6 Linking livestock production systems to rural livelihoods and poverty

One of the overarching objectives of understanding and mapping livestock production systems is to explore the impacts of these systems, and changes thereof, on people's livelihoods. For those whose livelihoods are highly dependent on farming, the types of production systems in which they are engaged or could become so has a significant bearing on their incomes, welfare and food security. In this section an attempt is made to link production system information with welfare and livelihoods, through three case studies. In the examples from Uganda and Viet Nam, detailed household survey data are explored in an attempt to disaggregate the mixed systems further. In each case the resulting systems classifications are analysed in relation to poverty statistics. In the third example from the Horn of Africa, livelihood data are used directly to map livestock production systems. While these case studies may be insightful in themselves, it is further hoped that from the specific lessons learned, patterns will emerge that may apply more generally and thus make a contribution to improving attempts at developing a global classification.

LIVESTOCK SYSTEMS AND POVERTY IN UGANDA

Uganda is a largely rural, agricultural society: about 88 percent of the population lives in rural areas. Some 40 percent of the rural population live below the poverty line, accounting for 95 percent of the poor in the country as a whole. Most of these depend on agriculture as their primary source of livelihood (Fan *et al.*, 2004). For the majority of Ugandans the agricultural sector is the main source of livelihood, employment and food security. The sector provided 73 percent of employment in 2005/06, and most industries and services in the country are dependent on it (UBOS, 2009). Smallholder production dominates the agricultural sector and crop-based agriculture is dominant within this, with bananas, cereals, root crops and oil seeds being the main food crops. Tea and sugar plantations are primarily large-scale commercial efforts (Matthews *et al.*, 2007), while other important cash crops are coffee, cotton and tobacco. Cash crops are the primary sources of export earnings.

Despite its importance, overall growth in agricultural output has been falling. A growth rate of 7.9 percent in 2000/01 was down to 2.6 percent in 2007/08 (UBOS, 2009; NPA, 2010). Agriculture's contribution to gross domestic product (GDP) fell from 20.6 percent in 2004 to 15.6 percent in 2008 (UBOS, 2009). While growth rates in overall agricultural output have declined, the livestock sector is growing in response to increasing demand for animal-source foods. Livestock production contributed 1.6 percent to total GDP in 2008 (UBOS, 2009). The number of cattle in the country doubled from 5.5 million in 2002 to 11.4 million in 2008 (UBOS, 2009). The numbers of sheep and goats more than doubled during the same period, and the number of pigs and chickens increased by 88 percent and 59 percent, respectively (MAAIF and UBOS, 2009).

About 71 percent of all households in Uganda owned livestock in 2008 (MAAIF and UBOS, 2009). Smallholders and pastoralists dominate the livestock sector, owning 90 percent of Uganda's cattle and almost all of the country's poultry, pigs, sheep and goats (Turner, 2005). Ugandans reliant solely upon crop agriculture are more likely to be poor than those whose production systems extend beyond crops to include livestock or fishing (Okidi *et al.*, 2004). For most Ugandan households, however, livestock is not the main source of cash income, ranking only second or third in its contribution (Ashley and Nanyeenya, 2002). Rather, the animals serve as a source of food, as a store of wealth, confer social status and, moreover, form an integral part of mixed production systems by providing draught power, fuel, manure and transport, and a profitable use for crop residues. Pastoralists are mainly found in the northeast and in the southwest of the country, where human population densities and rainfall are low. In other parts of the country, agropastoralism and mixed-farming systems dominate, alongside some commercial beef and dairy outfits, mainly located in Mbarara District in the southwest and around Kampala.

A number of classifications of agricultural production systems has been developed for Uganda. For example, NEMA (1996) distinguished five systems: 1) northern and eastern cereal–cotton–cattle; 2) intensive banana–coffee; 3) western banana–coffee–cattle; 4) west Nile cereal–cassava–tobacco; and 5) Kigezi afromontane. Musiitwa and Komutunga (2001) developed a classification which again was split into five classes, but with little overlap with the former: 1) long-rain unimodal systems (northern and west Nile systems); 2) transitional zone (Teso, Lango and banana–cotton–finger millet systems); 3) banana and coffee system; 4) montane systems (Elgon, Kabale-Kisoro and Ruwenzori); and 5) pastoral systems (Karamoja and the southwestern pastoral systems). Closely related are national estimates of agro-ecological zones. For example, Wortmann and Eledu (1999) distinguished 33 agro-ecological zones, including landscape, soils, land use, climate and cropping systems, each of which they described in detail.

The classification schemes above are highly specific to Uganda, while the more widespread classifications such as Dixon *et al.* (2001) and Thornton *et al.* (2002) tend to lack the required level of detail to be of real practical use at country level. Below, data on crops and livestock from an agriculture module of a national census have been used to explore a data-driven approach to the characterization of mixed production systems in Uganda. The resulting systems are then linked to welfare estimates.

Methods

Data on crops and livestock were obtained from the 2002 Uganda National Housing and Population Census (UBOS, 2004). The crop data comprised the number of plots of various crops for each of the 962 subcounties, defined as a piece of land within the holding on which a specific crop or crop mixture is cultivated. Crops included in the analysis were maize, millet, sorghum, rice, oil crops (groundnuts, soybeans, sesame), roots and tubers (cassava, sweet potatoes, Irish potatoes), banana, coffee, cotton, and pulses (beans, cow peas, field peas, pigeon peas). Livestock data were gathered and taken to be the number of cattle, goats, sheep, pigs and poultry in each administrative unit; these were grouped into ruminant and monogastric species.

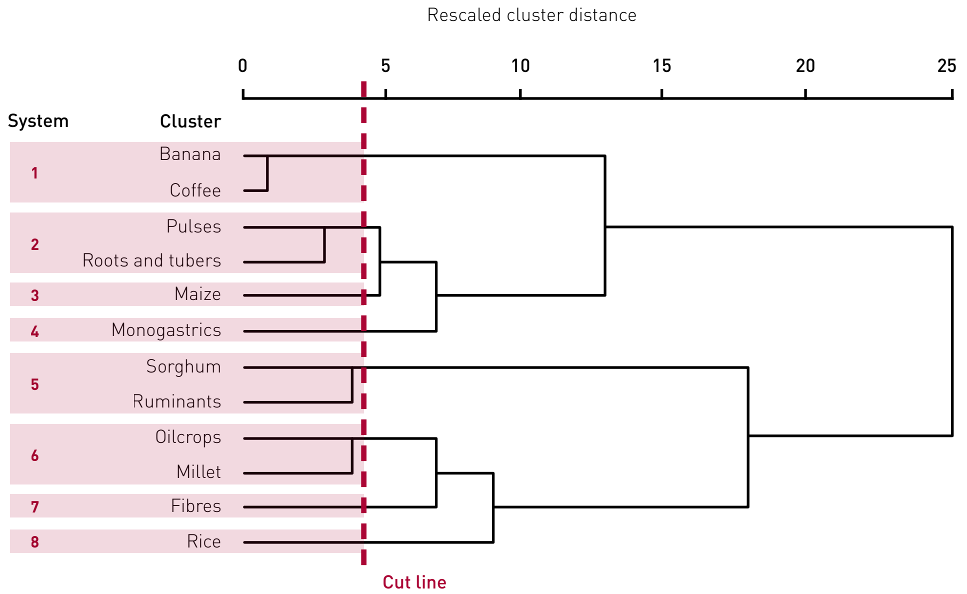
Cluster analysis identifies relatively homogeneous groups of cases based on selected characteristics, so that variation within groups is minimized and variation between groups is maximized (Kaufman and Rousseeuw, 1990). An explorative hierarchical cluster analysis was first used to visualize similarities among the variables used, followed by K-means clustering, which was used to create the clusters and assign cluster values to each case. Twelve crop and livestock variables were considered for 962 Ugandan subcounties. The squared Euclidean distance was chosen as the proximity measure, and representative clusters were identified using the final cluster centres, which represent the average value on all clustering variables of each cluster's member, and the Euclidean distance between final cluster centres.

The clusters obtained were then mapped and characterized in terms of a number of environmental and demographic variables, including poverty estimates. Furthermore, they were compared directly with the livestock production systems classification of Thornton *et al.* (2002) using a correspondence analysis (Greenacre, 1984).

