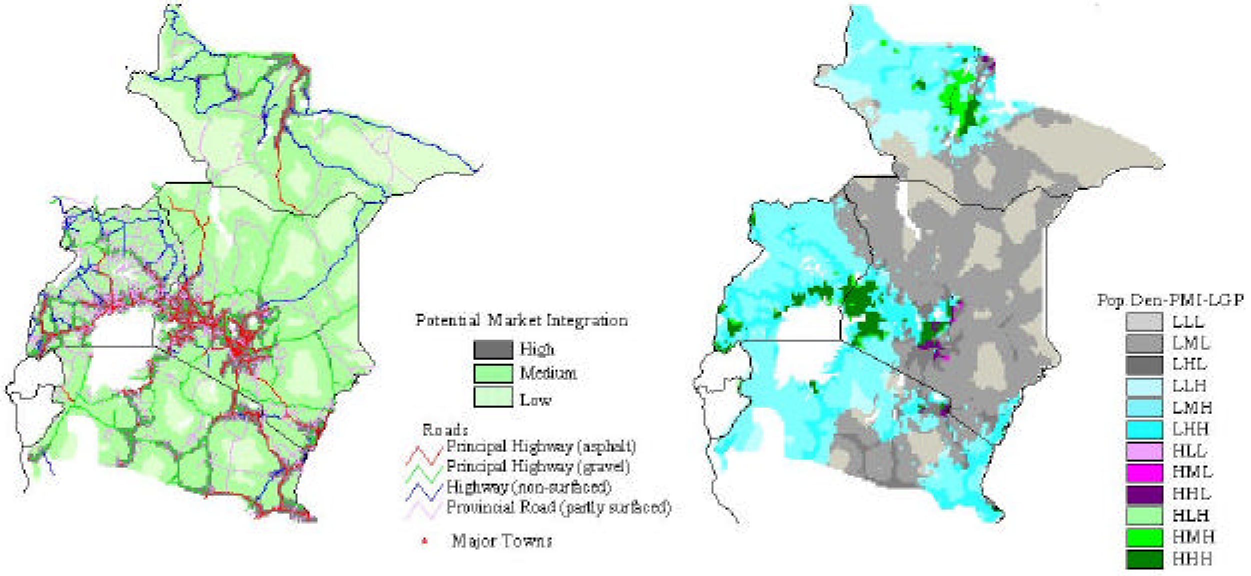
Figure 5 : Spatial Data in Strategy Characterization and Evaluation (cont.)

Determination of Development Strategy Domains



(e) Rainfed agriculture potential (water availability proxy)

(f) Population density - 1990 (third level admin units)



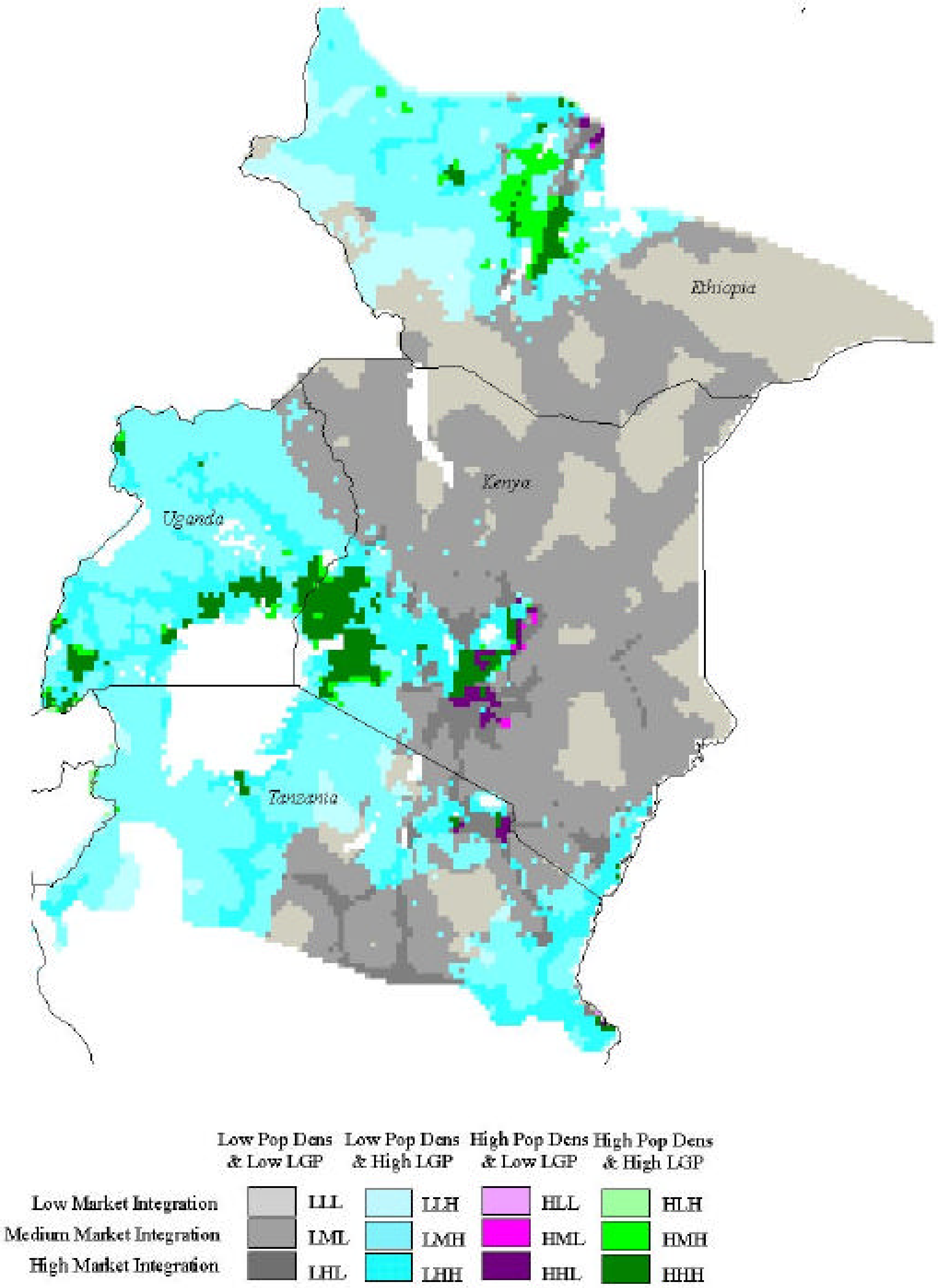
(g) Potential market integration

(h) Preliminary development strategy domains

Source: (e) - based on SCT data (Corbett and O'Brien 1997); (f) Uwe Diechmann, UNEP-GRID, Eros Data Center 1997; (g) World Resources Institute (1997)

Scale: 1: 26,000,000

Figure 5(h) : Preliminary Development Strategy Domains



Scale: 1: 12,000,000

and 7 km/h walking on a level path. Figure 5(g) shows the resultant map of the PMI variable reclassified into just the three ranges used in this example; No (market integration), low to medium, and medium to high. For the sake of clarity, only major cities, and not all settlements used in the analysis, are shown on the map. The cutoff value of the index between low and high was approximated visually to Pender et al.'s criteria of 100km distance to market, but the two measures do not correspond well since the PMI is much richer in its information content.

The intersection of the three input themes yielded a map showing 12 strategy domains (two agricultural potential classes, by two population density classes, by three PMI classes) as well as a cross-tabulation of the corresponding domain extents (Table 7).

The table shows that just under one third of the area examined falls in the category L(ow)-L(ow)-L(ow) for agricultural potential, population density, and PMI respectively, and less than three percent into the category H(igh)-H(igh)-H(igh). Of potential development interest are areas such as H-L-H, representing 8.8 percent of the mapped area, where there would appear to be the possibility for expanded agricultural output (based on the in-migration of labor) with minimal infrastructure (roads) investment, although clearly there are many omitted variables, such as the prevalence of pests and diseases, that could help explain the apparent status quo. Data and method constraints should always be kept in mind and certainly one major limitation in this example is the highly aggregated (small number of) classes used for each variable. It appears worthwhile to further explore how well the PMI variable may serve as a proxy not only for a range of transport and other transactions costs, but also for technology diffusion and public services.

Table 7 Preliminary estimation of development strategy domains (areas in square kilometers)

Country	Low population density[a]						High population density[a]					
	Low PMI	Med PMI	High PMI	Low PMI	Med PMI	High PMI	Low PMI	Med PMI	High PMI	Low PMI	Med PMI	High PMI
	Low agricultural potential[b]			High agricultural potential			Low agricultural potential			High agricultural potential		
Ethiopia	119,736	81,115	4,394	47,224	114,203	16,154	174	87	792	174	14,049	6,585
Kenya	104,818	337,059	31,980	100	26,831	33,090	-	910	5,050	-	2,830	26,332
Tanzania	27,177	72,901	21,428	19,344	163,073	48,408	98	-	1,287	98	196	1,986
Uganda	97	17,115	-	387	120,783	44,504	-	-	-	97	3,421	13,598
TOTAL	251,827	508,189	57,802	67,054	424,890	142,155	272	997	7,129	368	20,496	48,501

Notes: PMI (Potential Market Integration) is an index. Ethiopia and Tanzania are only partially included (see Figure 5e).

[a] Low population density < 175 person/km^2, high population density ≥ 175 person/km^2.

[b] Water availability (P/ET > 0.5) in months per year. High ≥ 6 months, Low < 6 months.

Table 8 Preliminary estimation of total population within strategy domains (thousands)

Country	Low population density[a]						High population density[a]					
	Low PMI	Med PMI	High PMI	Low PMI	Med PMI	High PMI	Low PMI	Med PMI	High PMI	Low PMI	Med PMI	High PMI
	Low agricultural potential			High agricultural potential			Low agricultural potential			High agricultural potential		
Ethiopia	544	935	404	1,124	7,084	1,892	44	12	166	27	3,364	3,081
Kenya	60	2,627	1,790	22	1,156	4,181	0	87	2,069	0	482	8,162
Tanzania	95	1,796	1,604	80	5,743	4,183	126	0	335	6	6	1,234
Uganda	0	185	0	15	5,510	5,044	0	0	0	15	6,53	4,470
TOTAL	701	5,544	3,799	1,242	19,494	15,301	170	99	2,571	49	4,506	16,948

Note: PMI (Potential Market Integration) is an index. Agricultural potential: Water availability (P/ET > 0.5), Months per year, High ≥ 6 months, Low < 6 months.

[a] Low population density < 175 person/km^2, high population density ≥ 175 person/km^2.

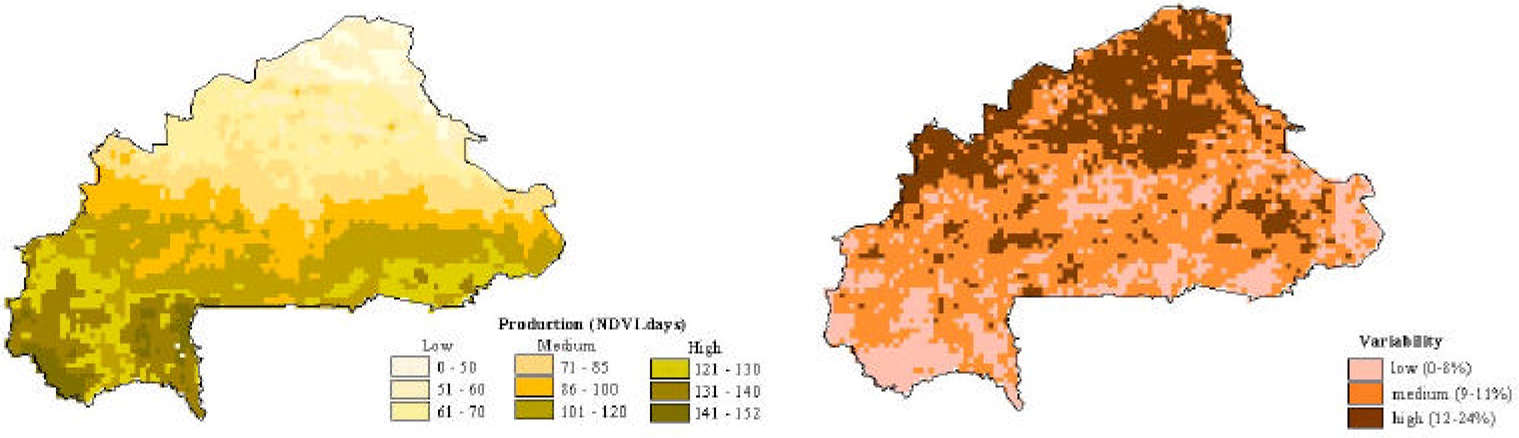
As an example of one of the many ways in which development domains could be analyzed and interpreted, Table 8 presents an estimation of the total population in each domain as estimated using the GIS. Comparison of Tables 7 and 8 reveals, for example, that within the low population density domains there is 29 percent more land with low agricultural potential than with high potential, but that there are almost four times as many people living in the high potential lands (population densities of 12.3 and 56.8 persons/km^2 perspectively). Furthermore, population densities range from 2.8 persons/km^2 to 350 persons/km^2 in the polar low-low-low and high-high-high domains.

