The Definition and Mapping of Small-holder Farming Systems for Agricultural Policy Development: An Application in Uganda

Ingrid Rhinehart and Jordan Chamberlin

Abstract

Spatially-explicit characterizations of farming systems are important to the definition of policies for economic growth, sustainable resource use and improving human welfare in rural populations. Much of the developing world, however, is characterized by patterns of small-holder land use that reflects fragmented and heterogeneous livelihood pursuits. This makes the multiple, overlapping spatial characteristics of livelihood enterprises particularly challenging to map in any detailed way. This paper presents a farming system characterization for Uganda, based upon a detailed national household survey, and its spatial rendering through a cartographic model that combines survey information with land use/land cover data.

1. Context

1.1. Rationale for this study

The Green Revolution has lifted millions of people out of poverty and has mitigated doomsday forecasts of global mass hunger. However, the enormous successes of the Green Revolution also put great stress on agroecological systems due to the increased use of inputs such as water and agrochemicals. For the most part, the Green Revolution was biased toward more favored land (Pender and Hazell 2002, Altieri 2001), characterized by productive soils on moderate slopes with adequate rainfall, drainage, and other details. Less favored areas, characterized by smallholder/subsistence agriculture, have to some extent been left behind, and yet the majority of the poor (about 370 million of the world's poorest) live in resource-poor, highly heterogeneous and risk-prone areas (Pinstrup-Anderson et al. 2001). It is critical to promote sustainable and productive land use systems where smallholders can improve agricultural productivity and avert future productivity losses with responsible and broad-based integrated natural resource management (INRM). A major challenge is to identify policies, institutions, and technologies to make the three goals of growth, poverty alleviation, and sustainable natural resource use more compatible.

The dedication of strategic planning frameworks to this purpose depends upon detailed information about the location and characteristics of rural agricultural enterprises. The multiplicity of concurrently pursued rural livelihood strategies is typically very complex, however, and difficult to render in discretely mapped entities. This complexity can be rendered more meaningful for policy analysis, through the definition and mapping of production systems defined on the basis of commodities produced by households. Once this information is available, a spatially-explicit framework can be constructed to evaluate the relationship between different production strategies and patterns or processes of interest, such as changes in population densities, or patterns of land conversion from natural landscape types to agricultural production.

1.2. Development planning needs in Uganda

Uganda has made great strides since the late 1980s towards economic growth and poverty reduction. The 1990s saw a precipitous climb of annual GDP growth of 6.9%, compared to only 3% per annum during the 1980s. As a result, the percentage of population below the poverty line has dropped from 56% in 1992 to 35% in 1999 (Fan et al. 2002). This rapid reduction in poverty in such a short period is rare not only in sub-Saharan African countries, but across the globe. The success in Uganda is extremely attractive to the foreign donor groups, including USAID. A key ingredient in USAID/Uganda's Integrated Strategic Plan for 2002-2007 is the merging of the economic growth and environmental Strategic Objectives (SOs). As identified under SO7, Expanded Sustainable Economic Opportunities for Rural Sector Growth (USAID 2001), SO7 will "assist Uganda to reduce rural-based poverty and sustain economic growth by expanding economic opportunities and increasing employment, income, and the viability of enterprises" while halting environmental degradation and biodiversity loss (USAID 2001). The key strategy for achieving this objective is the integration of economic growth, agriculture, and environmental and natural resource interventions (USAID 2001).

Developing sustainable and productive land use systems is essential for poverty eradication and sustained economic growth in rural Uganda where the vast majority of people rely on natural resources for their livelihood, and are expected to continue to do so into the foreseeable future. The present study focuses on production systems and their associated rural land use patterns in Uganda, a largely-agricultural country in sub-Saharan Africa. The goal of this work is to meaningfully relate knowledge of production systems and landscape resources in such a way that enables the design of development policy that successfully integrates the country's agricultural growth and rural livelihood needs with responsible environmental management.

1.3. Mapping production systems as a context for policy making

A common task for policy-makers in the developing world is to reconcile the necessary tradeoffs between agricultural expansion and maintenance of environmental goods and services. This requires decision-making tools that are able to relate the practice of agricultural livelihoods with specific environmental goods and services that may be affected by changes in those livelihood strategies. Such tools depend upon an understanding and representation of the complexity of livelihoods pursued within heterogeneous smallholder farming systems that characterize much of the developing world. Knowing the conditions under which different commodities are produced enables a better understanding of the agricultural-environmental interface. In other words, how the expansion of production of specific commodities may affect an area's natural resource base.

The definition of farming systems has enabled us to make sense out of complex systems. However, these are often coarsely classified and defined on the basis of *a priori* assumptions, deriving from expert knowledge. We propose an objective, data-driven approach to production system definition that will enable more policy-relevant analysis through associating specific systems and their constituent commodities with conditions that are mappable. By using mapped data within a digital cartographic environment, we present a methodological framework for evaluating location-specific environmental changes associated with expansion of production activities.

The methodological approach to defining and mapping Ugandan production systems is explained. The spatial distribution of these systems is presented here as a generalized framework for evaluating rural development policy scenarios, such as *ex ante* and *ex post* impact studies related to agricultural productivity, rural incomes, or land use/cover changes, to name a few typical policy concerns. We offer a brief example of landscape valuation within production system extents. The emphasis of this paper, however, is to present a novel methodology for mapping smallholder production systems and to identify and discuss some issues of reliability and representation associated with this methodology.