Results

The dendrogram from the hierarchical cluster analysis (Figure 6.1) was used to assess the cohe-

6.1 DENDROGRAM OF THE CLUSTER ANALYSIS, SHOWING THE CUT LINE USED TO DISTINGUISH EIGHT SYSTEMS



siveness of the clusters, and determine the appropriate number of clusters to retain. Using a heuristic approach, the tree was cut (shown by the vertical red line in Figure 6.1) so as to yield eight clusters with a reasonable number of subcounties in each (shifting the cut line to the left would increase the number of clusters; shifting it to the right would reduce that number).

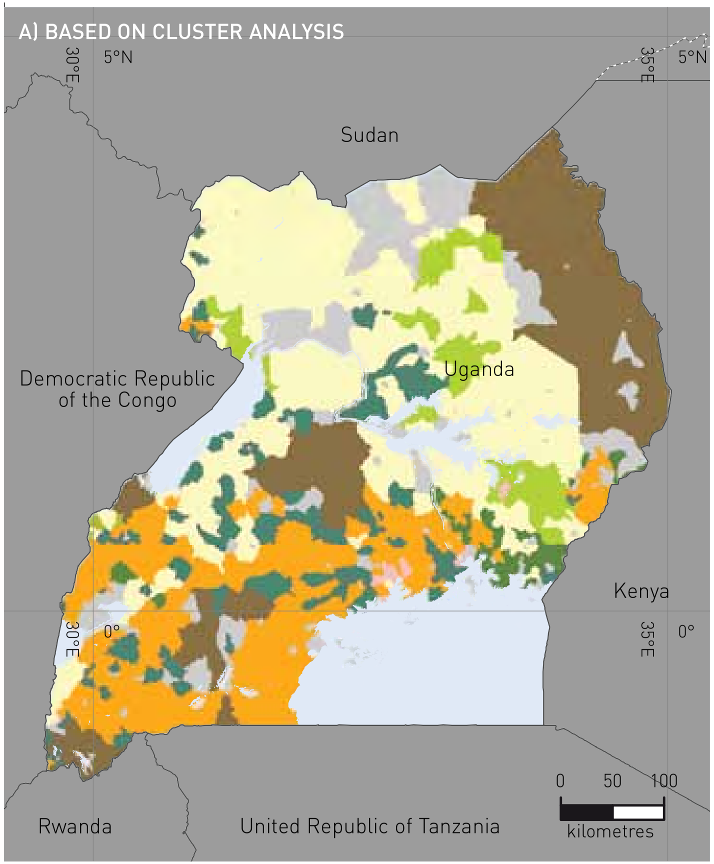
These eight clusters accounted for 793 (82.4 percent) of the subcounties. To these, a further system called 'mixed' was added, which was represented by 169 (17.5 percent) subcounties. In this class the values of the final cluster centres were very similar for all the variables used, which is why they were not readily included in any of the other clusters. The result was nine representative systems: 1) banana and coffee; 2) roots, tubers and pulses; 3) maize; 4) monogastrics; 5) ruminants and sorghum; 6) millet and oil crops; 7) fibres; 8) rice; and 9) mixed.

Figure 6.2 shows the spatial distribution of these, and Table 6.1 shows their values for a number of environmental and demographic variables. Tables 6.2 and 6.3 show the values for livestock densities and crop production by system.

The ruminants and sorghum system is typical in the northeast of Uganda, which is of generally low agricultural potential, low rainfall (average LGP is about 140 days), low population density, and where poverty rates are high. This system also occurs in central and southwest Uganda (with the exception of Mubende District, which has more forests and cropped areas) corresponding broadly overall to the area known as the 'cattle corridor'. The majority of cattle are kept in these areas, which are characterized by poor market access and low population densities. The monogastric system, dominated by pigs and poultry, is distributed in peri-urban areas around Kampala and other urban centres. The banana and coffee system, in which more than eight million rural Ugandans are engaged, is concentrated in the highland areas of Mount Elgon at the Kenyan border, in Nebbi District in the northwest (though less intensively), and on the shores of

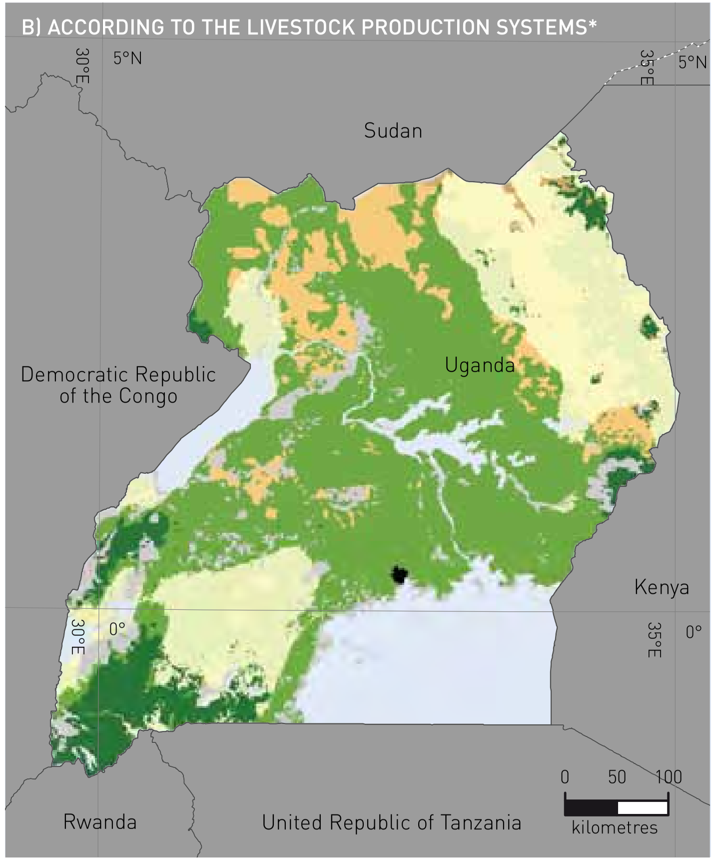
6.2 DISTRIBUTION OF AGRICULTURAL SYSTEMS IN UGANDA

A) BASED ON CLUSTER ANALYSIS



Banana and coffee | Fibres | Maize | Mixed
Millet and oil crops | Monogastrics | Rice
Ruminants and sorghum | Roots, tubers and pulses

B) ACCORDING TO THE LIVESTOCK PRODUCTION SYSTEMS*



* Version 3 (Kruska, 2006).

LGA | MRA | Urban areas
LGH | MRH | Other
LGT | MRT

TABLE 6.1 SUMMARY OF SELECTED ENVIRONMENTAL AND DEMOGRAPHIC VARIABLES (LAND AREA, POPULATION, PERCENTAGE OF POOR PEOPLE, ELEVATION, LENGTH OF GROWING PERIOD, PERCENTAGE OF POOR HOUSEHOLDS, AND MEAN WELFARE VALUES) BY AGRICULTURAL PRODUCTION SYSTEM IN UGANDA

System	Land area km²	%	Mean elevation (m)	LGP (days)[a]	Rural population[b]	Number of households[c]	Percent poor[c]	Mean monthly per adult equivalent expenditure (USh)[d]
Banana and coffee	40 505	20.0	1 349	205	8 060 170	2 159	28.4	15 555
Roots, tubers and pulses	16 401	8.1	1 227	213	2 072 510	549	30.6	15 652
Maize	4 059	2.0	1 271	225	952 841	267	41.9	14 909
Monogastric	779	0.4	1 156	246	88 523	50	4.0	18 990
Ruminants and sorghum	40 205	19.8	1 271	142	1 023 030	427	52.5	11 832
Millet and oil crops	67 070	33.0	1 021	208	4 946 350	1 345	49.9	14 310
Fibres	10 821	5.3	1 042	206	1 434 180	366	55.5	14 047
Rice	299	0.1	951	224	47 375	6	66.7	12 824
Mixed	22 832	11.2	1 122	191	1 115 840	280	40.4	13 766

[a] Jones and Thornton (2005) [b] CIESIN *et al.* (2004) [c] UBOS (2003) [d] In 2002 US$1 was equivalent to USh1 739.7

TABLE 6.2 LIVESTOCK DENSITIES (NUMBER PER KM²) BY AGRICULTURAL PRODUCTION SYSTEM IN UGANDA. LIVESTOCK DATA EXTRACTED FROM THE GRIDDED LIVESTOCK OF THE WORLD MAPS (FAO, 2007a)