Example 3: Strategy characterization and evaluation (Burkina Faso). This example extends the set of spatial stratification variables used in example 2 and shows an alternative method for constructing the agricultural potential map using satellite data from NOAA's Advanced Very High Resolution Radiometer (AVHRR). The AVHRR data has been interpreted onto an 8km by 8km grid for the Sahelian region as an index of vegetative production (the Normalized-Difference Vegetation Index, or NDVI). The data set, described in Los, Justice, and Tucker (1994) spans the period 1981-1991 and grid values of both average annual NDVI as well as its inter-annual variability were extracted for Burkina Faso. These images were classified and are presented in Figures 6(a) and 6(b). To construct the agricultural potential surface the two classified images were intersected (Figure 6(c)) and reclassified to depict combinations of level and variability that were considered (by the authors) to represent three broad classes of overall agricultural potential (Figure 6(d)). In a real-world analysis much more careful attention would be given to making such classifications based on local knowledge and field data.

Figure 6 : Burkina Faso - Determining a measure of agricultural potential

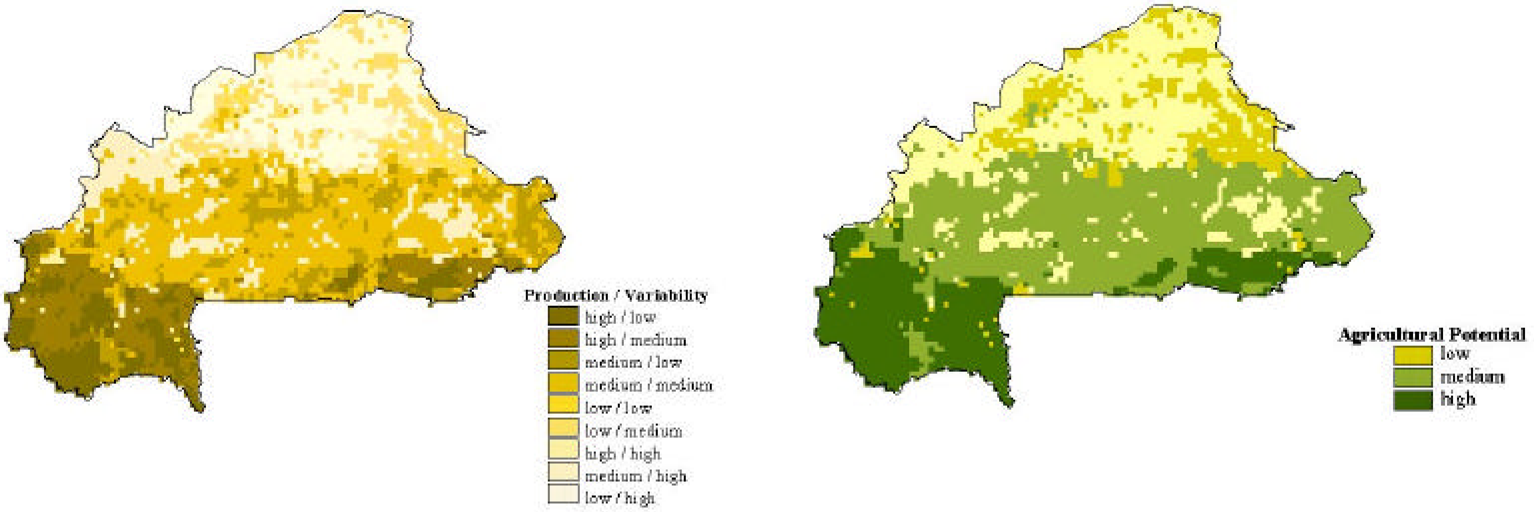
(a) Average annual production

(b) Year to year variability in production



(c) Production / Variability Intersection

(d) Agricultural Potential
(based on production / variability matrix)



Source: Author's classifications based on satellite derived NDVI days from NOAA's AVHRR data for 1981-1991 (Los et al. 1994)

Scale 1:10,000,000

The final image, even though aggregated into only three classes, shows some significant spatial variability that is not apparent from looking at long-term average precipitation or LGP maps alone. Compared to the aridity index proxy used in example 1, the NDVI-based agricultural potential is significantly more precise because it represents location-specific integration of both climate and soil conditions.[14] A limitation of coarse resolution NDVI is that it is strictly a "greeness" indicator and does not differentiate reliably between different types of vegetation, e.g., forest, grassland and cropland. However, other global, regional and national sources of information on land cover and land use could be used to further fine-tune the agricultural areas.

The Burkina Faso population density and PMI maps (Figures 7(b) and 7(c)) are taken from the same sources as in example 2. The new information included in this example is Crop Use Intensity (CUI), a measure of the percentage of land area under cultivation. The CUI variable is based on interpretation of Landsat imagery together with groundtruthing survey data from the early 1990s. The original dataset is classified into five levels of CUI ranging from low, 0-5 percent area cultivated, to high, greater than 70 percent cultivated (Dalsted and Westin 1996). By intersecting the four maps of agricultural potential, population density, PMI and CUI (Figures 7(a)-7(d) respectively) an illustrative development strategy domain map was generated for Burkina Faso.

Two partial views of that final map are presented in Figures 8(a) and 8(b). Figure 8(a) highlights the areas having low to medium agricultural potential, but within which

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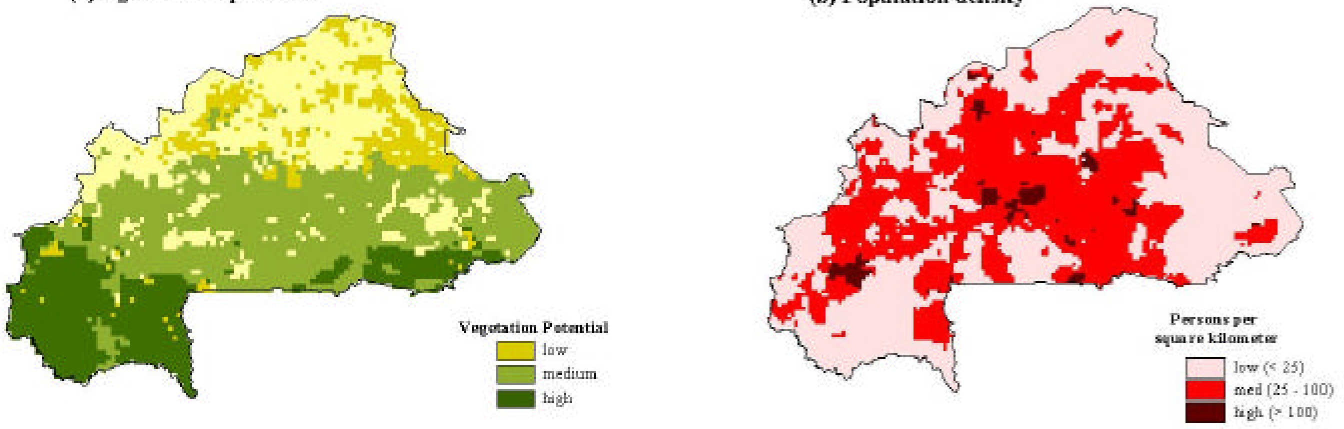
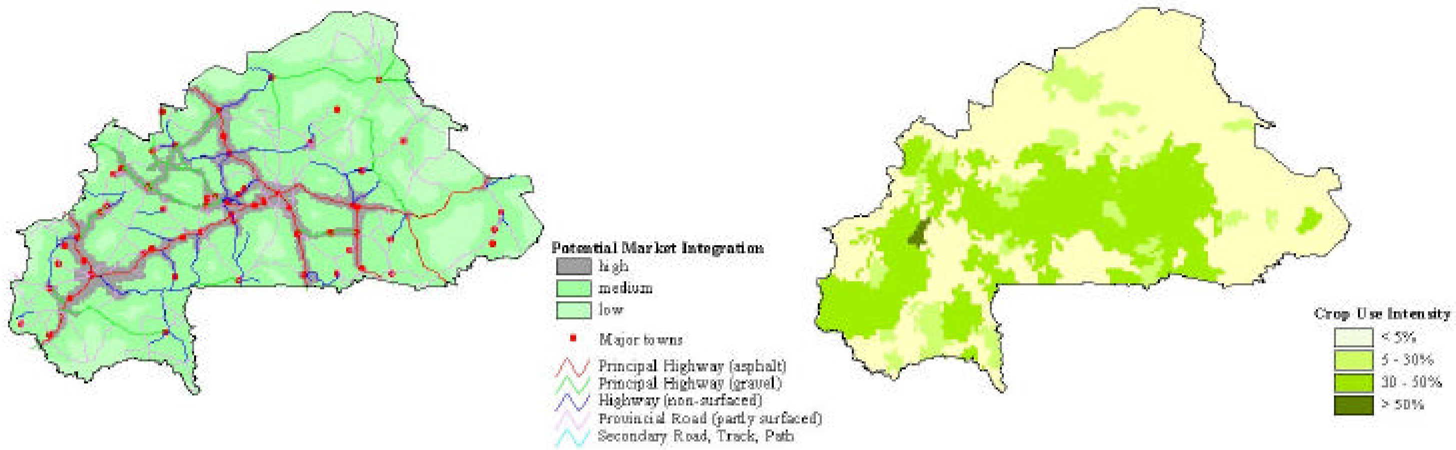
[14] Noting that the rainfall and potential evapotranspiration surfaces used to derive the aridity index are based on the spatial extrapolation of point (climate station) data. The climate station network in most rural areas of Burkina Faso is likely to be very much more sparse than the spatial resolution of the AVHRR observations.

Figure 7 : Burkina Faso - Determination of development strategy domains



(a) Agricultural potential

(b) Population density



(c) Potential market integration

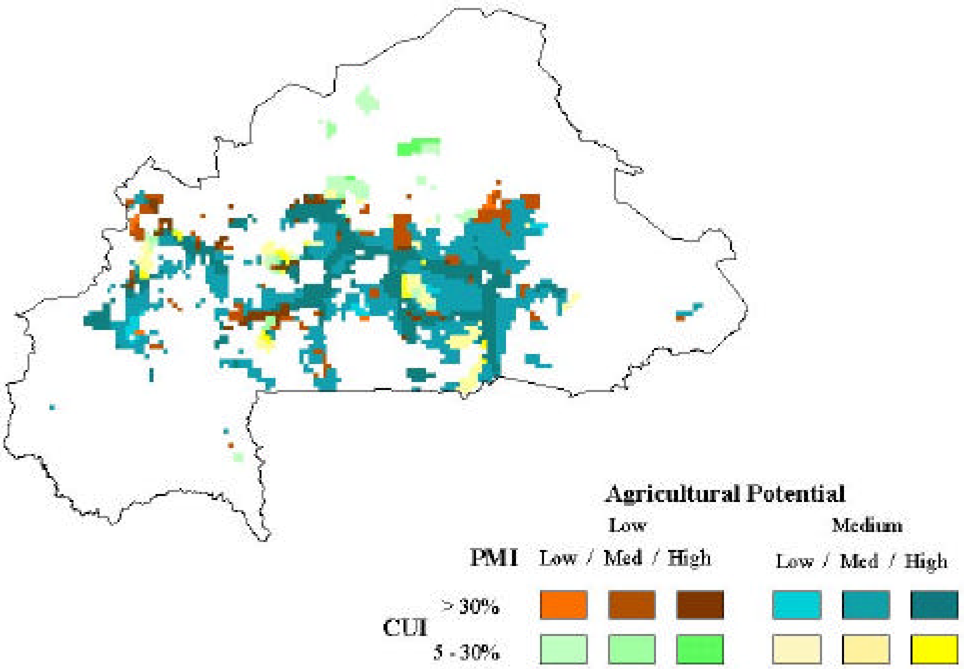
(d) Crop use intensity (CUI)

Source: (a) based on interpretation of NOAA's AVHRR satellite data (Los et al. 1994);
(b) Uwe Deichmann UNEP-GRID, Eros Data Center 1997; (c) WRI (1997); (d) USGS/EDC (1992)

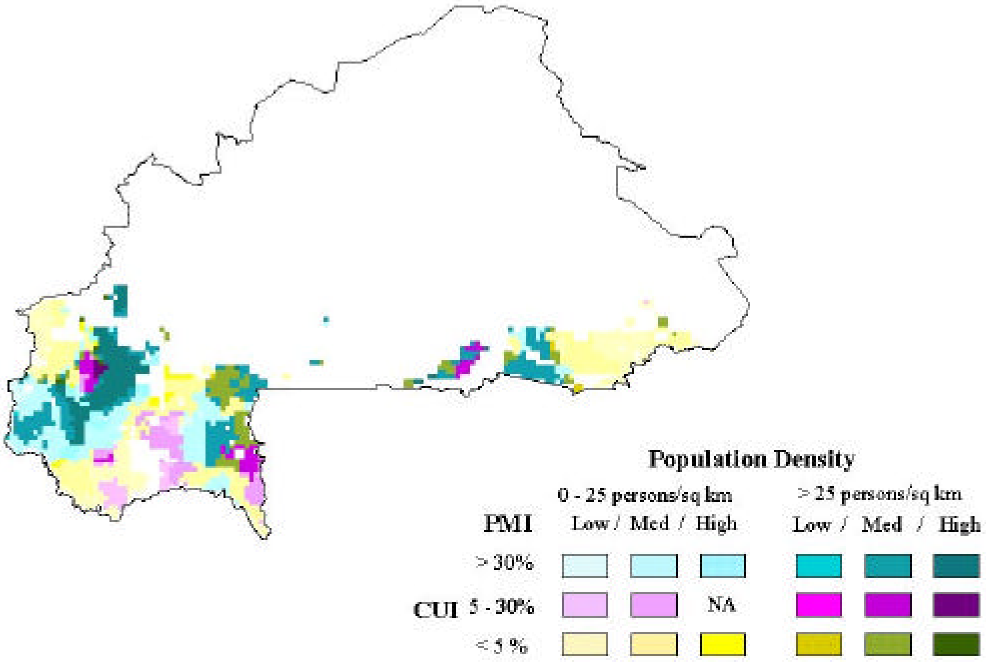
Scale 1:10,000,000

Figure 8 Burkina Faso: Preliminary Development Strategy Domains

(a) Populated areas with low to medium agricultural potential



(b) Areas with high agricultural potential



there is both significant actual cultivation and medium to high population density. In such areas there is clearly scope for high social returns to investment that could raise the productivity of agriculture – because agriculture is extensively practiced, and because there are many people (both as producers and consumers). Such areas may benefit from public investment policies that, for example, target agricultural R&D to address the technological problems faced, and that facilitate development of input markets and small-scale credit schemes. In areas where market integration is limited (low PMI) the existing significant presence of both people and agriculture might suggest specific investment in road infrastructure might be worthwhile. Clearly, there will also be a range of institutional and micro issues that warrant attention, but these would need to be identified through parallel assessments.

