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Resource management domains: a biophysical unit for assessing and monitoring land quality

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Abstract

With the advent of information technology there is a renewed interest to define and identify homogenous food production systems. International donor agencies, such as the World Bank and the US Agency for International Development, are especially interested in public/private partnerships to develop and integrate information including the socio-economic/cultural contexts of farm systems to improve knowledge about food systems, nationally to globally. The International Agricultural Research Centers, non-government organizations and national institutions require a spatial–temporal–hierarchical information system describing farm systems and communities from the ‘nation to the farm’. Agri-business requires methods to evaluate the performance of crop systems in varied environments in countries and/or around the world.

As the society is stratified by different information needs, decisions must be made about the units of study and the hierarchy of information integration. The proposed hierarchy, developed on the tenets of hierarchy theory, implies that optimization of biodiversity, ecosystem health and integrity, commodity production, or maintaining soil quality, are each articulated based on the objectives that apply to the planning area. Management goals, therefore, determine the planning area to be defined, the goods and services, and the desired conditions of the ecosystem. Defined biophysical units, such as resource management domains (RMDs), serve as a common denominator for synthesis of information which could be shared by a range of disciplines, such as hydrology, geomorphology, pedology, crop science, economics, sociology, land-use planning, and production technology. In this approach, system dynamics or temporal variations are de-emphasized with the assumption that each RMD has attained an equilibrium or quasi-equilibrium within the planning horizon of the society. This is due to the practical purpose for which land resource assessments are generally made. However, if time periods of 50 or more years are considered, the concept must be refined. The latter approach is required for assessments of forest ecosystems. Published by Elsevier Science B.V.

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1. Introduction

There are many institutions in the world, including the World Bank, whose decisions and strategic plans are based on large quantities of reliable information. National institutions and decision-makers at all levels of society require similar or, sometimes more

site-specific, information for decision-making. With the advent of computer technology and the ability to process information rapidly, there is a concerted effort by scientists to refine the techniques of manipulating information. Land resource, and other, information, together with a decision support system, with proper spatial–temporal information, can be used to more specifically infer the potentials of the land system (Bouma et al., 1995), and consequently, to define

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'homogeneous management domains' for food production systems around the world. Many international and regional donors and national institutions have been funding regional information systems through academic and non-profit communities to assist in characterizing food systems. The World Bank (Pieri et al., 1995), for example, is especially interested in public/private partnerships to develop and integrate information including the socio-economic/cultural contexts of farm systems to improve knowledge about food systems globally. The goal has always been to build a spatial-temporal-hierarchical information system describing farm systems and communities from the 'nation to the neighborhood' in each country, to link these to a region and, finally, enable a global assessment. Historical, natural and human managed inputs for and outputs of agricultural production systems within the socio-economic and environmental landscapes need to be developed. Such systems will be based on the relatively data-rich resources of national government institutions.

While significant amounts of data have been collected already, we cannot directly (and democratically) collect all the information necessary to fully understand the complexities of natural or human driving factors or the temporally and spatially varied responses of the food production systems. Orr (1998) has cautioned that, "We are drowning in unassimilated information, most of which fits no meaningful picture of the world." This, despite the statement of Cairns (1994) that "At best, only a primitive understanding exists of whole ecosystems — or landscape-level management." In an environmental context, however, there is a continuing and increased need for not only the private sector, but the public sector as well, to better understand the impact of world populations upon the food-producing landscape. Many organizations have been independently collecting data, and are beginning to build true information systems for localized areas, data mining and modeling approaches, particularly of space- and time-extensive information that are only just now promising to provide critically needed insight into complex food systems. Certain information generated by and for the use of private interests, from the individual precision farmer at the farm field level to large crop production corporations with global objectives, is intrinsic to such systems and must be protected through proven geo-commerce technique partnerships.

Multi-agency/multi-disciplinary public/private efforts are necessary to cost-effectively integrate and interpret needed information and no one organization is likely to succeed alone in such an endeavor. Data mining approaches and inferencing engines require comprehensive, hierarchical, integrated information frameworks working with common denominators.