System	Cattle	Sheep	Goats	Pigs	Poultry
Banana and coffee	56.77	16.45	80.05	14.14	124.40
Roots, tubers and pulses	30.51	8.03	40.24	12.21	92.29
Maize	31.53	4.52	68.03	27.68	242.73
Monogastrics	52.68	12.41	52.46	8.54	97.05
Ruminants and sorghum	25.98	6.22	17.32	3.11	63.21
Millet and oil crops	25.86	4.18	26.22	9.04	133.18
Fibres	39.93	6.29	38.18	10.94	287.20
Rice	5.22	2.54	55.87	1.34	18.03
Mixed	21.93	6.36	25.47	8.98	107.51
Uganda	**32.92**	**7.74**	**37.87**	**9.60**	**121.47**

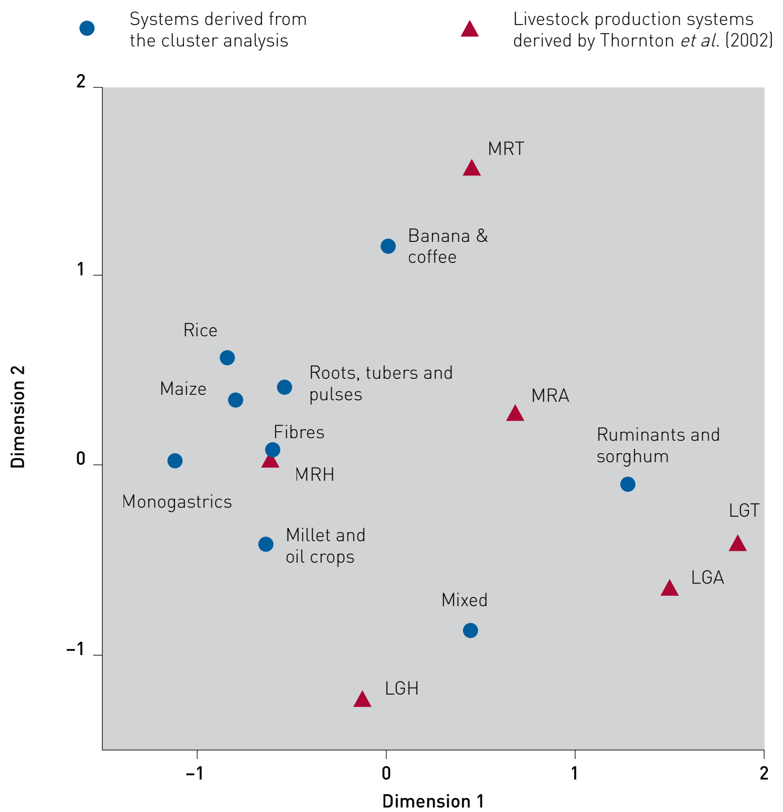
Lake Victoria – characterized by high soil fertility and a bimodal rainfall pattern. It is based on the production of bananas as the main food crop and coffee as the main cash crop. About 20 percent of Ugandans still derive their livelihood directly from coffee; 95 percent of these are smallholders (ADF, 2005). The mixed system (crop–livestock) is common, accounting for 11 percent of the land area and 5.7 percent of the rural population. In this system crop and livestock production are well integrated: crops benefit from manure from livestock while the latter feed on the residues of the crops (ADF, 2002). The roots and tubers, and pulses system and the maize system are more evenly distributed, though less prolific in northern Uganda. The fibres system is concentrated in the drier areas of the northern and eastern regions, where most of the cotton production (cotton is an important cash crop) is

TABLE 6.3 TOTAL CROP PRODUCTION (TONNES) BY AGRICULTURAL PRODUCTION SYSTEM IN UGANDA. CROP DATA WERE EXTRACTED FROM THE SPAM* CROP DISTRIBUTION MAPS

System	Banana and plantains	Beans	Cassava	Coffee	Cotton	Groundnuts	Maize	Millet	Potatoes	Rice	Sorghum	Soyabeans	Sugarcane	Sweet potatoes	Wheat
Banana and coffee	5 642 713	79 530	852 456	58 940	4 906	23 925	153 156	61 629	103 590	3 651	42 505	153 156	419 558	488 930	976
Roots, tubers and pulses	1 110 077	35 189	338 368	16 152	2 758	9 994	63 228	35 492	38 317	3 029	21 109	63 228	140 189	193 900	0
Maize	318 137	22 292	257 022	5 959	1 989	5 444	58 091	28 249	17 070	14 570	5 869	58 091	66 119	117 179	10 061
Monogastrics	27 075	1 579	47 590	1 038	0	121	459	3 663	1 863	205	6	459	6 158	2 410	0
Ruminants and sorghum	873 758	35 772	255 488	18 786	587	7 208	144 648	41 911	83 273	1 004	64 114	144 648	152 847	153 166	682
Millet and oil crops	889 988	131 248	1 813 187	13 641	26 187	60 618	455 855	215 050	96 238	33 407	136 465	455 855	493 428	846 134	12
Fibres	152 386	31 266	551 473	5 992	23 228	13 579	58 281	71 537	50 537	43 437	33 399	58 281	121 134	157 816	0
Rice	4 143	450	2 356	0	0	32	0	2	532	167	34	0	3 633	234	0
Mixed	894 881	51 027	366 476	10 730	4 708	12 101	97 404	38 797	23 190	3 856	31 815	97 404	133 200	208 037	20
Uganda	**9 913 158**	**388 353**	**4 484 416**	**131 238**	**64 363**	**133 022**	**1 031 122**	**496 330**	**414 610**	**103 326**	**335 316**	**113 691**	**1 536 266**	**2 167 806**	**11 751**

* SPAM data from You *et al.* (2009).

6.3 CORRESPONDENCE ANALYSIS PLOT BETWEEN AGRICULTURAL SYSTEMS DERIVED FROM THE CLUSTER ANALYSIS AND THE LIVESTOCK PRODUCTION SYSTEMS, VERSION 1, USING THE OVERLAPPING AREA AS A MEASURE OF CORRESPONDENCE (SYMMETRICAL NORMALIZATION)



concentrated. These two regions are also largely occupied by the millet and oil crops system.

The results of the correspondence analysis between these systems and those of Thornton *et al.* (2002) are given in Figure 6.3, which shows some agreement. The correspondence is quite close 1) between the livestock-only systems (LGA and LGT) and the ruminants and sorghum cluster; and 2) between the banana and coffee cluster and the highland zones of the mixed, temperate and tropical highland system (MRT). Agricultural production in the rest of Uganda overlaps mainly with the mixed, humid and sub-humid (MRH) system, which occupies 47.7 percent of Uganda's land area.

The values in Table 6.4 show the proportion of overlap between clusters and production systems mapped by Thornton *et al.* (2002), obtained from a cross tabulation of the row and column variables.

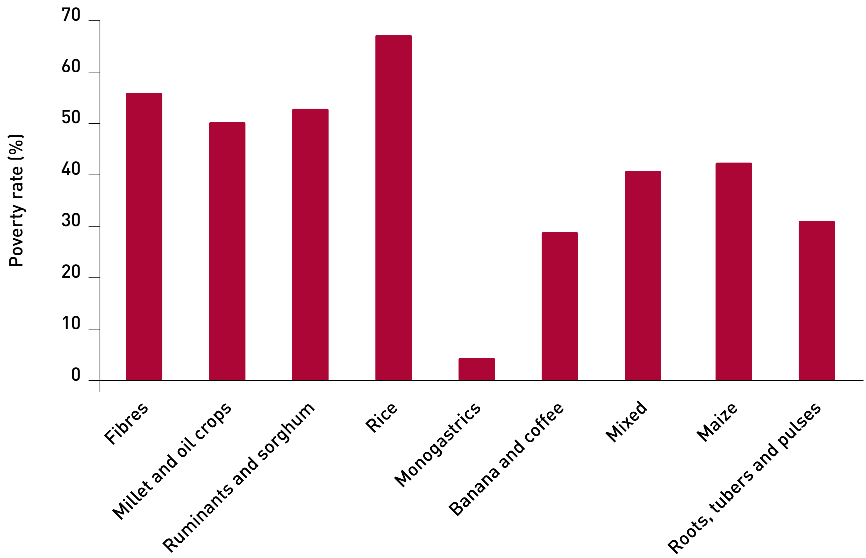
Poverty incidence was evaluated by extracting welfare estimates for the 5 497 geo-registered rural households included in the 2002/2003 Uganda National Household Survey (UBOS, 2003). About 39 percent of these households are classified as poor, and the average monthly per adult equivalent expenditure of these poor households is 14 495 Uganda shillings (USh) (SD = 4 038, N = 2 111). Table 6.1 shows poverty rates and average expenditure levels for the nine agricultural

TABLE 6.4 CORRESPONDENCE BETWEEN AGRICULTURAL SYSTEMS IN UGANDA DERIVED FROM THE CLUSTER ANALYSIS AND THE LIVESTOCK PRODUCTION SYSTEMS*

Cluster	Livestock production system							
	MRH	MRA	MRT	LGH	LGA	LGT	Urban	Other
Banana and coffee	34.5	17.8	18.3	8.8	3.3	2.5	8.0	6.9
Roots, tubers and pulses	53.1	8.4	6.9	11.9	4.0	1.0	4.3	10.5
Maize	60.4	3.6	6.2	5.1	3.0	0.3	15.2	6.2
Monogastrics	48.3	0.0	0.0	8.5	0.0	0.0	39.9	3.3
Ruminants and sorghum	17.1	45.4	8.1	4.4	18.9	2.1	1.5	2.4
Millet and oil crops	61.3	7.6	0.2	19.4	4.2	0.1	3.1	4.1
Fibres	60.5	12.7	0.0	13.6	6.5	0.0	5.9	0.8
Rice	48.5	0.0	10.2	4.6	0.0	1.2	8.3	27.2
Mixed	26.0	18.8	4.0	27.3	14.8	1.3	3.7	4.2

* Version 1 from Thornton *et al.* (2002).