In the high agricultural potential areas (Figure 8(b)) other development issues can be addressed. One is the extent to which high potential areas may be currently "underutilized" (low CUI) from an agricultural perspective. There may be very good reasons for this, such as the existence of forests, conservation areas, wildlife parks, and so on, but this situation could also be indicative of potentially modifiable constraints to agricultural expansion and intensification, such as endemic human and animal diseases, regional insecurity, or severe lack of infrastructure.

In all cases, spatial stratification coupled with appropriate local knowledge and interpretation can provide analysts and decisionmakers with relatively low-cost insights into development constraints and opportunities, how significant they may be, and how complex they may be to address (for example, are problems specific to a few contiguous areas or are they fragmented across much larger areas). Table 9 presents the full summary of the area extent within each domain of this protoype spatial stratification for Burkina Faso, but other variables, and other boundary values would probably need to be tested in a formal analysis. And, as in the previous example, the strategy domains can be characterized in terms of, say, total population (see Table 10), area of agricultural land (see Table 11), road density, or any other relevant indicator to support further assessment of their value for development planning purposes.

Table 9 Total population within each preliminary development strategy domain for Burkina Faso (thousands)

Crop use intensity (CUI)	Low PMI	Medium PMI	High PMI	Low PMI	Medium PMI	High PMI	Low PMI	Medium PMI	High PMI
	Low agricultural potential			Medium agricultural potential			High agricultural potential		
CUI in low population density									
Zero – 5 percent	208	368	27	78	192	14	36	120	9
5 - 30 percent	12	105	9	5	17	3	10	30	NA
30 - 50 percent	7	50	14	9	164	31	12	156	26
> 50	NA	NA	NA	7	3	NA	NA	NA	NA
TOTAL	227	523	50	99	376	48	58	306	35
CUI in medium population density									
Zero – 5 percent	179	720	160	21	431	139	7	159	6
5 - 30 percent	36	167	35	3	188	54	3	88	0
30 - 50 percent	18	229	130	40	1,161	892	2	381	157
> 50	2	NA	NA	5	10	NA	NA	NA	NA
TOTAL	235	1,351	325	69	1,790	1,085	12	628	163
CUI in high population density									
Zero – 5 percent	46	53	39	NA	19	23	NA	8	5
5 - 30 percent	NA	NA	NA	NA	NA	NA	NA	23	38
30 - 50 percent	NA	NA	NA	NA	184	1,062	NA	48	223
> 50	NA	NA	NA	NA	NA	NA	NA	NA	NA
TOTAL	46	53	39	NA	203	1085	NA	79	266
CUI across all areas									
Zero – 5 percent	433	1,141	226	99	642	176	43	287	20
5 - 30 percent	48	272	44	8	205	57	13	141	38
30 - 50 percent	25	279	144	49	1,509	1,985	14	585	406
> 50	2	NA	NA	12	13	NA	NA	NA	NA
TOTAL	508	1,692	414	168	2,369	2,218	70	1,013	464

Note: Population density is defined as: Low: < 25 person/km^2; medium: 25-100 person/km^2; and high > 100 person/km^2. PMI (Potential Market Integration) is an index. CUI (Crop Use Intensity) is a percentage of area cultivated. Agricultural potential is an index based on interpretation of NOAA's AVHRR satellite data.

Table 10 Total population within each preliminary development strategy domain for Burkina Faso (thousands)

Crop use intensity (CUI)	Low PMI	Medium PMI	High PMI	Low PMI	Medium PMI	High PMI	Low PMI	Medium PMI	High PMI
	Low agricultural potential			Medium agricultural potential			High agricultural potential		
CUI in low population density									
Zero – 5 percent	208	368	27	78	192	14	36	120	9
5 - 30 percent	12	105	9	5	17	3	10	30	NA
30 - 50 percent	7	50	14	9	164	31	12	156	26
> 50	NA	NA	NA	7	3	NA	NA	NA	NA
TOTAL	227	523	50	99	376	48	58	306	35
CUI in medium population density									
Zero – 5 percent	179	720	160	21	431	139	7	159	6
5 - 30 percent	36	167	35	3	188	54	3	88	0
30 - 50 percent	18	229	130	40	1,161	892	2	381	157
> 50	2	NA	NA	5	10	NA	NA	NA	NA
TOTAL	235	1,351	325	69	1,790	1,085	12	628	163
CUI in high population density									
Zero – 5 percent	46	53	39	NA	19	23	NA	8	5
5 - 30 percent	NA	NA	NA	NA	NA	NA	NA	23	38
30 - 50 percent	NA	NA	NA	NA	184	1,062	NA	48	223
> 50	NA	NA	NA	NA	NA	NA	NA	NA	NA
TOTAL	46	53	39	NA	203	1085	NA	79	266
CUI across all areas									
Zero - 5 percent	433	1,141	226	99	642	176	43	287	20
5 - 30 percent	48	272	44	8	205	57	13	141	38
30 - 50 percent	25	279	144	49	1,509	1,985	14	585	406
> 50	2	NA	NA	12	13	NA	NA	NA	NA
TOTAL	508	1,692	414	168	2,369	2,218	70	1,013	464

Note: Population density is defined as: Low: < 25 person/km^2; medium: 25-100 person/km^2; and high > 100 person/km^2. PMI (Potential Market Integration) is an index. CUI (Crop Use Intensity) is a percentage of area cultivated. Agricultural potential is an index based on interpretation of NOAA’s AVHRR satellite data.

Table 11 Crop use intensity for each preliminary development strategy domain for Burkina Faso

Crop Use Intensity (CUI)	Low PMI	Medium PMI	High PMI	Low PMI	Medium PMI	High PMI	Low PMI	Medium PMI	High PMI
	Low agricultural potential			Medium agricultural potential			High agricultural potential		
		(percentage)			*(percentage)*			*(percentage)*	
Low	1-7	3-12	9-22	2-9	9-20	15-28	3-12	12-25	20-35
Medium	4-13	7-17	11-23	20-36	20-36	24-42	6-17	18-35	29-48
High	0-5	0-5	0-5	0	27-45	28-47	0	20-39	26-46
TOTAL	1-8	4-14	10-22	4-12	16-30	23-41	3-12	14-29	26-44

Note: PMI (Potential Market Integration) is an index. CUI (Crop Use Intensity) is a percentage of area cultivated. Agricultural potential is an index based on interpretation of NOAA’s AVHRR satellite data.

Benchmark Sites and Extrapolation Domains

This is a relatively simple application in which a specific location (the benchmark location), known to have some desirable properties is characterized, and those characteristics are used as the basis of a GIS search to locate similar (analogous) locations. There are many reasons why a benchmark location could have important characteristics that warrant searching for elsewhere. In our context, the most likely benchmark locations would be those where certain strategies have been successful, and the hope would be that this procedure could identify other locations where such interventions may have the same favorable outcome. The problem, common to all characterization endeavors, is to select the most relevant and complementary set of characterization variables. Once those variables have been identified (and presuming we have, can obtain, or can approximate data for their spatial representation), we extract their value ranges at the benchmark location from the GIS database. Those (user determined) variables, and (computer determined) value ranges create the characterization schema for the benchmark site which can then be used in a subsequent GIS operation to locate all other similar areas within a specific geographic extent.

Example 4: Spatial extrapolation (East Africa). Using the same variables as for example 2 (agricultural potential, population density, and potential market integration - PMI) the district of Machakos was selected as a benchmark location and the GIS was used to determine the range of values of the three variables within that district. On the basis of that determination, other locations (in this case third level administrative units) were examined within the same geographical extent as example 2 (i.e., omitting southern

Tanzania and northern Ethiopia) in order to find like areas. The output of this search is shown in Figure 9, and highlights the relatively unique nature of the Machakos district in the early 90s. From a development perspective it would be most interesting to undertake this type of analysis based on the characteristics of Machakos areas at different stages of its documented degradation and rehabilitation, or by constructing characterization variables that reflect the integration of human activities over time.

It should be noted that there are other, more sophisticated methods of "automated" site characterization and extrapolation, primarily the use of cluster analysis (see Wood and Pardey 1998), but the basic sequence of operations remains as described above.

3. CONCLUSIONS[15]

The notion that spatial perspectives provide significant benefits to policy analysts and others is based on evidence that rural development opportunities are affected by spatial patterns and processes related to the environment, demography, and infrastructure. Moreover, many "non-spatial" policy, market, and institutional variables exhibit spatial aspects that can be taken into account.[16]

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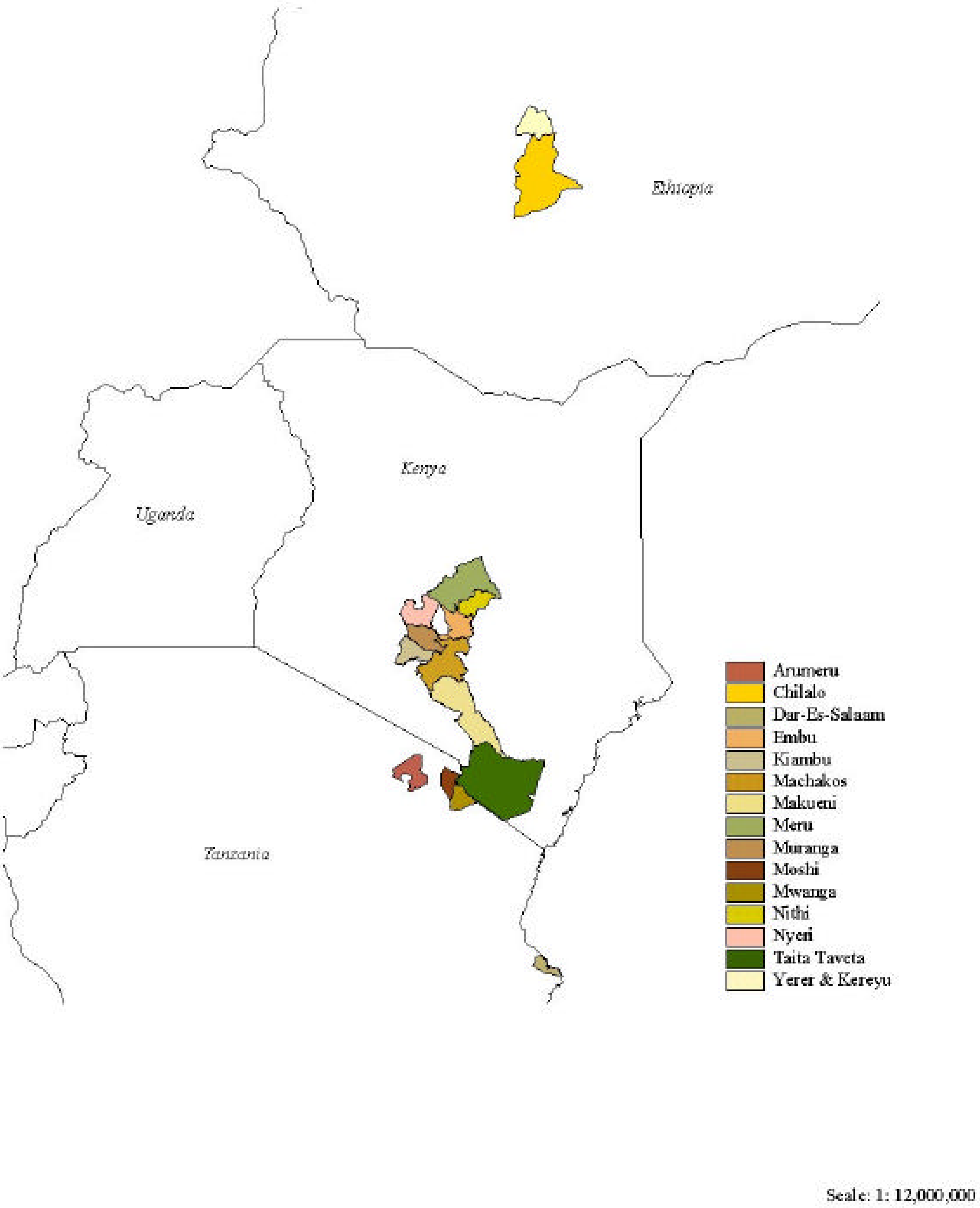
[15] Some separate conclusions regarding data aspects of strategic assessment at a regional scale are given in the appendix (section3).