In developing countries, data collection is often more sporadic and usually incomplete (Kam and Oberthuer, 1998). Techniques to use fragmented information are rapidly being developed. This and related technologies are the key to a better knowledge about current and future food production areas at the homogeneous domain level as they assemble facets comprising the larger world. Utilities can be developed for such situations. Effective user interfaces will range from the simplest configurations through the most complex of structured query language (SQL)-driven commands that directly drive the utility (Maizel, 1998). Effective expression of utility analyses requires the highest capacity, internet-based information management technologies in the more 'living' and flexible digital world as accessed through interfaces. Rapidly exploding information needs of the research, education and private and public decision-making community are quickly demanding accessible, though off-site means for information access management and distribution. Products of such remotely accessible systems do not have to be large databases. They can range from simple GIF files (pictures down-loaded to a PC) through user fees and licenses to full-fledged, licensed utility system spin-offs running in a very large server environment. With the advent of geographic information system (GIS) technology, development and manipulation of RMDs become more reliable. With GIS, spatial data can be linked to tabular data facilitating the use of SQL to generate new maps to assist in decision-making.

Under the leadership of the World Bank (Pieri et al., 1995) and in collaboration with many international and national organizations, there is an effort to develop a set of land quality indicators (LQI) for assessment and monitoring of sustainable land management (FAO, 1993) and for the strategic and tactical development of a nation's land resources. Land by definition, encompasses both the biophysical and socio-economic components and the interaction of these characteristics results in a multitude of entities. The number of

possible combinations and permutations is too large to handle but with reasonable assumptions, homogenous entities can be defined for most purposes. These are referred to as resource management domains (Dumanski and Craswell, 1998; Eswaran et al., 1998) and this paper looks at considerations for developing them to serve as basic units for LQIs.

2. Resource management domains

RMDs are geographic areas that are homogenous with respect to defined agricultural uses, have defined physiographic boundaries, and have similar land quality characteristics (Eswaran et al., 1998). In data-sparse environments, such as developing countries, soil resource inventories with some supporting climatic information are generally the only kinds of information available for characterizing the resource potentials of the nation or region. Depending on the land conditions and details of primary information, land quality within RMD may show large variations. RMDs can be created from such information and become the basis of analytical frameworks to estimate outcomes of alternative program delivery options; however, refining the RMD is a continuing task. In data-rich environments, such as the US and the developed countries, using clustering techniques of a large number of parameters that impact the objective may attain similar goals. Even in these situations, a biophysical basis for designing RMDs has advantages as it provides a permanency in the resource assessment/characterization process. The land quality profile of such RMDs is generally homogenous for most agricultural uses. The RMDs may be split or clustered further if the objectives require refinement.

There must be permanency in RMDs for national resource inventories. The ability to analyze temporal information is as important as spatial information. Dumanski and Craswell (1998) have envisaged, “*a Resource Management Domain (RMD) as a spatial (landscape) unit that offers opportunities for identification and application of resource management options to address specific issues. It is derived from geo-referenced biophysical and socio-economic information, and it is dynamic and multi-scale in that it reflects human interventions in the landscape.*” The dynamic and multi-scale nature of the RMD envis-

aged by Dumanski and Craswell (1998) is a critical attribute, but fails to emphasize a most important function. In principle, one could create an RMD for each objective. Although this may satisfy immediate needs of the user, the ability to transfer information to other users for other purposes may be lost. Thus, RMDs to some extent must have the capability to serve multi-purposes and not just specific issues. A landscape based biophysical unit will not always meet this requirement and where it does not, RMDs can be split or grouped to meet these other needs. A landscape based unit enables communication between all sectors of society, which becomes extremely important for land management legislation and transfer of technologies. An RMD must be amenable to be linked to other kinds of analysis. Crop simulation models, land management models, and any model that deals with ecosystems, require a unit of land to simulate the processes or conditions to back-stop decision support systems. The computing capacity, data availability, and the desired accuracy are variables that determine the size of the land unit. For pragmatic purposes, the unit must be sufficiently large to meet these requirements — usually larger than polygons on detailed soil maps. A practical solution is usually clustering of map units. From the spatial/temporal associations among physical/environmental and known management factors within an RMD, it is possible to infer by correlative means, domains in other parts of the country or the world where landscape and climate characteristics together with other crop-specific variables are similar. These other areas may lack the information for managing the land and by using default information from homologous RMDs, one can address the land management constraint. Such areas are expected to respond similarly to management within certain limitations of the knowledge base. Finally, RMDs must serve other purposes and particularly non-agricultural purposes such as agriculture census or even population census. An RMD is, hence, necessarily a biophysical unit demarcated on the landscape with available land-use and land-conditions information and becomes a permanent feature in evaluating a nation's land resources.