6.4 AVERAGE POVERTY RATES BY AGRICULTURAL PRODUCTION SYSTEM IN UGANDA



production systems derived; these average poverty rates are illustrated in Figure 6.4. If we exclude the rice system represented only by 0.1 percent of Uganda's land area, then the ruminants and sorghum system, the fibres system, and the millet and oil crops system account for the highest percentages of poor people (Figure 6.4). Though the sample size is quite small (n = 50), those engaged in the monogastric system are by far the best off, with only 4 percent living below the poverty line and average expenditures of nearly 19 000 USh per month per adult equivalent. Also fairing well are the banana and coffee system and the roots, tubers and pulses system, which have poverty rates of about 30 percent and average expenditures of some 16 000 USh per month per adult equivalent.

Conclusions

Uganda has emphasized agricultural sector development as a strategy for raising rural incomes and reducing rural poverty (NEMA, 2005). Developing sustainable and productive farming systems is essential for poverty eradication and sustained economic growth in rural Uganda.

To date, production systems have largely been defined by researchers and policy-makers through expert knowledge and *a priori* characterization (Dixon *et al.*, 2001). The use of multivariate statistical techniques, such as cluster analysis, to identify farm types is not new (Köbrich *et al.*, 2003) but a lack of data usually precludes this kind of approach at large scale. An explorative approach has been developed here that can help to provide reliable and realistic information about agricultural production systems in Uganda, showing distinct patterns for mixed farming systems. While this analysis represents an independent methodology based on detailed empirical data, its repeatability is highly dependent on the level of data available at national, regional or global levels. During recent years much effort has gone into modelling global crop distributions (You *et al.*, 2009) and livestock densities (Robinson *et al.*, 2007; FAO, 2007a). While it may be possible to repeat this approach at global or regional scales using these modelled livestock and crop data, comparable information on livelihoods is still missing at the same levels of consistency and spatial resolution.

AGRICULTURAL SYSTEMS AND POVERTY IN VIET NAM

Of Viet Nam's 80 million population, nearly 80 percent live in rural areas and 67 percent of the total labour force works in agriculture. Economic reforms over the past 20 years have resulted in individual farming households replacing the cooperatives and state-owned farms as the basic unit of agricultural production, and farmers have become increasingly free to decide for themselves what to grow on their land. Rice remains the most important crop, but horticultural production and perennial crops such as coffee, pepper, tea and mulberry have been produced in increasing quantities. Livestock has gained importance as a source of income for many of the rural poor. While fisheries and aquaculture make an important contribution to the rural economy along parts of Viet Nam's coast, in the river deltas and, to a lesser extent, in a few upland areas on the shores of the larger lakes, forestry activities provide an important share of rural household incomes in many of the mountainous regions.

Viet Nam is broadly divided into eight agro-ecological regions. The poor mountainous upland areas of the northern part of the country, the northeast and the northwest regions, as well as the mountainous parts of the north central coast and south central coast, are characterized by very low population densities, underdeveloped market infrastructure and little commercialized agriculture. Agriculture in these areas is largely based on upland rainfed mixed-cropping systems, dominated by rice and corn, with most households raising some cattle, pigs and chickens.

The Red River Delta, the Mekong River Delta, and the southeast are densely populated and close to major urban areas, with comparatively low poverty rates and well developed markets. The agricultural systems here are dominated by irrigated intensive paddy rice cultivation, which in the Mekong River Delta is often mixed with aquaculture systems. Livestock production is an important commercial activity, with industrial pig, broiler and dairy production. The lowlands of the north central coast and the south central coast have moderate population densities and poverty rates. Markets tend to be underdeveloped in the northern part and somewhat better developed in the southern part. The fishing industry is important, particularly in the south. Irrigated and rainfed rice cultivation dominates, though cash crops such as peanuts, coffee and rubber are increasingly grown, too. There is limited dairy and beef cattle production, but buffalo production is relatively well developed and smallholders of goats and sheep are common in the dry, more southerly areas.

The central highlands and their southern foothills have low population densities. Poverty rates are high in the mountainous areas and relatively low in the plains. The area is well known for commercial tree crop production – particularly rubber, coffee and cashew nut – as well as for commercial horticulture. Beef and dairy production are relatively well developed and forestry is also important.

However, these broad descriptions hide the considerable heterogeneity of agricultural production systems within these agro-ecological regions. A spatial analysis of the 2002 Viet Nam Rural Agriculture and Fisheries Census reveals the distinctive spatial patterns in the production of the many different agricultural products, including the different livestock and crop types (Epprecht and Robinson, 2007). Such detailed information on the spatial distribution of the production of different agricultural products is useful for commodity-specific analysis and decision-making. However, the distribution of the typical household production systems, and the relationships between these systems and the livelihoods and well-being of the households that operate within them, cannot easily be grasped.

The system classifications of Dixon *et al.* (2001) and Thornton *et al.* (2002) described above were developed at a global scale, and have relatively little practical use at the national scale. More detailed national production system classifications for Viet Nam that would be of greater practical use do not currently exist. The availability in Viet Nam of detailed agricultural census and household survey data presents the opportunity to explore a data-intensive modelling approach to agricultural production systems classification. An attempt has been made here to develop and map a national agricultural production systems classification for Viet Nam using the best available national data sets. The classification scheme described below deals with agricultural production systems in general but addresses the livestock components in particular detail.

Methods

The approach taken involves two main steps: 1) the statistical classification of households based on sample survey data; and 2) an 'extrapolation' of the predominant commune-level production system from the sample communes to the entire country by applying a neural network to detailed census and spatial data.

The stage 1 categorization of production systems was based on data from the 2002 Viet Nam Household Living Standards Survey (VHLSS), which covers a sample of 29 530 households in 2 900 communes, from a total of 10 500. A breakdown of household income sources enabled household level production systems to be determined in surveyed communes. The classification was very broadly determined according to the main agricultural activities: 1) arable agriculture; 2) livestock; 3) aquaculture and fisheries; and 4) forestry. The importance of each system component was measured by its respective contribution to total household income; those contributing to at least 10 percent of household income were included. The predominant production system type was then assigned to each sample commune by taking the most frequently occurring type at household level for each of the communes. This provided a commune-level production system map for the sample communes which could then be used to train a neural network applied to the more complete census data.

For stage 2, commune-level data were compiled that may contribute to explaining the occurrence of a particular production system at a particular location. These included agricultural, infrastructural, environmental and demographic variables derived from GIS layers or statistical datasets. Observed relationships between commune-level explanatory variables at survey locations and the prevalent production systems in the sample communes were used to predict the dominant production system type for each commune.

The 2002 Rural Agriculture and Fisheries Census, covering all 13.9 million rural households in Viet Nam, contains some information on agricultural production, including numbers held of different livestock species, areas planted to annual and perennial crops, area used for forestry, and area used for aquaculture. Commune level aggregates of the census data were made available for this analysis. Other relevant spatial variables were compiled and summarized at commune level, including elevation, slope, roughness, soil type, climatic data, LGP, land cover, and proximity to various types of water bodies. Population density and accessibility to various types of infrastructure and other 'targets' were also calculated for each commune. The suite of commune-level attributes that was available for all (rural) communes is summarized in Table 6.5.