[16] In reality, few of the measurable variables with which we are concerned are truly "non-spatial." Policy variables and household data, are oft quoted examples of non-spatial data. But policies, e.g., taxes, subsidies, quotas, and so on, have a spatial limit of validity such as a country boundary and, *at a different scale*, most households can be located spatially, even if the location changes in time (such as with transhumance).

Figure 9 : Spatial Extrapolation to Analogous Areas

Administrative Areas Like Machakos
(based on Agriculture Potential, Population Density and PMI)



Formulating good development strategies is a complex matter. One of the complexities is the dynamic interaction among natural and human-induced factors and the stocks and flows of natural and other resources. Obtaining an improved vision, literally and metaphorically, of such interactions can foster improved approaches to policy formulation, not only by the existence of a geographically referenced universe, but also because geographical information systems (GIS) support the analytical integration of spatial and (seemingly) non-spatial data. The spatial framework can be catalytic by providing both a common focus for multidiscipline inputs to designing and testing development strategies, as well as common formats for the integration of multi-discipline information. This framework presents opportunities for time and cost savings in design and analysis, and offers considerable scope for shaping more effective strategy options. This is particularly so if a spatial structure can serve to make the policy process more understandable to non-specialists and, by this means, make the process more accessible to a greater range of stakeholders. With these considerations in mind we have proposed bringing an explicit spatial dimension to the procedures by which problems are identified and diagnosed, strategies designed and tested, and knowledge is extrapolated from local experience.

With regard to the specific challenge of developing a characterization schema for the fragile lands of Sub-Saharan Africa in the context of designing improved development strategies, we have expressed several reservations. Firstly, the term “fragile lands,” and its various definitions, appear inadequate to capture the broad range of development issues that underlie the concern for its characterization. We interpret that significant concern to be the search for development strategies (policy instruments, institutions, and technologies) that contribute to conserving, and perhaps improving, the long-term productive capacity of natural resources while satisfying the needs of current populations. From this development policy perspective we have suggested that "the suitability of a *location* to support specific economic activities over time" rather than land fragility would be a more appropriate focus. We consider that human-induced changes in suitability are brought about by the cumulative impact of a host of biophysical and socioeconomic factors, the scope and relative importance of which depends upon the precise nature of the economic activities (in our case, agricultural production activities) involved. We, thus, conclude that a generic characterization schema would be extremely difficult to conceive, limited in its practical value and, perhaps above all, unnecessary. Rather we recommend investment in programs and methods that foster the build-up of human and technical capacity to generate problem-specific characterization schema that are certain to change as our databases, analytical tools, and fundamental understanding of development processes and outcomes improve.

The basic contention of this paper has been that developing the capacity to acquire, generate, manage and interpret spatial information, and using it creatively in the strategy development process would focus, accelerate, and enrich that process, and ultimately improve the likelihood of favorable social and environmental outcomes. The paper sets out some ambitious, but achievable, ideas about how methods not traditionally embraced by economists (who are normally among the closest to the policy process) could be used to support and improve strategy design and development. The visual presentation of data in spatial formats, in and of itself, can bring a new perspective on agricultural and resource-related issues. An overview of the relative spatial distribution of key variables may offer some insights into causality, as well as point to issues of data resolution and quality. Most importantly, the approach offers a geographically-focused perspective of the likely feasibility and attractiveness of specific development options in agriculture - an activity whose success is often critically dependent on location-specific factors.

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APPENDIX: A REGIONAL OVERVIEW OF CLIMATE, SOIL, AND TERRAIN CONDITIONS AND DATASETS FOR SUB-SAHARAN AFRICA

Section one identified climate, soil, and terrain as key biophysical determinants that condition both the suitability of land for agricultural use, as well as its likely susceptibility to degradation as a consequence of that use. Here we briefly review the range of climate and soil conditions encountered in Sub-Saharan Africa and the regional datasets available to describe them. We place particular emphasis on the amount and variability of annual rainfall, and the nature and extent of soil limitations.

RAINFALL[17]

Over 60 percent of the African continent is semi- to hyper-arid, drought-prone land (UNSO 1997). This fact has been underscored during the past 20 to 30 years in which widespread drought conditions have persisted over the Sahel (defined as the area ten to 20 degrees north, and west of ten degrees east) (Nicholson 1993). The Sahel receives most of its moisture from the south-west, monsoonal flow off the tropical Atlantic and the Sahelian droughts are linked to anomalous sea surface temperatures (SST) over the tropical Atlantic Ocean (Lamb and Peppler, 1992). Over East Africa (about ten degrees south to five degrees north, and east of 26 degrees east), rainfall is influenced by both the Indian and Atlantic Oceans giving rise to the possibility of two distinct growing seasons. In El Niño years, rainfall tends to be below average over the sub-Sahelian region (five to 20 degrees north) and southern Africa (south of ten degrees south), and above average in East Africa (Dai et al., 1997; Nicholson and Kim, 1997).

Annual Rainfall Patterns and Seasonal Variations

Figure 10(a) shows the broad geographic patterns of mean annual precipitation together with their standard deviations for the 1950-1979 period (data from Shea 1986). Over the sub-Sahelian region annual rainfall decreases northward from approximately 1,500mm, around six degrees north, to about ten to 20 mm around 20 degrees north, while in Central Africa annual rainfall exceeds 2,000mm. Over Ethiopia and Somalia, rainfall decreases rapidly eastward. In southern Africa (including Namibia, Botswana, and South Africa), annual rainfall decreases sharply southward to southwestward from about 700mm around 20 degrees south, to about 100mm in western South Africa. The mountain ranges in southern Namibia (elevation greater than 1,500m) and western Ethiopia (elevation greater than 2,000m) contribute to the steep rainfall gradients over the

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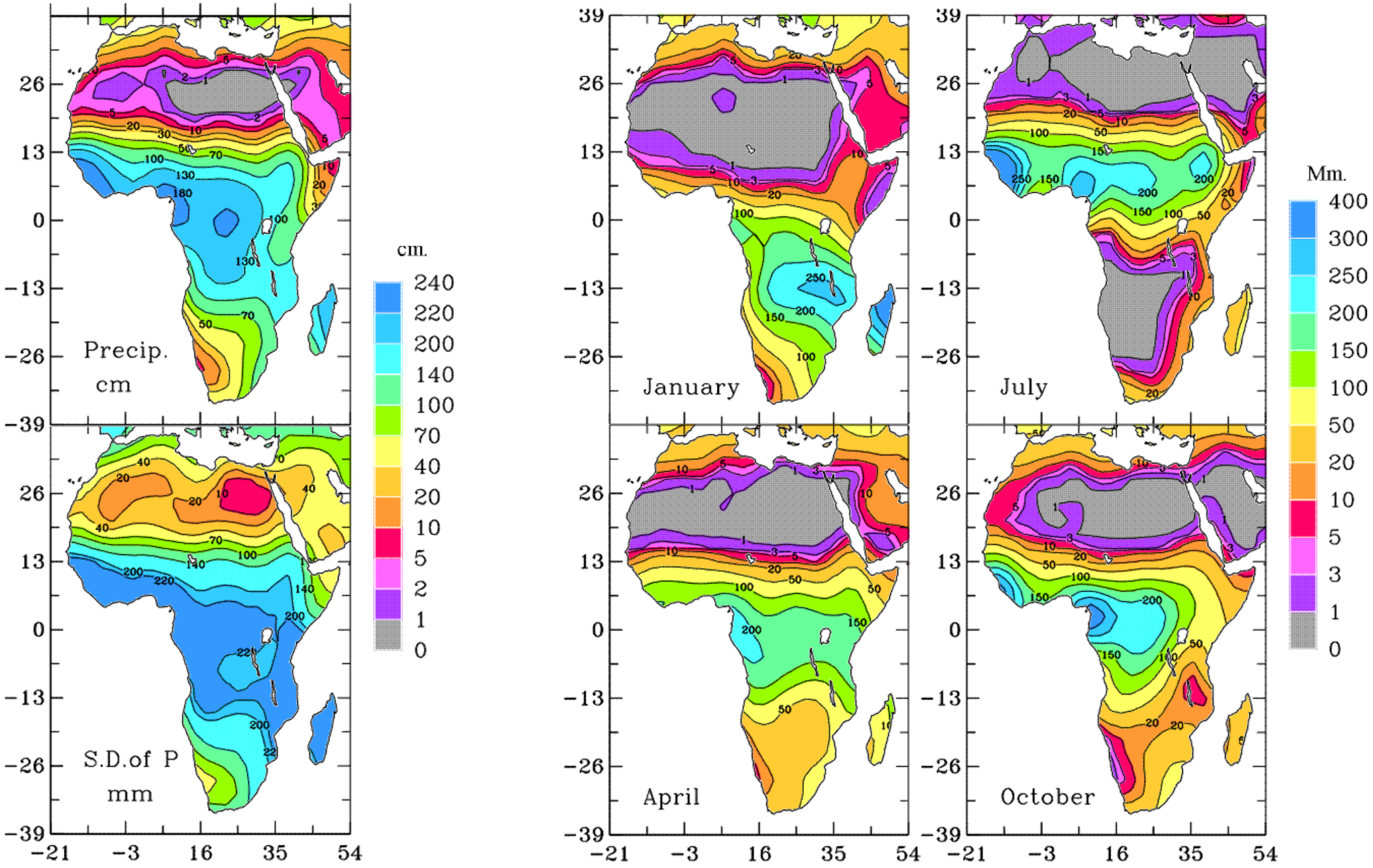
[17] Our discussion here draws on rainfall data compiled to emphasize temporal variability since this is a major biophysical factor conditioning the vulnerability of agricultural production established at a given location. Other datasets exist, of which the monthly, long-term average climate surfaces included in the Spatial Characterization Tool CDs (Corbett and O’Brien 1997) are probably the most readily available and have good spatial resolution. The SCT climate database was used in the worked examples since temporal (multi-year) aspects were not considered.

Figure 10: Climatological Precipitation: Mean, Standard Deviation and Seasonal Variation, 1950-79 (Shea, 1986)



(a) Annual Rainfall: mean and standard deviation

(b) Seasonal rainfall patterns

Source: Adapted from Dai et al. 1997

two regions, while much of the rest of the Sub-Saharan region is relatively flat. The spatial patterns of the rainfall standard deviation (SD) are similar to those of the mean rainfall in that where mean annual rainfall is low, the SD tends to be higher. The SD is about ten to 20 percent of the mean rainfall over Central Africa and increases to 20 to 40 percent of the mean over the sub-Sahelian region, East Africa and southern Africa.