3. Defining RMD-based LQIs

The RMDs, which are defined, and the LQIs used for assessment and monitoring must meet the needs of

a variety of users. Both national and local politicians are interested in targeting programs and determining how well their objectives are met. Naming the RMD with a locality name or simple numeric codes is usually well received. Implementing agencies and decision-makers on land management programs must have the capability to determine how well these political objectives are met. They also have to monitor progress and status so that corrective actions for not only the target RMD but also linked RMDs are known. They have to be accountable for spending public sector funds. The technical-scientific community is interested in system processes and RMDs provide a sufficient homogenous entity to base their models. Finally, since RMDs are defined on biophysical characteristics, they become an entity to evaluate the socio-economic impacts on defined ecosystems.

The work of the Task Force on Land Quality Indicators of the World Bank has elucidated the concept of LQIs and discussions are underway for global assessments. The determination of dynamic changes of land quality is crucial to the development and implementation of policies designed to ensure sustainable agroecosystems. A dynamic change in the conditions of land is a function of the cumulative changes of state of individual ecosystem attributes, throughout the period of interest. The change of an attribute from time zero to a new time period requires estimates of the reference state and the selection of an appropriate time frame for its measurement of change, and RMDs provide the land unit for such measurements. Resilience of the land is one way of evaluating soil management systems for degrading or improving processes. In systems where $dLQI/dT$ is greater than zero, the system is sustainable.

The challenge for the scientist is to select LQIs that are significant indicators of the status and trends of agroecosystems quality and are related to the processes caused by various land management practices. Both qualitative and quantitative indicators have relevance:

- Qualitative indicators — those associated with rather easily observed changes occurring on the land. They are associated with day-to-day awareness and experiences. People observe changes in the crop performance; they detect salt crusts or surface sealing of soils; they note the sediment load in streams; they recognize declining yield trends, etc. What we should learn is how to utilize this

common knowledge in our efforts to scientifically backstop and develop quantitative indicators of sustainability of agroecosystems.

- Quantitative indicators — dynamic changes in agroecosystems must be science-based and should be capable of providing reliable assessments of the consequences of land management practices. Such indicators must rely on the scientific knowledge of relationships supported by theory and experimentation. It is a never-ending search for meaningful and practical ways of efficiently, and effectively, assessing and evaluating changes. The operational approach basically consists of (i) a careful selection of observation/test sites, (ii) setting up of validated standards, (iii) definition of 'present' base level status to serve as a 'benchmark', (iv) decisions on the periodicity of monitoring, and (v) setting up a framework for coordination of research and information gathering.

Decisions must be made about the units of study and the hierarchy of information integration (Singh and Singh, 1995). This is because society is also stratified with different information needs for the different sectors (Grandstaff, 1992). To be meaningful, land-resource information must be managed according to scale. Eswaran et al. (1998) proposed a hierarchy of units (Table 1) to reflect the spatial basis for evaluation. This hierarchy, developed on the tenets of hierarchy theory (O'Niell et al., 1986), implies that optimization of biodiversity, ecosystem health and integrity, commodity production, or maintaining soil quality, are each articulated based on the objectives that apply to the planning area. Management goals, therefore, determine the planning area to be defined, the goods and services, and the desired conditions of the ecosystem (Wagner, 1995). Defined biophysical units as those described in Table 1, serve as a common denominator for synthesis of information which could be shared by a range of disciplines, such as, hydrology, geomorphology, pedology, crop science, economics, sociology, land-use planning, and production technology. In this approach, system dynamics or temporal variations are de-emphasized with the assumption that each RMD or FMD has attained an equilibrium or quasi-equilibrium within the planning horizon of the society. This is due to the practical purpose for which land-resource assessments are generally made. However, if time periods of 50 or more years are considered,