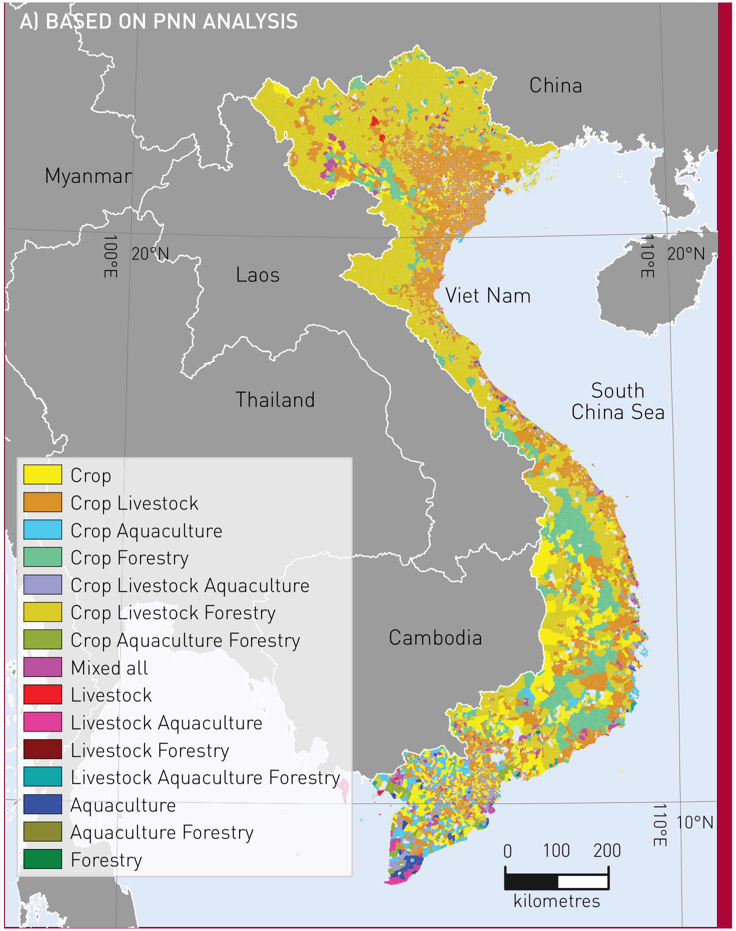
Given the large number of classes to be predicted, a probabilistic neural network (PNN) approach was chosen over conventional regression approaches, to establish relationships between the explanatory variables and commune-level production systems at survey locations, and to predict the most likely production system for non-survey locations. PNN is a pattern classification routine based on 'nearest-neighbour' algorithms (see e.g. Montana, 1992). PNN is a double layer network: the first layer calculates the distances from the input vector to the training vectors and produces a further vector containing those distances. The second layer sums the contributions for each class of inputs to produce a vector of probabilities. The routine was run on the commune data and, for each, the class that corresponded to the highest of these probabilities was assigned. In order to prevent the model from overfitting the training data – which would severely restrict its power in making predictions beyond the scope of the training data (a high risk with neural network type approaches) – the number of classes to be predicted was restricted,

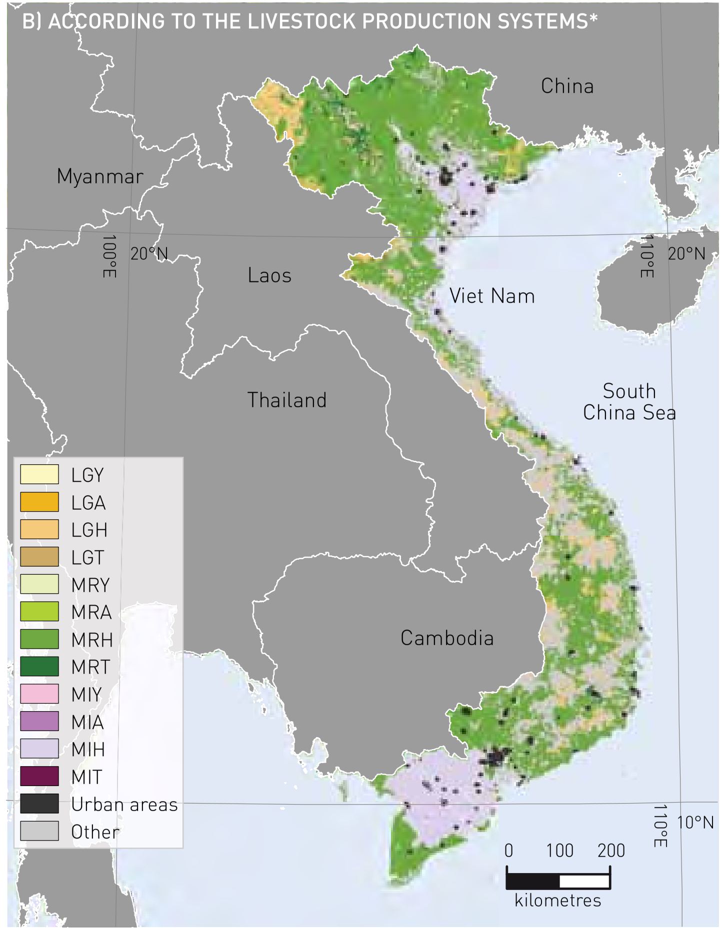
TABLE 6.5 COMMUNE-LEVEL DATA AVAILABLE FOR MODELLING DOMINANT PRODUCTION SYSTEMS

Attribute	Variable
Environmental	**Elevation**
	Slope
	Roughness
	Length of growing period
	Soil type
	Soil suitability
	Rainfall
	Temperature
	Solar radiation
	Land cover
	Agro-ecological region
Demographic	Population density (human)
	Welfare
Agricultural	Livestock densities by type (cattle buffalo, pig, chicken, duck)
	Flock/herd sizes by type (cattle buffalo, pig, chicken, duck)
	Percentage of the communal area under agricultural land
	Percentage of the communal area under forestry land
	Percentage of the communal area used for aquaculture
	Percentage of rural households that engage in animal husbandry
	Percentage of district-level rural household income from crops
	Percentage of district-level rural household income from livestock
	Percentage of district-level rural household income from aquaculture and fisheries
	Percentage of district-level rural household income from forestry
Infrastructural	**Travel distance to the sea**
	Travel distance to a large water body
	Travel distance to major cities (≥1 million people)
	Travel distance to urban areas

Variables emboldened in red are those actually used in the model.

6.5 DISTRIBUTION OF AGRICULTURAL SYSTEMS IN VIET NAM





* Version 5 as described in Section 3.

TABLE 6.6 CONFUSION MATRIX OF PREDICTED VERSUS OBSERVED PRODUCTION SYSTEMS IN VIET NAM IN THE VALIDATION DATASET

	Production system	Observed													
		C	CL	CA	CF	CLA	CLF	CAF	CLAF	L	LA	LAF	A	AF	Total
Predicted	C	**14**	5	5	2	2	5	0	0	0	1	0	1	0	**43**
	CL	2	**125**	2	7	4	1	0	4	0	0	0	0	0	**157**
	CA	2	1	**2**	0	1	3	1	1	0	0	1	0	2	**14**
	CF	6	5	0	**18**	1	0	0	0	0	0	0	0	0	**28**
	CLA	2	7	2	0	**3**	3	1	0	0	0	0	1	1	**22**
	CLF	2	24	0	6	2	**69**	0	3	0	0	0	0	0	**91**
	CAF	0	0	0	0	0	1	**2**	2	0	1	0	0	0	**6**
	CLAF	0	0	0	0	1	2	1	**0**	0	0	0	0	0	**4**
	L	0	0	0	0	1	0	0	0	**3**	0	0	0	0	**1**
	LA	0	0	0	0	0	0	0	0	0	**3**	0	2	0	**3**
	LAF	0	0	0	0	0	0	0	0	0	0	**0**	0	0	**0**
	A	0	0	0	0	0	0	0	0	0	0	0	**2**	0	**2**
	AF	0	0	0	0	0	0	0	0	0	0	0	1	**0**	**1**
	Total	**28**	**167**	**11**	**33**	**15**	**84**	**5**	**10**	**3**	**5**	**1**	**7**	**3**	**372**

C = Crop, **L** = Livestock, **A** = Aquaculture, **F** = Forestry

the number of explanatory variables was kept to a minimum, and the independent variables were classified into quintiles. To finish, the extrapolated production systems were characterized in terms of their extent, the numbers of people engaged in each, and indicative poverty levels.