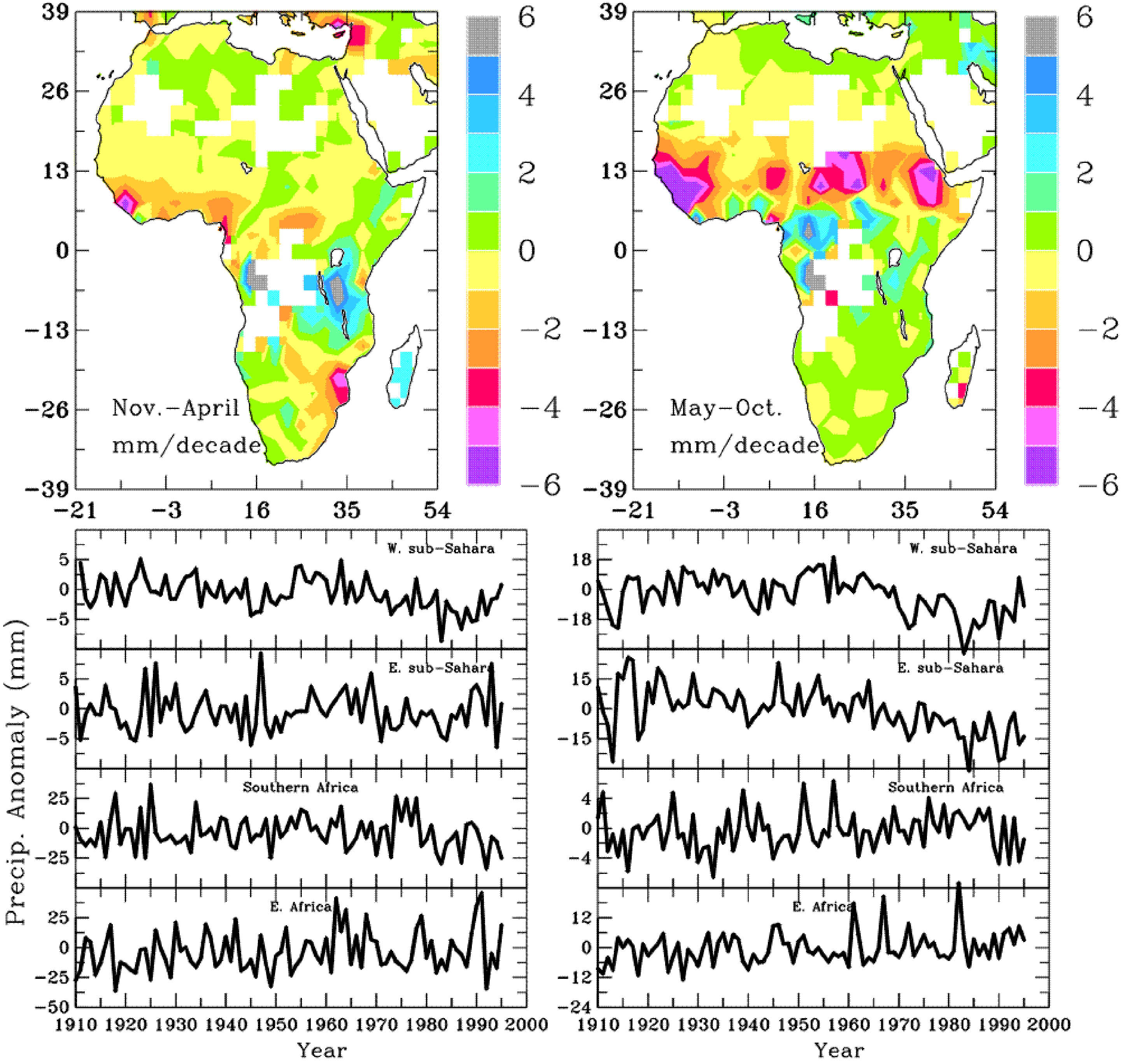
There is a distinct dry-wet seasonal cycle over Sub-Saharan Africa. Accompanying the north-southward movement of the intertropical convergence zone (ITCZ), the rainbelt (monthly rainfall greater than 50mm) moves northward from about three degrees north in January, to 13 degrees north in April, to 18 degrees north in July, and then southward to 13 degrees north in October, and further south to three degrees north in January, completing the cycle (Figure 7(b)). This ITCZ-associated north-southward movement of the rainbelt controls the timing of the rainy and dry seasons over the Sub-Saharan region. For example, over the Sahel, 97 percent of annual rainfall occurs from May to October (August contributes most, 37 percent) (Lamb and Peppler 1991). In southern Africa, the seasonal pattern is just the opposite. As the ITCZ and the rainbelt moves northward during northern summer, Southern Africa (south of about 10 degrees south) receives little rainfall from May to October. Over East Africa, March to May and October to November are relatively wet months.

Long-Term Rainfall Trends

Figure 9 shows maps of the trends of November-April and May-October rainfall from 1910 to 1995, although data after 1988 are sparse over eastern sub-Sahel and eastern Africa and, thus, over the two regions the area-averaged time series may not be reliable for the period 1989-1995. Also shown are the area-averaged rainfall time series for four regions: Western sub-Sahel (six to 18 degrees north and west of 18 degrees east), Eastern sub-Sahel (six to 18 degrees north and 18 to 40 degrees east), Southern Africa (south of ten degrees south), and Eastern Africa (26 to 40 degrees east and ten degrees south to five degrees north). Apparently rainfall (mostly from May to October) has decreased during this century in the six to 20 degrees north zone, especially in Guinea, Sierra Leone, Mali, Niger, Chad, Sudan, and Ethiopia. The decreasing trend started around the mid-1960s and continued until the mid-1980s. Thereafter, there has been some increase in rainfall in the western sub-Sahel region. November-April rainfall also has decreased in Mozambique, Zimbabwe, and north-eastern South Africa. On the other hand, rainfall (mostly during November-April) has increased during the period in Tanzania, Zambia, Uganda and western Kenya, while May to October rainfall has increased in Cameroon and Central Africa.

Many studies have linked the drought conditions in the Sahel to SST anomalies in the tropical Atlantic and other parts of the world (e.g., Lamb and Peppler 1992; Fontaine and Janicot 1996). Indeed, rainfall over many parts of Africa, including the sub-Sahelian region, East Africa, and southern Africa, are influenced by El Niño-Southern Oscillation (ENSO), which induces SST anomalies over the Atlantic and Indian Oceans (Nicholson and Kim 1997). Although ENSO mainly induces inter-annual to multi-year variations in rainfall, it has displayed some decadal variations during recent decades, which may have contributed to the rainfall trends over the sub-Sahel, southern Africa and East Africa.

Figure 11: Trends in Nov-Apr and May-Oct Rainfall, 1910-95



Source: Dai et al. (1997)

Plots of the Palmer Drought Severity Index (PDSI – Figure 12), a measure of soil moisture content calculated using surface air temperature and precipitation (Dai et al. 1998), reveal that the sub-Sahelian region has been in severe to moderate (PDSI less than -2.0) drought conditions (during both the dry and wet seasons) since the early 1970s while much of southern Africa has been in severe to moderate drought conditions since the late 1970s. On the other hand, soil moisture content has increased over Tanzania, Zambia, Uganda and western Kenya during the course of the century.

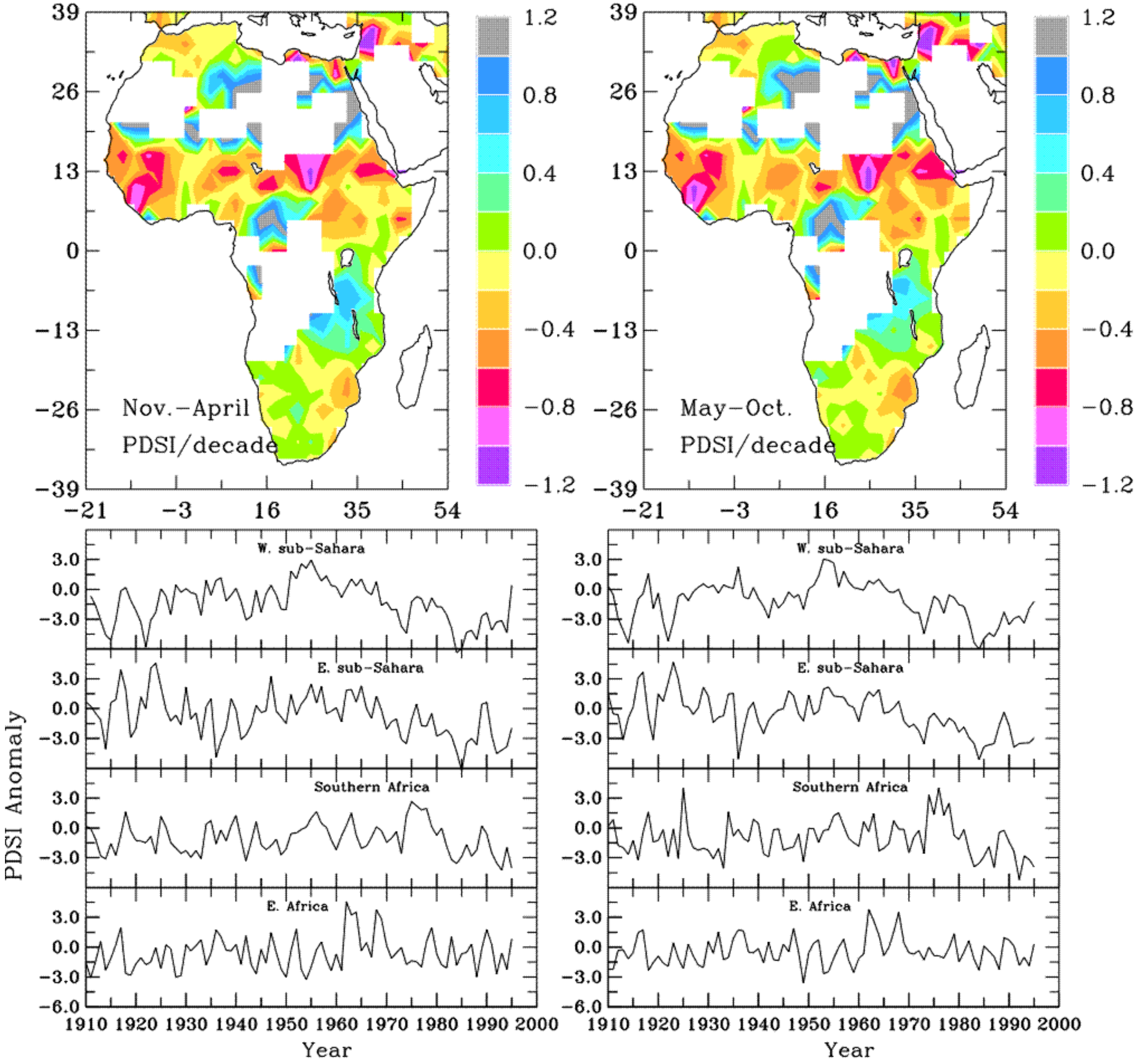
Outlook for Near-Future Temperature and Rainfall

The trends of increasing temperature during recent decades over the sub-Sahelian region (mostly during the wet season), East Africa and southern Africa are well established. Temperatures over these regions are likely to stay at record levels in the next five to 10 years. Global climate models (GCMs) predict a warming of about one degree Celsius over much of Africa with a doubling of atmospheric carbon dioxide content by about the year 2030 (IPCC 1996). While some of the recent trends may be attributed directly to increasing carbon dioxide and other trace gases, a large portion of the temperature increase is likely due to other factors such as low-frequency variations in ENSO, and changes in vegetation and soil moisture content (many of which have been attributed, at various times, and to varying extents, to human activity within and beyond Africa).

GCM predictions of rainfall with increased carbon dioxide in the low latitudes vary among different models. In general, however, rainfall is expected to change little or decrease slightly over much of the African continent (IPCC 1990 and 1996). In the next five to 10 years, rainfall over the sub-Sahelian region, East Africa, and southern Africa will depend more on El Niño activities rather than the effect of greenhouse gases. There is some evidence of increased rainfall in the western sub-Sahelian region during the 1990s compared with the 1980s. Rainfall data for the eastern sub-Sahelian region are insufficient for more recent years. Over southern Africa, rainfall has been below average since the late 1970s, which is closely related to the recent shift in El Niño towards more warm phases during the 1980s and the 1990s (Trenberth and Hoar 1997). With increasing temperatures, soil moisture content is expected to remain low over sub-Sahelian and southern Africa in the near future unless rainfall increases substantially. The overall effect of these changes on agriculture, while complex and gradual, are expected to be quite significant in terms of both production and global food trade (Fischer et al. 1996). Setting aside the significant data and method limitations to this type of global climate change analysis, the Fischer et al. study predicts significantly negative economic impacts for Africa under practically all conceivable scenarios of climate change and induced production adjustments over a 1990-2060 analysis period.

However, useful model predictions of ENSO events can now be made up to 12 months in advance, and could be used to predict rainfall anomalies, at least qualitatively, over the sub-Sahelian region, East and Southern Africa. If proven to be sufficiently reliable in Africa, the economic impact of such forecasts to inform input suppliers, reservoir operators, farmers, and herders of seasonal weather expectations is potentially

Figure 12: Palmer Drought Severity Index, Nov-Apr and May-Oct, 1910-95



Source: Dai et al (1997)

very large, and long-range forecasting probably merits much greater attention from the international scientific and development communities.[18]

SOIL AND TERRAIN DATA

Any biophysical stratification of land is confronted with the difficulty of characterizing complex soil and terrain information in a meaningful way that allows for further analysis and interpretation.

Soil and Terrain Data Availability

A difficulty often encountered, particularly at the sub-regional and regional levels, is finding soil data that are sufficiently harmonized and homogeneous to allow systematic interpretations for a wide range of purposes. Given the size of Sub-Saharan Africa and the evolution of soil mapping in the region, often closely linked to pedagogical schools of colonizing nations, it is perhaps not surprising that the only harmonized picture for the region as a whole, is the Soil Map of the World, SMW (FAO, 1971–1981). Although this map is now available in digital format and includes soil data interpretation programs for potential agricultural use (FAO, 1995), the scale of the map (1:5 million) and the fact that most data were derived from surveys carried out thirty or more years ago, preclude reliable analysis at a detailed level. Nevertheless, the digital dataset does provide a good overview of the diversity and extent of soil and terrain constraints and potentials, particularly for larger countries and at the sub-regional level.

While the SMW remains the best available national map for some countries in Sub-Saharan Africa, most others have undertaken more detailed soil studies since the 1970s and high quality national soil maps are available, for instance, in Ghana and Ivory Coast (at 1:250,000 scale), and in Kenya and Botswana (1:1 million scale). Nachtergaele (1996) provides an overview of the current situation with regard to national soil maps in the region. Furthermore, a number of more or less harmonized digital soil maps have now been prepared based on existing national datasets. In this respect, two datasets are of particular note:

- The Southern African Development Council (SADC) digital soil dataset (SADC 1997) containing harmonized soil information at an equivalent scale of 1:1 million, for Angola, Botswana, Malawi, Mozambique, Tanzania, Zambia, and Zimbabwe. Terrain data are less harmonized, since national physiographic classifications have been retained.
- The northeastern Africa compilation by FAO and ISRIC, using an earlier being prepared for publishing on CD-ROM (FAO 1998a) together with a

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[18] For example Houghton (1997, 24) reports the response of Peruvian farmers to predictions of the onset and likely intensity of the 1986-87 El Niño. Farmers were able to substitute rice in some cotton areas and, it is estimated, boost total production by 3 percent. In comparison, the poorer forecast of 1982-83 El Niño event contributed to a reported 14 percent decrease in total production.