Table 1
Hierarchy for and attributes of land management units

Descriptor	Analysis scale	Minimum area for decisions (ha)	Criteria for differentiation	Purpose and general use
Agroecological zones (AEZ)	<1:10,000,000	>40,000	Broad groupings of climate, generally resulting from global atmospheric conditions; (Groupings of soil moisture and temperature regimes; Broad ecosystem patterns.	General global/continental/regional assessment; Global climate change studies; Analysis of international production and trade patterns; Priority setting for continent/regional technical assistance and donor support.
Land resource regions (LRR)	1:1,000,000 to 1:10,000,000	4000–40,000	Contiguous areas with similar natural resource endowments; Ecosystems with distinct vegetation affinities usually determined by limiting factor/s of precipitation and/or temperature. Watersheds used to subdivide LRRs with similar hydrologic functions.	Demarcate areas in regions or large countries for assessment and implementation of economic development programs; Priority setting for multi-purpose uses of land resources; Infrastructure development to assure equity in development; Basis for diversification of agriculture and uses of land resources.
Major land resource areas (MLRA)	1:250,000 to 1:1,000,000	250–4000	Contiguous areas with similar production systems; Climate controlled largely by continental weather patterns such as length of dry season or cold weather; Generally characterized by combinations of climate, geomorphology, and topography; these control the general hydrology of the area.	Development of strategic plans for regional development; Allocation of national financial resources for natural resources development and management; Basis for coordinating national resource assessment programs; Basis for implementing environmental management programs.
Resource management domains (RMD)	1:25,000 to 1:250,000	2.5–250	Production units with similar land use and land management requirements; Units described by soils, climate, and socio-economic factors.	Targeting research and development for specific land use or cropping systems; Implementing conservation practices; Implementing ecosystems based assistance; Community development/awareness projects; Monitoring sustainability; Modeling ecosystem performance
Farm recommendation domains (FRD)	1:1,000 to 1:25,000	0.004–2.5	Units described by socio-economic characteristics of farm; Though land use is similar, variability in soil conditions determine management technology and production capabilities.	Basic units for extension/technology transfer; Modeling cropping systems performance; Implementing soil-specific farming; Addressing socio-economic concerns.

the concept must be refined. The latter approach is required for assessments of forest ecosystems.

In the last decade, much work has been done on land quality and soil quality. These are not synonyms as their assessment is based on scale of observation. In Table 1, the two lowermost units are referred to as resource management domains and farm recommendation domains, each having a range in scale within which each has most relevance. Land quality indicators (LQIs) are ideal to evaluate RMDs. Soil quality indicators (SQIs), due to the requirement for more detailed information on soil properties and conditions, are more appropriate for use in farm recommendation domains. For some purposes, LQIs and SQIs may be used outside their normal scale of usefulness. This is particularly true of LQIs, which can be used for smaller scales, such as major land resource areas.

For most practical purposes, the LQIs must have a monetary value attached or could be eventually evaluated in monetary terms. Although physical indicators can be collected, monitored and assessed for dynamic changes, it is essential to have real cost economics of the consequences of the land management practices.

4. RMD attributes and profiles

Variables considered for defining resource management domains (Eswaran et al., 1998) are presented in Table 2. The utility of each variable is determined by several factors including, availability of data on the attribute over a time frame, sensitivity of the data to changes being monitored, relevance of information to local situation, and statistical techniques to be employed for processing information. For general land management purposes, each RMD can have a profile (Table 3) providing information on biophysical characteristics, land quality attributes and indicators sensitive to change, socio-economic features that enable aggregation of RMDs for socio-economic assessments, and other features that show the linkage of one to another. Although there may be a commonality of basic information, location-specific information provides the unique features of the RMDs.