Results

A basic agricultural production systems classification was thus produced, indicating the combinations of the four production systems components. The neural network model was applied to the predictor variables for all rural communes and the results were mapped. Of the 15 potential combinations of the four system components, 13 production systems were represented.

Figure 6.5a depicts the spatial distribution of these 13 systems. The model fitted the training data well ($R^2 > 0.9$), and appeared to classify the non-survey communes meaningfully. Furthermore, the proportional distribution of communes per production system type in the training sample compares well to the one predicted for the whole of rural Viet Nam.

To validate the model every sixth observation was excluded from the training data set, the network was re-trained, and the new network was applied to the validation data set made up of the previously excluded observations, to come up with predicted systems that could be compared with the observed systems. Table 6.6 provides the confusion matrix of predicted against observed production systems in the validation data set. Overall, 65 percent of predictions were the same as the observations (compared with an expected 26 percent), and an acceptable Kappa value of 0.53 was obtained (Cohen, 1960). Although the predictive power of the model was not exceptionally high, the table points to the main weaknesses, which lie in an overemphasis on the forestry component in the modelled systems compared with the observed systems. For example, 21 percent of 'C' communes were incorrectly classified as 'CF' and 14 percent of 'CL' communes were incorrectly classified as 'CLF'. This is probably largely explained by the modelling of the predominant communal household production systems being based on a different source of information – household sample survey data – than is the subsequent spatial extrapolation model, which is based on communal agricultural census data and environmental statistics. A household's community-based forestry activities tend to be under-reported at household level compared with commune level. This may have arisen because the household survey data contain relatively weak information on the forestry component of the household's production systems.

The spatial distribution of the predominant agricultural production systems shows some distinct geographic patterns (Figure 6.5a): crop–livestock (CL) mixed production systems dominate in the Red River Delta region and along much of the coast, whereas crop–livestock–forestry (CLF) systems dominate in much of the northern mountainous regions and in the north central region. Crop–forestry (CF) systems are prevalent in the Central Highlands region, along with crop-based production systems (C). Parts of the south central coastal areas, and particularly the Mekong River Delta, show much more patchy and fragmented distributions of production systems, where aquaculture plays an important part in many of the local production systems, most notably in the Mekong River Delta.

By comparing this map of basic agricultural production systems with the map of livestock production systems, Version 5 (Figure 6.5b), clear parallels in the spatial patterns are evident. The areas classified as mixed irrigated, humid and subhumid tropics and subtropics (MIH) in the livestock production systems map coincide in the northern and central parts of Viet Nam with the crop–livestock (CL) production system. However, the large monolithic MIH area in the Mekong River Delta region, evident in the livestock production systems map, reveals a much more diverse, differentiated and patchier picture in the production systems map of Figure 6.5a. The other main production system in Viet Nam according to the livestock production systems map is the mixed rainfed, humid and subhumid tropics and subtropics (MRH) system, which dominates many of the upland areas of Viet Nam. This relates spatially to the crop–livestock–forestry (CLF) system in the uplands of the northern and central parts of the country, and also to crop (C) and crop–forestry (CF) systems in the central highlands. While the observed spatial coincidence of the different classification schemes represented by the two maps is reassuring of their validity, the two schemes appear also to complement each other with further, independent information.

Having defined, extrapolated and mapped these production systems, they were characterized in terms of their extent, the numbers of people engaged in each, and typical poverty rates associated with them. For this characterization commune-level poverty estimates generated by IFPRI and the Institute of Development Studies were used. These were based on small area estimation techniques using data from the 1999 population census and the 1998 Viet Nam Living Standards Survey (Minot *et al.*, 2006). The results are shown in Table 6.7.

Overall, as shown in Figure 6.5a, the predominant agricultural production systems are crop–livestock (CL) and crop–livestock–forestry (CLF) systems, both in terms of area and in terms of the total population involved in these. The CL production system covers one-quarter of the rural area and predominates in almost half of Viet Nam's rural communes, covering much of the densely

TABLE 6.7 CHARACTERISTICS OF THE AGRICULTURAL PRODUCTION SYSTEMS IN VIET NAM

Production system	Area (km^2)	Number of communes	Population (thousands)	Poverty incidence (%)	Poverty density (per km^2)	Number of poor (thousands)
C	34 368	858	7 296	37	79	2 718
CL	77 748	4 253	29 344	41	155	12 015
CA	7 714	210	1 978	42	109	837
CF	40 124	530	2 585	51	33	1 316
CLA	7 527	434	3 724	40	200	1 507
CLF	133 374	2 252	9 538	57	40	5 397
CAF	3 761	69	802	43	92	347
CLAF	6 185	151	1 289	43	89	550
L	949	45	296	37	115	110
LA	2 015	52	504	39	97	196
LAF	679	14	109	48	76	52
A	2 355	64	626	43	115	271
AF	381	15	93	59	145	55
National	**317 180**	**8 947**	**58 185**	**44**	**80**	**25 371**

C = Crop, **L** = Livestock, **A** = Aquaculture, **F** = Forestry

populated lowlands. Half of Viet Nam's rural population, as well as nearly half of the country's rural poor, live in these areas. The average poverty rate is slightly below the national average of rural areas. In the uplands, which account for almost half of the country's area, the CLF production system dominates. There, crops, livestock and forestry each play a significant role in livelihoods, as determined by income. However, those areas that are much more sparsely populated compared with the lowlands are home only to about one-sixth of the country's rural population. More than half of the population in CLF systems live below the poverty line, placing it among the poorest systems.

Communes with a predominant household production system that involves forestry are among the poorest, whereas those involving aquaculture are typically better off. This pattern probably reflects the geographic potential of the respective areas: the lowland areas near rivers or the sea, where aquaculture is possible and access to people and markets is good, compared with the rugged upland areas that are characterized by poor accessibility, where livelihood activities are restricted by the inhospitable terrain to forestry. The more specialized production systems, where only crops or livestock predominate, are the ones with the lowest poverty rates.

Conclusions

In this summary the analysis has been restricted to combinations of the four major systems components. A next logical step would be to model more detailed production system subclasses. Test runs will show whether the many different complex classes can be extrapolated through a single model, or whether production systems will need to be modelled in a step-by-step fashion, with separate models for the major systems, the subclasses of these, and further attributes to those subclasses.

The level of detail in the VHLSS 2002 household survey would allow subcomponents to be distinguished based on proportional contribution to income, as follows. In the case of arable agriculture the dominant crop type can be further specified as either annual crops or perennial crops. For livestock the dominant types can be specified too, as pigs, chickens, water-fowl, dairy cattle, beef cattle, buffaloes or small ruminants. The importance of each system component could be measured by its respective contribution to the total household income using a minimum contribution of 10 percent as a threshold. Table 6.8 lists the 11 subclasses. However, in combination these include 10 or less classes – because with a 10 percent income threshold more than ten contributors are not possible – and this may give rise to as many as 2 046 production systems, including the class where none made a 10 percent contribution. In reality most of these potential combinations would not occur, but this approach still threatens to throw up an unwieldy number of production system classes.

Again, using available data from the household survey, each of these 11 subcomponents can be further specified according to four attributes: 1) their degree of commercialization, i.e. commercial versus subsistence production, measured by the marketed share of the total output; 2) the scale of the production, i.e. small-scale versus large-scale, measured by area planted or by numbers of animals per production unit; 3) the intensity of the production, i.e. intensive versus extensive, measured by the amount of output per unit of production, the number of livestock, the area cropped, and so on; and 4) for households with both crops and livestock, depending on whether those two components were integrated or independent (possibly measured, for each livestock type, by the proportion of income from that livestock type that is spent on feed).

Combining all possibilities of these would obviously result in an impossibly large number of production systems that would be of no use whatsoever. A more practical approach may be to map these four attributes separately and to overlay these on the systems maps.

TABLE 6.8 SUMMARY OF THE MORE DETAILED HOUSEHOLD LEVEL PRODUCTION SYSTEM CLASSIFICATION

Level 1	Level 2
Arable	Annual Perennial
Livestock	Dairy cattle Beef cattle Buffaloes Small ruminants Pigs Chickens Water-fowl
Aquaculture, fisheries	
Forestry	

Even with four production system components, which would result in 15 production systems, a threshold of 10 percent is possibly too low for evaluating the importance of a system component to livelihoods. By increasing this threshold to, say, 20 percent, we would end up with a more general classification that would enable some of the less widespread classes to be dropped.