> version of the SOTER[19] methodology (FAO 1993). These data are presently viewer program and land suitability interpretations for irrigated agriculture. An example of the output of this map is given in Figure 13b, which illustrates the soil and terrain suitability for the irrigation of upland crops in the ten countries covered by this dataset (Burundi, Djibouti, Egypt, Eritrea, Ethiopia, Kenya, Rwanda, Somalia, Sudan, Uganda).

A soil and terrain compilation based on the SOTER methodology is being prepared in parallel with ongoing national efforts for the southern Africa region (covering Mozambique, Botswana, Namibia, Angola, Swaziland and, perhaps, South Africa) at scales varying between 1:1 and 1:2 million. Publication of this compilation is expected by the end of 1999. In West Africa, proposals have been made for harmonizing existing soil data and maps, but funding has not yet been assured. For smaller countries, where the SMW often remains the only reference, any update will probably be limited to the addition of terrain information, with little or no new soil data. An updated soil and terrain database for the whole of Sub-Saharan Africa is expected by the year 2002 (Nachtergaele 1996).

Problems of Interpreting Soil Maps

Soil maps have been criticized as being unable to transmit the information required, because of the complex language used to describe soils, and because soil maps themselves seldom identify the pure, homogeneous units preferred by users for easy interpretation and GIS storage. Furthermore, there is no standardized way in which soils are described. Many Francophone West African countries have been mapped using a variant of the Commission Projet de Classification des Sols (CPCS, Aubert and Duchaufour, 1956), a system no longer used in its country of origin. The eastern and southern parts of Africa have often adapted the FAO legend as a basis for soil mapping, while South Africa has developed a sophisticated system of its own (MacVicar et al., 1977). Some countries, such as Cameroon, Mali and Zambia have been mapped using one of the versions of the USDA Soil Taxonomy (Soil Survey Staff, 1981).

At the international level there is widespread agreement on the need to promote a single international soil correlation system. The World Reference Base (WRB) for Soil Resources (FAO/ISRIC/ISSS 1998), to be presented at the upcoming International Congress of Soil Science in Montpellier (August 1998), stands a good chance of being accepted as such a system. However, it will take considerably more time for any single system to be adopted and applied.

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[19] SOTER: SOil and TERrain database: a methodology for collecting and storing soil and terrain information on a physiographic basis. Landscape units are first defined, within which soil units are identified, each of which is characterized by a typical soil profile. All information is stored in a relational database system. This three-tier approach is promoted by the International Society for Soil Science (ISSS) and has been actively supported by FAO, ISRIC, and UNEP.

The problem of delineating homogeneous soil units, particularly in smaller scale maps, exists because of the high variability in most soils over very short distances. One of the techniques employed by soil scientists to address this problem is to hold tabular information describing the real-world heterogeneity of the dominant and associated soils contained within every soil mapping unit. Whereas the *proportion* of a mapping unit occupied by each soil type is specified, the *location* of the soil type within the unit is unknown. The development of the SOTER methodology is helping to resolve some of these limitations by more precisely documenting the distribution and location of soils within natural landscape units, and also by providing access to morphological and analytical soil profile data linked to each soil unit. This should facilitate the understanding and use of soil information by other disciplines.

Inherent Land-Related Constraints

There are several approaches to translating soil characteristics into agronomic constraints and potentials. One of the better known, is the Fertility Capability Classification (FCC) developed by Sanchez et al. (1982). The FCC criteria have been applied to the digital SMW to estimate the areal extent of the most important soil constraints encountered in Sub-Saharan Africa. A country-level summary of this information is given in Table 12.

The FCC classification criteria were linked to the soil mapping units of the SMW using “taxotransfer functions”, algorithms based on expert knowledge or statistical analysis of a large number of soil profiles belonging to the same classification unit (Batjes et al. 1997), in order to derive soil properties for each taxon (classification name). For instance, the indicator *hydromorphy* in the FCC classification is correlated with all soil units belonging to Fluvisols, Gleysols, or Histosols and to gleyic units in other soil groups; *shallow soils* are identified by the presence of lithic or hardpan phases on the map; *low cation exchange capacities* (CEC) values are associated with Arenosols and most Ferralsols with sandy topsoil textures; *high phosphate fixation* is correlated with fine textured Ferralsols and Acrisols; *vertic properties* with Vertisols and vertic soil units in other soil groups; *salinity* is equated with areas with Solonchaks and saline phases; while *aluminum toxicity* is considered prevalent in Ferralsols and Acrisols (except humic ones) and in dystric Planosols, dystric Gleysols and dystric Cambisols. *Erosion prone soils* are those soils present on very steep slopes (slope of greater than 30 percent) or soils located on moderate slopes (eight to 30 percent) but having coarse textures overlying much finer ones.

The country results can be grouped and used for preliminary screening of potential development strategies or technology transfer potential (Nachtergaele and Brinkman 1996).

Wetlands

The problem of hydromorphic soils and the complex problem of managing wetlands including such diverse environments as mangrove coastal plains, small inland valleys, “mbugas,” “*dambos*,” and peats in Sub-Saharan Africa were recently discussed

Table 12 Area of major soil constraints in Sub-Saharan Africa (FCC indicators[a])

Country	Total area	Soil constraint															
		Hydromorphy		Low CEC		Aluminum toxicity		High P-fixation		Vertic properties		Salinity		Shallowness		Erosion risk	
	1,000km^2	1,000km^2	%	1,000 km^2	%	1,000 km^2	%	1,000 km^2	%	1,000 km^2	%	1,000 km^2	%	1,000 km^2	%	1,000 km^2	%
Angola	1,247	153.4	12.3	387.8	31.1	339.2	27.2	68.6	5.5	11.2	0.9	5.0	0.4	57.4	4.6	147.1	11.8
Benin	111	11.8	10.6	1.2	1.1	-	-	-	-	2.7	2.4	0.1	0.1	8.7	7.8	24.4	22.0
Botswana	567	29.5	5.2	250.6	44.2	2.8	0.5	-	-	45.9	8.1	62.9	11.1	14.2	2.5	26.6	4.7
Burkina Faso	274	41.9	15.3	20.3	7.4	2.5	0.9	-	-	27.1	9.9	12.6	4.6	66.0	24.1	54.8	20.0
Burundi	26	2.3	8.7	-	-	9.7	37.4	7.4	28.5	1.0	3.8	0.4	1.7	1.1	4.3	10.0	38.6
Cameroon	465	43.7	9.4	11.6	2.5	261.8	56.3	20.5	4.4	12.6	2.7	1.9	0.4	26.0	5.6	100.0	21.5
CAR	623	51.1	8.2	108.4	17.4	319.6	51.3	24.3	3.9	1.9	0.3	1.2	0.2	45.5	7.3	122.1	19.6
Chad	1,259	79.3	6.3	192.6	15.3	0.2	-	-	-	83.1	6.6	35.3	2.8	200.2	15.9	104.5	8.3
Congo D. R.	2,267	380.9	16.8	591.7	26.1	1362.5	60.1	494.2	21.8	6.8	0.3	1.8	-	9.1	0.4	108.8	4.8
Congo Republic	342	102.9	30.1	98.8	28.9	147.7	43.2	17.1	5.0	-	-	-	-	1.7	0.5	22.9	6.7
Djibouti	23	0.2	1.0	-	-	-	-	-	-	-	-	10.0	43.5	9.4	40.8	0.4	1.7
Equatorial Guinea	28	5.9	21.0	2.8	10.0	14.6	52.0	-	-	-	-	-	-	2.8	10.0	2.5	9.0
Ethiopia & Eritrea	1,101	5.5	0.5	22.0	2.0	56.2	5.1	8.8	0.8	101.3	9.2	56.2	5.1	331.4	30.1	342.4	31.1
Gabon	258	34.8	13.5	31.0	12.0	122.0	47.3	21.4	8.3	-	-	1.8	0.7	24.5	9.5	26.8	10.4
Gambia	10	2.8	28.4	-	-	-	-	-	-	-	-	0.9	8.7	0.4	3.6	0.7	7.1
Ghana	228	22.6	9.9	8.7	3.8	58.4	25.6	2.1	0.9	4.1	1.8	0.2	0.1	23.0	10.1	48.3	21.2
Guinea	246	21.2	8.6	5.7	2.3	97.4	39.6	7.1	2.9	0.5	0.2	3.4	1.4	79.5	32.3	71.3	29.0
Guinea Buissau	28	4.5	16.2	1.2	4.4	2.4	8.7	-	-	-	-	2.4	8.5	5.9	21.0	5.9	21.1
Ivory Coast	318	18.8	5.9	10.8	3.4	185.1	58.2	9.2	2.9	1.3	0.4	-	-	19.4	6.1	84.9	26.7
Kenya	569	21.6	3.8	18.2	3.2	32.4	5.7	2.3	0.4	26.2	4.6	53.5	9.4	122.3	21.5	122.3	21.5
Lesotho	30	2.3	7.8	-	-	0.2	0.5	0.1	0.3	-	-	-	-	9.1	30.3	21.2	70.5
Liberia	96	15.1	15.7	8.8	9.2	60.6	63.1	11.6	12.1	-	-	2.8	2.9	7.5	7.8	16.9	17.6
Madagascar	582	39.0	6.7	44.8	7.7	185.7	31.9	8.7	1.5	7.6	1.3	4.7	0.8	31.4	5.4	204.3	35.1
Malawi	94	4.6	4.9	3.1	3.3	21.2	22.5	6.7	7.1	2.6	2.8	0.6	0.6	13.5	14.4	23.4	24.9
Mali	1,220	63.4	5.2	158.6	13.0	7.3	0.6	-	-	14.6	1.2	19.5	1.6	202.5	16.6	136.6	11.2
Mauritania	1,025	4.1	0.4	92.3	9.0	-	-	-	-	3.1	0.3	9.2	0.9	225.5	22.0	92.3	9.0
Mozambique	784	31.4	4.0	136.4	17.4	150.5	19.2	52.5	6.7	21.2	2.7	11.0	1.4	54.1	6.9	232.8	29.7
Namibia	823	14.0	1.7	185.2	22.5	0.3	-	-	-	59.3	7.2	33.7	4.1	135.8	16.5	75.7	9.2
Niger	1,267	34.2	2.7	351.0	27.7	-	-	-	-	8.9	0.7	11.4	0.9	149.5	11.8	83.6	6.6
Nigeria	911	123.9	13.6	118.9	13.0	75.6	8.3	0.3	-	17.3	1.9	20.0	2.2	128.5	14.1	240.5	26.4
Rwanda	25	2.0	8.0	-	-	4.8	19.3	4.0	15.8	0.1	0.4	-	-	1.9	7.7	16.1	64.5
Senegal	193	28.6	14.8	53.1	27.5	0.1	-	-	-	4.1	2.1	6.6	3.4	35.7	18.5	18.7	9.7
Sierra Leone	72	7.1	9.8	2.6	3.6	42.5	59.0	1.2	1.6	-	-	2.6	3.6	13.0	18.1	8.9	12.3
Somalia	627	10.7	1.7	33.2	5.3	8.2	1.3	3.8	0.6	17.6	2.8	57.1	9.1	233.2	37.2	47.0	7.5
South Africa	1,221	52.5	4.3	256.4	21.0	35.4	2.9	19.5	1.6	61.1	5.0	12.2	1.0	233.2	19.1	295.5	24.2
Sudan	2,376	180.6	7.6	211.5	8.9	114.0	4.8	11.9	0.5	401.5	16.9	23.8	1.0	304.1	12.8	235.2	9.9
Swaziland	17	2.2	13.1	1.4	8.0	4.5	26.6	3.2	18.6	-	-	-	-	2.6	15.1	6.6	38.6
Tanzania	884	74.3	8.4	63.6	7.2	261.7	29.6	32.7	3.7	53.0	6.0	16.8	1.9	69.8	7.9	259.0	29.3
Togo	54	5.1	9.4	0.8	1.4	0.3	0.6	-	-	1.5	2.8	0.5	0.9	8.5	15.7	12.8	23.7
Uganda	200	21.0	10.5	5.8	2.9	93.6	46.8	5.0	2.5	7.0	3.5	0.4	0.2	14.6	7.3	31.6	15.8
Zambia	743	136.7	18.4	170.1	22.9	274.9	37.0	82.5	11.1	26.0	3.5	-	-	43.8	5.9	71.3	9.6
Zimbabwe	387	16.6	4.3	53.8	13.9	10.8	2.8	1.9	0.5	32.5	8.4	3.1	0.8	38.3	9.9	55.3	14.3
TOTAL	**23,621**	**1,904.0**	**8.1**	**3,714.0**	**15.7**	**4,366.0**	**18.5**	**982.2**	**3.9**	**1,064.0**	**4.5**	**483.7**	**2.0**	**3,005.0**	**12.7**	**3,612.0**	**15.3**

Source: Authors calculations, based on an interpretation of the 1:5M soil map of the world (FAO 1995) using the Fertility Capability Classification algorithms (Sanchez et al. 1982, FAO 1997).

by Koohafkan et al. (1997). Although there are few countries where these represent the dominant land resource (Gambia and Republic of Congo have the highest extents, covering nearly 30 percent of their territories), most countries have a significant proportion of such wetlands, often used for seasonal grazing and extensive rice production. For more intensive agricultural use these lands require special management techniques. A fundamental problem, however, is finding means to harmonize agricultural and environmental sector policies in order to foster a mix of wetland uses that balance ecological and biodiversity value with agricultural intensification potential.