Aggregation of RMDs may be necessary for purposes such as those below:

- Crops are indicators of managed and natural environmental conditions. Clusters of RMDs for specific

Table 2

Variables considered for defining resource management and farm recommendation domains

Biophysical properties/attributes	Socio-economic attributes
Climate	
Temperature	
Frost incidence	
Rainfall pattern/quantity	Farm size
Risk of drought	Land tenure
Risk of flooding	Access to markets
Altitude	Access to family labor
Onset and duration of climatic events	Access to other labor
Soils	
Texture	Access to credit
Drainage	Access to cash
Slope and land form	Access to energy/power
Effective soil depth/water holding capacity	Access to irrigation
Cation exchange capacity	
Organic carbon	Off-farm labor opportunities
Soil pH	Off-farm inputs
Salinity/alkalinity	Proportion of farm income available for non-food items
	Food preference and diet
Surface stoniness	Community customs and awareness
Other limiting properties	Social obligations
Fertility parameters	
Biology	
Disease incidence	Risk aversion
Pest incidence	Religion
Weed incidence	National and local policies
Crop phenology/genetic coefficients	Availability of extension services
	Response to new technologies

crop (corn) production systems will enable an analysis of the performance of this crop production sector of the economy. Such an analysis is made using crop simulation models and RMDs are appropriate units to serve as the basis for such assessments.

- Pests are indicators of crop growth conditions and vice versa. RMDs using pests as indicators can be developed by inference from a series of observations on crop/pest associations. RMDs have the added advantage in being able to be used as a basis for extrapolation.
- Fertility management cannot be done based on plots and it is not practical to compound fertilizers by soil type. RMDs offer a functional alternative to enhance the efficiency of fertilizer use.

Table 3
General usefulness of some attributes to develop a profile of a RMD^a

Attribute	Descriptor	General usefulness
<i>Socio-economic</i>		
Urbanization	Proportion of farms to towns; density of different classes of roads;	Medium
Mobility of people	Number of migrants	Low
Social class	Homogeneity in race, color, religion	Medium
Economic status	Average income; use of off-farm inputs; status symbol possessions	High
Educational status	Of different sectors of population; literacy status	High
Occupation	Extent of non-farm functions of farmers or proportion of off-farm income of farmers	High
Transport	Amount of kinds of vehicles for transport – bicycles, pick-ups, trucks	High
Family type	Several generations or single generation in one house	Medium
Age structure	Proportion of adults in family	Medium
Energy source	For house, farming	Medium
Infrastructure	Water and electricity supply, roads, marketing facilities	Medium
Land tenure	Owned, leased and conditions of lease	High
<i>Biophysical</i>		
Land-use	Proportion of land cultivated; kind of crops/ cropping systems	High
Value of production	Farm gate market value of produce	High
Farm capacity	Size of farms	Medium
Social laws of land-use	None to very rigid	Medium
Soil quality	In the context of farming system	High
Land potential	Current production to achievable levels	High
Land-use configuration	Context of ecosystem equity	Low
Historical land-use pattern	Changes in farming systems over defined periods	Medium
Productivity trends	Changes in yield over time	Medium
Quality of SLM	Application of conservation measure, use of agri-chemicals, use of hybrid seeds	High

^aRating: High-to-low, is locale specific.

Though RMDs may be aggregated for specific purposes, each RMD must have its own profile with its own set of attributes. Splitting or clustering of RMDs should not result in a loss of their individual identities.

5. Conclusions

The final geo-referenced RMD map of a country or region becomes the basis for several major assessments and can be linked to other databases to provide answers for decision-making. Features of some of the products generated from the basic RMD maps and RMD profiles include:

- *Broad public educational value.* Information can be developed to illustrate this for the non-technical user using modern day, computer-driven visualization techniques.

- *Have private as well as public value.* Means for integrating corporate and farmers-specific information while protecting the private property interests of the partners must be explored.
- *Have value to the private sector.* To meet needs for marketing of effective and appropriate crop-production systems, the domains will be developed according to parameters of known value to the corporations or farmer organizations.
- *Serve as basis for national resource inventory,* which determines the state and conditions of the resource base and using land quality indicators, to monitor changes in the conditions.
- *Targeting management within RMDs.* RMDs are ranked by their means in terms of performance with a production system or success in adopting land management technologies. Targeted RMDs are then approached with appropriate programs and features.
- *Private sector applications.* Crop and livestock consultants, fertilizer dealers, chemical and seed

companies, and technology marketers would have an enhanced and more specific tool with which to promote products.

- *Extend the land quality indicators (LQI) applications.* The LQI is a unique and invaluable tool, and when fully functional, it would have the capability for integration into new information systems. For some purposes, the LQI is a descriptor of the RMD by which preliminary assessments can be made for land-use planning.

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