There is no doubt that this approach holds much potential in production system classification. The results here have already demonstrated that a detailed breakdown of the systems in Viet Nam is possible, and that this concurs with our general understanding of these systems and how they are distributed. While the approach is of value, its application will be restricted to countries where detailed household survey and census data are available – and where these contain relevant information. This means that the household survey data must contain information on incomes, disaggregated by production system components, and that the census data contain information that is highly relevant to production systems. Countries with survey and census data meeting these criteria are relatively few and, moreover, comparable datasets across countries that would enable global or even regional analyses do not exist.

There may nevertheless be some merit in exploring the possibility of extrapolating the classified systems regionally, using regionally-consistent datasets rather than country-specific census data.

LIVELIHOOD ANALYSIS AND LIVESTOCK PRODUCTION SYSTEMS IN EASTERN AFRICA

One of the main reasons for studying agricultural production systems is to understand and therefore help improve poor people's livelihoods. In this context, it is important to explore the extent to which the environmental parameters and GIS layers used to map livestock production systems globally are capable of capturing relevant livelihood patterns, especially in rural areas of the developing world. An opportunity to shed light on the relationships between livelihoods and global environmental datasets is offered by data gathered or collated in the framework of livelihood analysis (Scoones, 1998; Carney, 2003; Seaman *et al.*, 2000).

In livelihood analysis, areas that are homogenous in terms of farming practices, consumption patterns, expenditure, trade and exchange are identified, and a range of livelihood data are assembled, often including quantitative or qualitative information on income derived from livestock and crops. Livelihood analyses have been carried out extensively in member states of the Intergovernmental Authority for Development (IGAD)[14], thus allowing a regional, livelihood-based map of livestock production systems to be created (Cecchi *et al.*, 2010).

One of the goals of the study in the IGAD region was to explore the extent to which global maps of livestock production systems may capture relevant patterns of rural people's livelihoods. The previous two case studies in this section, from Uganda and Viet Nam, used detailed, country-specific data on the distribution of agricultural commodities, or income derived from them, to define agricultural systems in a country-specific manner. This third case study was based not on household survey data, but on data obtained through rapid rural appraisal methods – mainly semi-structured interviewing of focus groups. Such data are less detailed but are explicitly linked to livelihoods. Moreover, there is a reasonable level of harmonization in the collection of livelihood data across a number of countries, meaning that it was possible to produce a regional map.

Using the ratio of income derived from livestock to that derived from crops, three categories were defined: pastoral, agropastoral and mixed farming systems. The resulting map was compared with the global map of livestock production systems (Version 4). Livelihood-based systems were further characterized in terms of the LGP, a key geospatial layer used to generate the global livestock production systems map, with a view to clarifying the relationship between this variable and production patterns on the ground.

Methods

All data collected in the IGAD region from the year 2000 onwards in the framework of livelihood analysis were collated. These included full coverage of Djibouti, Eritrea, Kenya, Somalia and Uganda. Livelihood information for a few regions in Ethiopia and Sudan was also available. Data on the average income[15] derived from livestock (L) and crops (C) were used to define three production systems as follows:

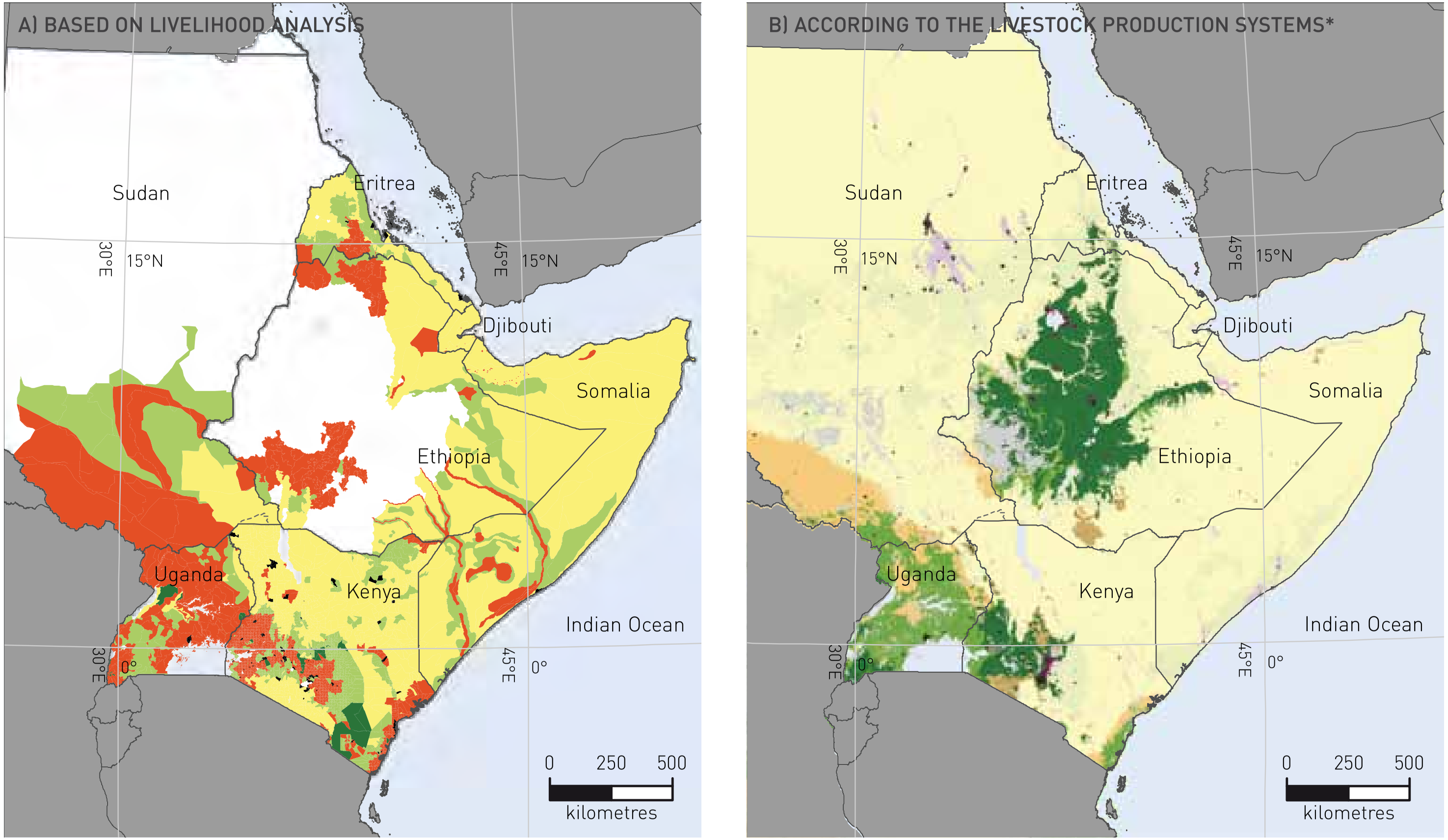
- Pastoral production systems: where $L/C \geq 4$.
- Agropastoral production systems: where $1 < L/C < 4$.
- Mixed farming production systems: where $L/C \leq 1$.

For each livelihood zone in the IGAD region that was described in livelihood studies, the dominant production system was defined based either on quantitative data, qualitative information or expert opinion. This allowed all zones to be classified into one of these three categories. The resulting map (Figure 6.6a) also includes some 'urban and other

[14] IGAD is a regional economic community comprising six countries in the Horn of Africa: Djibouti, Ethiopia, Kenya, Somalia, Sudan and Uganda. At the time of writing, Eritrea's membership had been suspended.

[15] Income includes the value of the marketed production and the estimated value of subsistence production.

6.6 DISTRIBUTION OF AGRICULTURAL SYSTEMS IN EASTERN AFRICA



* Version 4 as described in Section 3.

A) Pastoral; Agro-pastoral; Mixed farming; Urban and other areas; Protected areas; No data

B) LGA; LGH; LGT; MRA; MRH; MRT; MIA; MIH; MRT; Urban areas; Other

Source: adapted from Cecchi *et al.* (2010).

areas' (defined as areas where L + C is less than 10 percent of total income) and protected areas. For the sake of visual comparison, Figure 6.6b shows Version 4 of the global map of livestock production systems for the same geographical area.

The map in Figure 6.6a was matched to that shown in Figure 6.6b using correspondence analysis (Greenacre, 1984)[16]. Rural population (rather than area) was used as measure of correspondence between the two classifications, because the dominant livestock production system within a given livelihood zone is that associated with the majority of the rural population in that zone, not the one covering the largest area. Values of LGP (Jones and Thornton, 2005) were also extracted and analysed for the production systems shown in Figure 6.6a.