Soils with Low Inherent Fertility

Soils with a low cation exchange capacity (CEC) occupy nearly four million square kilometers in Sub-Saharan Africa. They are particularly important in countries where sandy plains (Arenosols) dominate such as in Angola, Botswana, Namibia, Niger, Senegal, and Zambia, but also where coarse textured tropical soils (Ferralsols) occur such as in parts of both Congo's.

Low nutrient reserves, often accompanied by a low soil moisture storage capacity, dictate the use of relatively high inputs (in particular, those that boost organic matter content) if these soils are expected to produce at above subsistence levels.

Aluminum Toxicity and Phosphate Fixation

High rainfall, coupled with the presence of extremely old soils in humid, tropical Africa favors the leaching of nutrients, acidification and the accumulation of aluminum, a toxic element for most crops. This problem affects over 5 million km^2 in the region, particularly countries such as Angola, Burundi, Cameroon, Central African Republic, The Republic of Congo, the Democratic Republic of Congo, Gabon, Ghana, Guinea, Ivory Coast, Liberia, Madagascar, Malawi, Tanzania, Uganda, and Zambia, where more than one fourth of these countries' territories are affected. Although some crops (pineapple, tea) are quite resistant to aluminum, and remedial action (careful liming) is relatively straightforward, the associated problem of phosphate fixation is widespread in Burundi, Congo, Rwanda, and Swaziland and can only be overcome through increased external inputs. The World Bank initiative on the use of rock phosphate represents a significant attempt to ameliorate this problem.

Vertic Properties

Black clay soils (vertisols) have particular characteristics that makes them difficult to till when dry and practically inaccessible when wet. These soils which are generally rich chemically, require specific management techniques if intensification of agriculture is envisaged. Cotton is known to perform quite well on these soils which occupy large areas in Burkina Faso, Chad, Ethiopia, and Sudan (Gezira).

Saline Soils

In the drier areas of Sub-Saharan Africa, saline (and sodic) soils occur naturally. However, the tabulated extents generally do not capture the presence of large areas affected by secondary salinization due to poorly managed irrigation schemes. The reclamation of these areas is not always straightforward and often uneconomic, pointing to the importance of improved management practices as an essential component of irrigation.

Shallow Soils

Steep sloping lands, although relatively rare in Africa compared with other continents, often have soils less than 50 centimeters deep and therefore do not provide sufficient foothold or root development space for many crops. These lands have a reduced soil moisture storage capacity and are erosion prone. In some less hilly or mountainous areas, lateritic or other hardpans (duripans, petrocalcic horizons) may occur. Very little can be done to improve the performance of these soils, which ideally should be kept under natural vegetation.

Erosion Prone Soils

Soils occurring in very steep sloping lands (Burundi, Lesotho, Rwanda) and soils with contrasting textural layers occurring in sloping lands are particularly sensitive to landslides and removal and movement of topsoil and nutrients downhill. Adapted soil conservation techniques have been inventoried for many parts of Sub-Saharan Africa under the World Overview of Conservation Approaches and Techniques initiative, WOCAT, a joint venture between the University of Bern, UNEP, FAO, OSS and GTZ (FAO 1998c).

Although many technical solutions are well known (FAO 1991 and 1996), it is recognized that the acceptance and local adaptation of improved soil conservation practices depends upon the perception of farmers and local communities about the cost-effectiveness of those practices. Since the attractiveness of soil conservation relates to complex, site-specific issues, there is much scope for a closer dialogue between concerned institutions and land users in recognizing significant degradation problems and formulating appropriate interventions. In this respect it is also important to distinguish between soils naturally at risk for nutrient or soil loss as described here (so-called problem soils), and degradation that might occur on any soil through human intervention (see section 1.2).

Soil and Terrain Suitability Evaluations

The diversity of soils and soil problems suggest that care is needed in the geographic targeting of agricultural development strategies, particularly those seeking to minimize negative natural resource impacts. Furthermore, different crop and livestock systems have very different requirements with regard to the (climate and) soil conditions under which they are most likely to be economically viable. As stressed earlier in this paper, soils and land *per se* are neither good nor bad, but rather they are good or bad for specific purposes characterized by different bundles of outputs, production technology, inputs, and management.

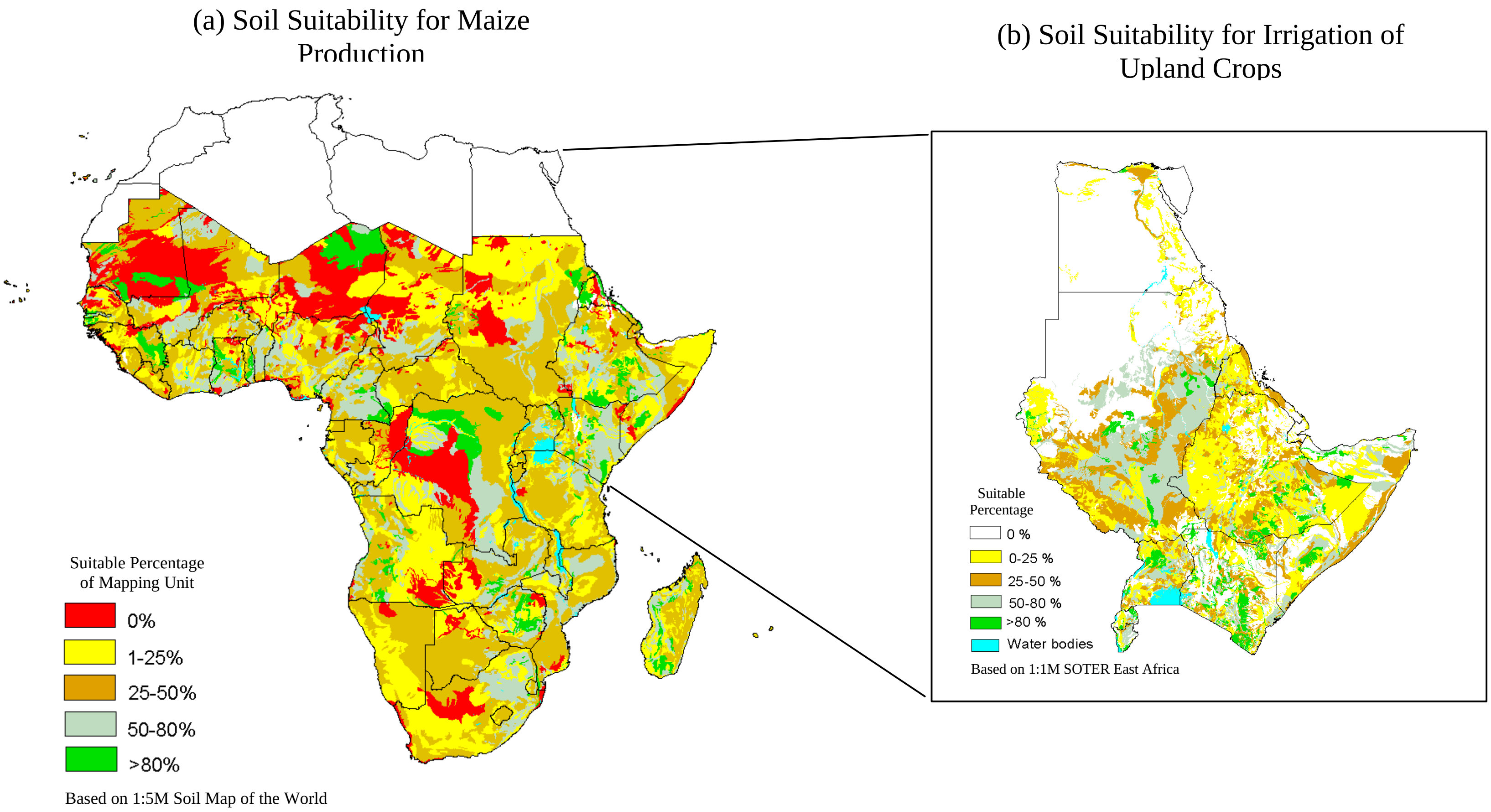
During the late 1970s, FAO developed the agroecological zones (AEZ) approach as a means of assessing the physical production potential of land. The approach includes both an agroclimatic as well as a soil and terrain evaluation component and AEZ outputs, including both a detailed land inventory (comprising some 32,000 distinct entries for Africa) and physical crop suitability estimates for 11 crops, have since been used extensively (although often in very aggregate form) in many global, regional, sub-regional, and even national studies. And the current availability of more detailed soil and climate databases for the region, as well as advances in AEZ methodologies themselves, suggest there may be utility in updating and extending that original study, emphasizing the improved capacity to tailor AEZs to better coincide with specific policies, agricultural production systems, and technologies of interest.

Some typical soil and terrain suitability assessments are shown in Figure 13. Figure 13(a) shows the suitability for rainfed maize production for the whole of Sub-Saharan Africa, based on an analysis of SMW mapping units under an assumption of low input levels. Figure 13(b) shows the suitability to support irrigation of upland crops based on the 1:1 million scale soil and terrain database for north-eastern Africa. These figures also illustrate the difficulty of representing land evaluation results in one image/map. Because the outputs comprise a distinct suitability class for *each* of the soil units contained within the mapping unit, it is impossible to convey the full richness of the underlying information in a single map.

One continuing problem in assessing the overall suitability of a location for a specific agricultural activity is the need to address broader concerns than just biophysical (land) production potential, and this requires greater integration of a range of non-land variables (that we have elsewhere referred to as socioeconomic factors). Some of these challenges arise simply because social scientists are often not accustomed to working in an explicitly spatial context, but more serious is the problem of finding common spatial scales and common levels of information generalization that meet the needs of different disciplines. The predominant social science focus on detailed characterization of individual locations, at the expense of thinking about characterizing across locations, exacerbates this difficulty.

The AEZ approach relies, for the most part, on a model of linear interaction and reclassification of separate thematic data overlays. While this has advantages in terms of analytical transparency and ease of computation, it does represent a gross simplification of real-world interaction and feed-back, and for some applications (like those of concern here, in which there are dynamic relationships between land use and natural resources) this may be a significant limitation. There are a growing number of situations for which it is now feasible to perform stylized simulations of biophysical processes, e.g., for crop yield, soil erosion, and nutrient leaching. There is also the emerging area of bioeconomic modeling (e.g., Barbier and Bergeron, 1997) in which land use and investment decisions are linked through a dynamic simulation to such factors as current (or expected) natural

Figure 13: Suitability Interpretations of Soil and Terrain Data



(a) Soil Suitability for Maize Production

(b) Soil Suitability for Irrigation of Upland Crops

Source: Adapted from FAO GIS, 1998

resource and market conditions. Such methods offer promise for meaningful interdisciplinary dialogue and analysis of land use over space and time.

Land Degradation Status

In the late 1980s, UNEP and ISRIC undertook a global inventory of the status of human-induced land degradation (Oldeman et al., 1991). The Global Assessment of Soil Degradation (GLASOD) approach involved a structured elicitation of national, regional and international experts on the location, severity and nature of land degradation throughout the world. Expert information was integrated into standardized regional topographic base maps that contained only country boundaries, major cities and hydrological features. Results were published in a 1:10 million scale map in which the relative extent and severity of soil degradation is depicted according to type; water erosion, wind erosion, salinization, acidification, pollution, and physical deterioration. The map also indicates the location of stable land and “wastelands” (e.g., deserts and ice caps).

Table 13 provides a country summary of the area and area shares in each of GLASOD’s five degradation severity classes, along with the dominant cause and type of degradation. Given the use made in this paper of the spatial variation of population density as a factor influencing development strategy design, it was considered useful to examine the spatial correspondence between that variable and the GLASOD degradation severity index. Table 13 therefore, also contains an estimate of the average population density (Tobler et al., 1995) in the areas corresponding to each soil degradation severity class.

Inspection of the table suggests a relationship between the two variables. In many countries higher population densities are associated with areas judged to be more intensely degraded.[20] However, for some countries one may suspect out-migration from, and even abandonment of, degraded lands and, hence, a possible decrease in population densities in the worst affected areas. In other cases, such that of Machakos (Tiffen et al., 1994), there are circumstances in which increased population pressure and high levels of degradation have induced actions that lead to successful land rehabilitation.

Nevertheless, taking the degradation measures at face value, the table does indicate that the severest assessments of degradation are associated with very high population densities in hilly highland countries in the region (Burundi, Ethiopia, Lesotho, Rwanda), while other cases are associated with higher deforestation rates in the more humid countries such as Cameroon, Nigeria and Togo, sometimes associated by higher population density (Nigeria and Togo), and in other cases not (Cameroon). Overgrazing appears to be a major cause of moderate to severe land degradation in most of the dryland countries of the region. The dominant degradation type is closely associated with prevailing climatic conditions, with water erosion and nutrient depletion dominating in

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[20] However, with the GLASOD approach it is impossible to know whether expert judgement was based, explicitly or implicitly on an assumption of this relationship when the degradation severity data were first assembled. Consequently no strong assertions of causality are possible. Furthermore, there are other difficulties associated with the inclusion of urban areas and populations.