2. Data & Methods

2.1. Defining production systems

To date, production systems have largely been defined by researchers and policy-makers through expert knowledge and *a priori* characterization (see for example, Dixon et al. 2001, Wortmann and Eledu 1999, Quiroz et al. 2000). In an effort to produce unbiased classifications of production systems we define these through cluster analysis of household data from the Uganda National Household Survey of 1999-2000. We then project the outcomes using multinomial logit regression technique using other geographically referenced data representing climatic and demographic conditions.

Cluster analysis is a method of grouping observations with similar characteristics into larger units of analysis in order to classify sets of observations or identify patterns in data. In this exercise, a combination of hierarchical and non-hierarchical clustering methods was used (as described by Hair et al.1998.). An agglomerative hierarchical analysis was performed to visualize the similarities in the data and to determine the appropriate number of clusters for the study. Following this, a non-hierarchical method of creating clusters and assigning cluster values using multi-dimensional distance calculations was performed.

For this analysis, the record for each household reflects what crops they produce and what types of livestock they raise through the assignment of ones and zeros. This binomial system allows combinations of crop and livestock production to be the predominant issue (as opposed to production share levels or farm scale) and therefore disregards value measures at this level of analysis. Five clusters were identified and are summarized in Table 1. The sixth cluster (Cluster 0) consists of all of the non-agricultural households in the household survey and was used as a comparison group.

Clusters 1 and 3 are fairly similar in production while 2 and 4 are also very similar. In clusters 1 and 3, the majority of Uganda's matooke is grown as well as maize, beans and sweet potatoes. The major difference between 1 and 3 is the stronger presence of livestock in cluster 3 including goats and chickens. Clusters 2 and 4 are generally represented by production of maize, cassava, sweet potatoes and chickens. Cluster 2 is also strong in beans while cluster 4 has a high proportion of households growing millet, sorghum and goats. Cluster 5 has low participation levels in the production of many commodities but is strongest in maize and beans. It is also important to note that the majority of cotton, sesame and rice production (notably crops of higher value) takes place in clusters 2 and 4, while the majority of matooke (all types) and Irish potatoes are grown in clusters 1 and 3.

A multinomial logit regression was used to analyze the clusters and estimate a surface using biophysical and demographic characteristics as the independent variables. These variables include a market access index (Potential Market Integration), population density, elevation, and July rainfall (to account for precipitation and seasonality). The coefficients and relative predictive accuracy are summarized in Table 2. The strength of the results (minimal differences between actual and predicted) indicates that this method is fairly accurate with respect to this particular frame of analysis and we can be confident in our application.

The predicted surface did not initially cover all of Uganda due to the limited range of values associated with the household locations. The predictive surface can be extended for practical purposes to the rest of the country to provide information to policymakers. This extrapolation should be viewed with some skepticism, but we believe the surface to be relatively accurate due to the strength of the predictive elements as mentioned above and knowledge of the areas concerned.

These predicted surfaces are shown in Figure 1. Clusters 1, 3 and 5 occupy similar regions, primarily the southwestern highland area and the northeastern portion of the country. These areas are represented by higher and more variable elevation, bimodal rainfall patterns and higher market access. Clusters 2 and 4 are found primarily in the northern half of the country, which is characterized by unimodal rainfall patterns, lower and less variable elevation and lower market access.

Table 1: Final Cluster Centers

Final Cluster Centers (share of participation)	1	2	3	4	5
Matooke (Food)	0.92	0.02	0.92	0.07	0.45
Matooke (Beer)	0.35	0.08	0.37	0.07	0.10
Matooke (Sweet)	0.13	0.05	0.13	0.05	0.03
Maize	0.80	0.77	0.86	0.59	0.68
Millet	0.27	0.28	0.29	0.78	0.17
Sorghum	0.08	0.05	0.11	0.86	0.36
Rice	0.01	0.05	0.03	0.09	0.01
Beans	0.94	0.73	0.97	0.45	0.79
Field Peas	0.01	0.07	0.01	0.26	0.02
Cow Peas	0.02	0.02	0.03	0.05	0.12
Pigeon Peas	0.01	0.06	0.01	0.12	0.01
Groundnuts	0.32	0.37	0.40	0.48	0.07
Soybeans	0.02	0.02	0.05	0.05	0.01
Sesame	0.01	0.16	0.01	0.28	0.02
Cotton	0.01	0.10	0.02	0.19	0.02
Irish Potatoes	0.12	0.06	0.15	0.02	0.22
Sweet Potatoes	0.82	0.58	0.87	0.54	0.47
Cassava	0.75	0.98	0.73	0.84	0.01
Coffee	0.68	0.04	0.65	0.02	0.06
Tobacco	0.01	0.06	0.02	0.02	0.02
Cows	0.23	0.12	0.37	0.34	0.16
Bulls	0.06	0.04	0.13	0.20	0.06
Oxen	0.00	0.01	0.01	0.11	0.02
Pigs	0.13	0.09	0.24	0.16	0.05
Goats	0.28	0.35	0.51	0.63	0.24
Donkeys	0.02	0.01	0.01	0.02	0.01
Chickens	0.00	0.56	1.00	0.73	0.28