Results

Correspondence analysis showed substantial agreement between the global map of livestock production systems and the livelihood-based map, as shown in Figure 6.7 and Table 6.9.

Figure 6.7 is fairly self-explanatory since, in correspondence analysis plots, similar categories appear close to one another. However, the results for the category 'livestock only, humid and subhumid' (LH) call for further explanation, as this category appears to be predominantly associated with mixed-farming livelihood zones. This is probably explained by the fact that, in the IGAD region, the few LH areas that exist are interspersed with 'mixed, humid and sub-humid' (MH) areas within the boundaries of zones where livelihoods depend predominantly on crops – most notably in the highly fertile green belt in Southern Sudan (SSCCSE and SC-UK, 2005). As such, the association between LH areas and mixed farming zones is likely to be an artefact of limited coverage and spatial resolution rather than a functional association. Livelihood maps at higher spatial resolution would probably not have generated this mismatch.

The relationship between livestock production systems and LGP in the IGAD region was also characterized and is shown in Figure 6.8.

Predictably, areas with low LGP values are dominated by pastoral systems and areas with high values are dominated by mixed farming. In a narrow intermediate range between 130 and 170 days, agropastoral systems are the most common (Figure 6.8a). If agropastoral and mixed farming systems are combined (Figure 6.8b), it is possible to identify the threshold separating pastoral systems from the others: 110 days. Similarly, 180 days marks the threshold between crop-dominated and livestock-dominated systems (Figure 6.8c).

In addition to LGP, the map in Figure 6.6a was matched with human population densities (CIESIN *et al.*, 2004), and land cover derived from Africover[17] (Cecchi *et al.*, 2010). The results of the analysis are not presented here, but it is worth mentioning that they indicated that different livestock production systems also show markedly different patterns with respect to population density and land cover composition. This provides further confirmation that using such datasets for global mapping of livestock production systems is not only practical but also well founded.

Conclusions

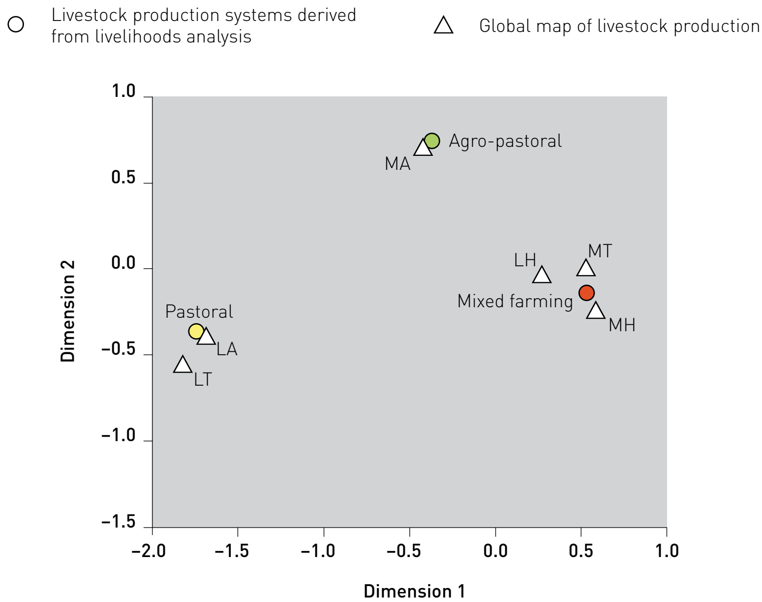
The analysis in the Horn of Africa showed that global maps of livestock production systems based on environmental datasets are capable of capturing important livelihood patterns, such as the relative contribution of livestock and crops to the average income of rural households.

It also suggested that some of the environmental datasets used for global mapping – LGP in particular – could be used to refine the classification further by distinguishing two types of mixed farming systems: agropastoral systems, where income derived from livestock exceeds that from crops, and crop-dominated mixed farming systems, where the opposite is true. A few issues need to be tackled before the results of this analysis

[16] Mixed irrigated and rainfed classes were merged for each agro-ecological category due to the relatively sparse distribution of irrigated areas in Eastern Africa.

[17] Africover: http://africover.org

6.7 CORRESPONDENCE ANALYSIS PLOT BETWEEN LIVELIHOOD-DERIVED AND GLOBAL MAP OF LIVESTOCK PRODUCTION SYSTEMS USING RURAL POPULATION AS A MEASURE OF CORRESPONDENCE (SYMMETRICAL NORMALISATION)



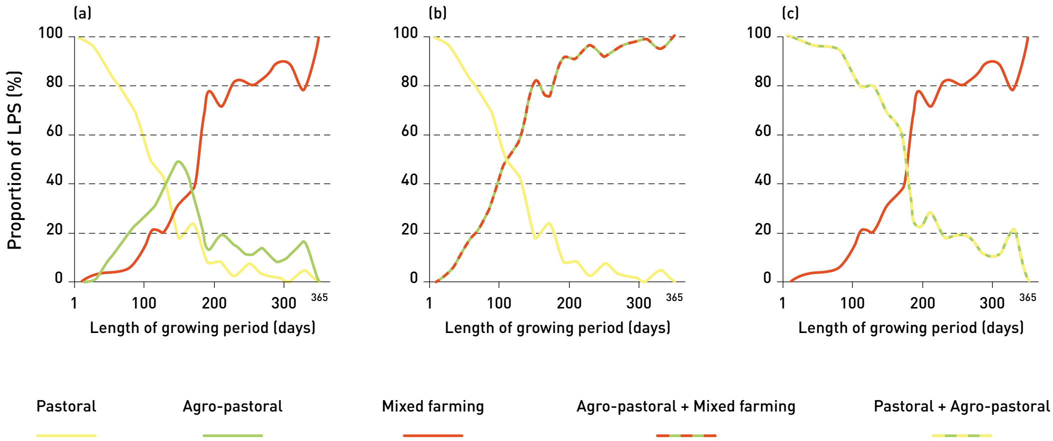
Source: adapted from Cecchi *et al.* (2010).

TABLE 6.9 CORRESPONDENCE ANALYSIS BETWEEN LIVELIHOOD-DERIVED AND GLOBAL MAP OF LIVESTOCK PRODUCTION SYSTEMS (VERSION 4) (COLUMN PROFILE BASED ON THE CORRESPONDENCE TABLE). RURAL POPULATION IS USED AS A MEASURE OF CORRESPONDENCE

		Livelihood-derived livestock production systems			
Global livestock production systems	**Code**	**Pastoral (%)**	**Agro-pastoral (%)**	**Mixed farming (%)**	**Total (%)**
Livestock only, hyper-arid	LY	97.8	0.0	2.2	100
Livestock only, arid and semi-arid	LA	64.7	26.0	9.3	100
Livestock only, temperate and tropical highland	LT	69.5	24.1	6.5	100
Livestock only, humid and sub-humid	LH	8.8	16.8	74.4	100
Mixed, hyper-arid	MY	0.0	0.0	0.0	-
Mixed, arid and sem-iarid	MA	23.6	32.4	44.0	100
Mixed, temperate and tropical highland	MT	1.2	15.5	83.3	100
Mixed, humid and sub-humid	MH	1.1	11.6	87.3	100

Source: adapted from Cecchi *et al.* (2010).

6.8 LIVESTOCK PRODUCTION SYSTEMS (DERIVED FROM LIVELIHOOD ANALYSIS) AND LENGTH OF GROWING PERIOD



Source: adapted from Cecchi *et al.* (2010).

can be used to inform global mapping. First and foremost among these is the geographical coverage. Livelihood data from other regions of the world should be analysed in a similar manner to establish whether results for the Horn of Africa have a broader validity. Second is the issue of definitions of production systems. Global mapping approaches have been loosely linked to definitions provided by Seré and Steinfeld (FAO, 1996), which combined elements of farm income with other farming practices such as the type and origin of dry matter fed to animals. Lack of data precludes the use of these definitions to map production systems from livelihood studies – hence the use of a different definition, based on the ratio between livestock-derived and crop-derived incomes. Third is the issue of mapping unit and spatial resolution. The mapping units for livelihood analysis are the livelihood zones, and these are often based, at least in part, on administrative units. By contrast, global maps are generated from gridded environmental layers at different resolutions, which are combined to predict the livestock production systems in cells of between 3 arc minutes and 30 arc seconds (approximately 5 km to 1 km at the Equator). Further analysis may help us to overcome these issues, and thus to combine the two mapping approaches in a more meaningful way.