Table 13 Population density and GLASOD human-induced land degradation status in Sub-Saharan Africa

Country	Total area	Severity of degradation															Main Cause	Main Type
		None			Light			Moderate			Severe			Very severe				
		Area		Pop. density	Area		Pop. density	Area		Pop. density	Area		Pop. density	Area		Pop. density		
	1,000 km^2	1,000 km^2	%	pers/km^2	1,000 km^2	%	pers/km^2	1,000 km^2	%	pers/km^2	1,000 km^2	%	pers/km^2	1,000 km^2	%	pers/km^2		
Angola	1,247	761	61	6	194	16	7	121	10	8	65	5	10	105	8	27	D	W
Benin	111	0	NA	NA	60	54	19	28	25	29	11	10	41	12	11	243	D	W
Botswana	567	173	31	1	253	45	2	76	13	5	24	4	11	42	7	2	O	N
Burkina Faso	274	0	0	NA	59	22	29	59	22	33	36	13	42	120	44	42	O, D, A	W
Burundi	26	2	7	275	0	0	NA	5	18	127	0	0	NA	20	75	248	A	W
Cameroon	465	184	40	11	24	5	85	85	18	35	67	14	55	107	23	19	A, O, D	W
CAR	623	273	44	1	322	52	6	17	3	10	2	0	3	9	1	65	D	W
Chad	1,259	501	40	1	374	30	8	83	7	10	284	23	6	17	1	13	O	N, W, P
Congo D.R.	2,267	744	33	14	1,174	52	14	179	8	39	147	7	32	22	1	229	D	W, C
Congo Republic	342	268	78	3	42	12	25	24	7	1	2	1	37	6	2	105	D	C
Djibouti	23	0	0	NA	0	0	NA	23	100	18	0	0	NA	0	0	NA	O	N
Equatorial Guinea	28	22	79	12	6	21	21	0	0	NA	0	0	NA	0	0	NA	D	C
Ethiopia & Eritrea	1,101	48	4	23	113	10	40	632	57	26	88	8	129	220	20	109	O	W
Gabon	258	210	81	3	8	3	8	23	9	2	17	7	11	0	0	NA	D	C
The Gambia	10	0	0	NA	5	55	59	5	45	166	0	0	NA	0	0	NA	D	W
Ghana	228	13	6	38	57	25	121	136	60	52	7	3	71	14	6	129	D	W
Guinea	246	0	0	NA	193	78	24	43	18	39	10	4	75	0	0	NA	D	W
Guinea Bissau	28	0	0	NA	7	25	21	21	75	42	0	0	NA	0	0	NA	D, A	W, C
Ivory Coast	318	9	3	7	252	79	48	45	14	22	0	0	NA	12	4	24	D	W, C
Kenya	569	37	7	20	233	41	3	126	22	36	109	19	111	65	11	129	O	W
Lesotho	30	0	0	NA	0	0	NA	0	0	NA	22	74	55	8	26	97	O	W
Liberia	96	38	40	12	48	50	20	0	0	NA	10	11	68	0	0	NA	D	C
Madagascar	582	0	0	NA	26	5	102	144	25	32	281	48	20	131	22	10	A	W
Malawi	94	37	39	67	3	3	110	54	58	125	0	0	NA	0	0	NA	A	W
Mali	1,220	560	46	0	215	18	19	83	7	37	163	13	9	199	16	9	O	W, N
Mauritania	1,025	760	74	1	0	0	NA	0	0	NA	181	18	7	84	8	2	O	N
Mozambique	784	244	31	18	228	29	20	312	40	24	0	0	NA	0	0	NA	A, D	W
Namibia	823	467	57	2	97	12	1	70	9	1	174	21	2	15	2	1	O	W
Niger	1,267	687	54	0	10	1	21	0	0	NA	353	28	15	217	17	14	O	N
Nigeria	911	27	3	174	345	38	67	39	4	122	245	27	106	255	28	197	D, O	W
Rwanda	25	0	0	NA	0	0	NA	7	27	106	0	0	NA	18	73	251	A, D	W
Senegal	193	0	0	NA	76	39	15	49	26	39	27	14	18	41	21	110	D, O, A	W, C
Sierra Leone	72	0	0	NA	35	48	42	10	14	75	28	38	70	0	0	NA	D	W, C
Somalia	627	146	23	10	60	10	15	328	52	10	0	0	NA	93	15	39	O,A	W
South Africa	1,221	272	22	49	101	8	37	62	5	32	226	19	61	559	46	14	O	W, N
Sudan	2,376	1,105	47	8	310	13	7	250	11	16	348	15	16	364	15	14	O	W, N
Swaziland	17	0	0	NA	0	0	NA	17	100	49	0	0	NA	0	0	NA	A	W
Tanzania	884	108	12	25	273	31	20	278	31	43	215	24	37	10	1	109	A, O	W
Togo	54	0	0	NA	13	25	37	11	21	54	16	30	55	13	25	150	D, A	W
Uganda	200	8	4	83	2	1	11	86	43	56	82	41	130	23	11	129	O, D	W
Zambia	743	133	18	6	155	21	6	330	44	13	124	17	15	0	0	NA	D	W
Zimbabwe	387	34	9	7	203	53	32	150	39	29	0	0	NA	0	0	NA	A, O	W
TOTAL	**23,621**	**7,871**	**33**	**8**	**5,575**	**24**	**21**	**4,011**	**17**	**29**	**3,363**	**14**	**37**	**2,801**	**12**	**53**		

Source: Authors calculations, based on interpretation of GLASOD (Oldeman et al. 1990), land area data (FAO Agrostat), and population (Tobler et al. 1995).
Key: A - Agriculture; C - Chemical Erosion; D - Deforestation; O - Overgrazing; P - Physical Erosion; W - Water Erosion; N - Wind Erosion.

the more humid countries of the region, and wind erosion and physical deterioration prevailing in the dryland areas.

It would be feasible to explore further whether the inclusion of other variables such as livestock density (Wint and Rogers 1998; Kruska et al. 1995), and slope (USGS 1996) would provide greater explanatory insights into the GLASOD degradation severity classes, but again it would be impossible to assume that these were indeed independent given the way in which the GLASOD data were constructed.

Another approach is to establish whether the susceptibility of a soil to degradation, as assessed by an interpretation of its physical, chemical, and biological properties, is a useful predictor of actual degradation. Figure 14 shows the relationship between national aggregates of the GLASOD (actual) land degradation severity and the FCC erosion risk (potential) indicator. Again there appears to be some evidence of a relationship confirming that soil and terrain indicators merit inclusion as explanatory variables in predicting likely degradation rates.

While there is clearly some scope for improved *prediction* of land degradation, there are still many problems in the *measurement* of degradation, be it nutrient depletion (Smaling 1993) or net topsoil loss (Stocking 1986), and even more controversy about interpreting the economic and social impact of that degradation (see, for example, Pimental et al., 1995, and the response by Crosson 1995). Despite the high political profile attached to actions for mitigating the negative impacts of development on the environment, surprisingly little attention has been paid to the systematic measurement, compilation, and interpretation of data that could better inform national governments and trans-national institutions about the appropriate type and scale of potential interventions.

DATA FOR STRATEGIC ASSESSMENTS

The soil information available for Africa south of the Sahara can be improved, and could be harmonized and collected at larger scales across the whole continent, in order to provide a richer and more reliable basis for regional and country development assessments. There appears to be a specific need for improved interpretations of soils and other information in the assessment of degradation. Furthermore, gathering hard evidence on the scale and nature of degradation and trying to untangle important aspects of causality would need monitoring systems that, while often debated, appear far off.[21]

The analysis of problem soils in the Sub-Saharan region shows that there are large differences within regions and within countries in the type of soil problems encountered, with aluminum toxicities and phosphate fixation prevalent in humid zones and physical soil deterioration dominating in dryland areas. These problems require appropriate management techniques and better information and incentives that foster the generation and adoption of cost-effective solutions.

There is clearly scope for continued and improved linkages between national, regional and international agencies engaged in building and managing datasets and developing analytical tools that could be of broader interest. The rapidly expanding

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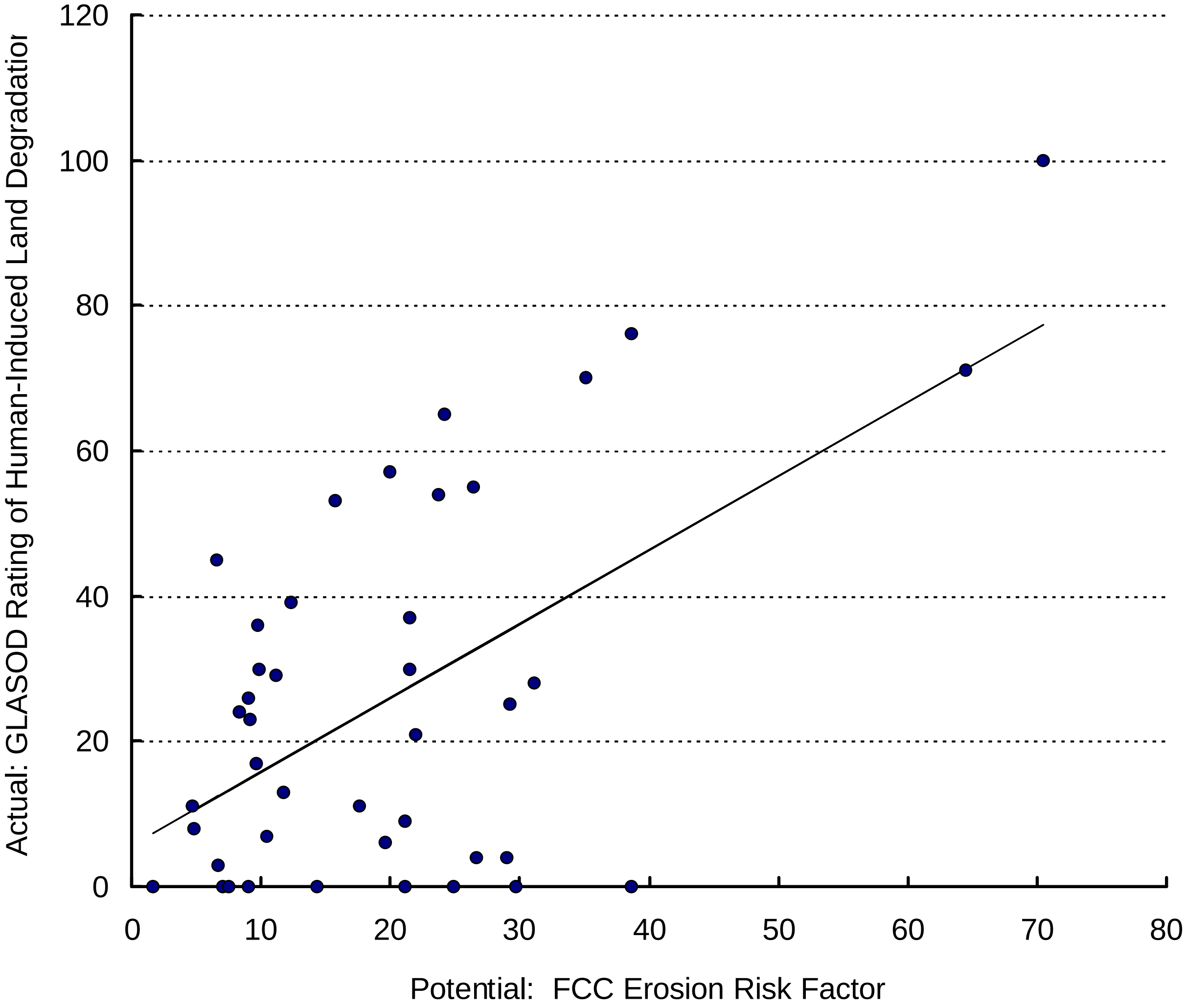
[21] Although activities planned under the auspices of the Convention to Combat Desertification include a monitoring system targeted to the specific problems of land degradation in dryland areas (CCD 1995).

Figure 14 FCC (Potential) and GLASOD (actual) indicators of land degradation



global access to the Internet and electronic mail provides one significant means to fostering information sharing.

While there are certain national sensitivities, there remain significant scale and scope economies in the collection of some types of data (e.g., satellite imagery), in methods development, and in the development of data protocols. However, it is a matter of concern that many international standards on classification schema for soil, terrain, land cover, land use, land degradation and climatic data are little known or not accepted. It is important to better understand if such schema are inappropriate, poorly promoted, or difficult to understand and utilize. In this respect, those of the internationally endorsed initiatives, such as SOTER, WRB, WOCAT and GLASOD-like methodologies that best serve national and international users, would probably merit wider support in Africa (and beyond).

Elsewhere in this paper we have also encouraged the implementation of cost-effective mechanisms to allow development analysts working at a national level to tap into local level information, where it exists. The objectives would be to improve the characterization of intervention successes and failures, as well as gain a better understanding of local level production-cum-resource issues to interface with national level policies and strategies. This could lead to the design of better, and better targeted interventions.