4 From potential to actual production systems: accounting for crops, livestock and other livelihood options

The livestock production systems mapped by Thornton *et al.* (2002) may possibly be better referred to as 'potential livestock production systems', since they contain no information whatsoever on the actual distribution, or role, of livestock. The same does not apply completely to crops because – issues of accuracy notwithstanding – the land cover classification of cropland is based on satellite images and therefore should depict the actual distribution of crops, if not the types of crops or combinations thereof found on the ground.

The second level in the scheme proposed in Table 2.1 incorporates more detail on livestock systems – in particular detail related to the distributions and types of crops and livestock species that prevail in different places – and accounts for livelihood options that go beyond crops and livestock. By incorporating empirical data on crops, livestock and other livelihood options, we attempt in this section to move from the 'potential livestock production systems' of Thornton *et al.* (2002) towards a classification that reflects more closely the actual situation on the ground.

INTEGRATING MODELLED LIVESTOCK AND CROP DISTRIBUTIONS

The possibility of integrating detailed spatial data on crop and livestock distributions with the global livestock production systems is explored in this section, with two main objectives. First, to modify the potential livestock production systems of Thornton *et al.* (2002) to reflect the actual distribution of livestock. An area deemed livestock only, based largely on its land cover characteristics, may not support livestock in reality, as indeed many so-called mixed crop–livestock areas may support few or no livestock for a variety of reasons. As discussed earlier, the same is not directly true for crops, since mixed systems are determined by the detection of crops or fields from satellite data. The second objective of including empirical crop and livestock data is to characterize the potential livestock production systems, and in particular, to disaggregate further the mixed crop–livestock systems.

Subnational agricultural statistics are collected regularly by national governments, usually through agricultural censuses conducted every ten or so years; these form the baselines from which the data reported in statistical yearbooks are estimated. Various efforts, described below, are made to compile such subnational data globally, for example Agro-MAPS[8] for crop statistics (George *et al.*, 2009) and the Global Livestock Impact Mapping System (GLIMS) for livestock data (Franceschini *et al.*, 2009). However, the resulting statistics are often patchy and vary considerably in terms of spatial resolution (level and size of administrative units) and reference date. Modelling approaches have been developed to overcome these shortfalls and to produce global, high-resolution estimates of these distributions, offering the possibility of incorporating such data into agricultural systems classifications and maps.

Livestock distributions

FAO has an ongoing programme to collate and disseminate subnational livestock statistics for the globe: the GLIMS (Franceschini *et al.*, 2009). Subnational livestock statistics are collected from a variety of sources and geo-registered to digital administrative area boundaries at the level at which they are reported for the various countries. Subnational boundaries are standardized to the

[8] Agro-MAPS: http://kids.fao.org/agromaps

Global Administrative Unit Layers (GAUL)[9] system where possible. There is a number of products derived from the GLIMS information system. One of these is GLiPHA[10] – the Global Livestock Production and Health Atlas – which provides a coarse spatial resolution view of the data (usually at administrative level 1). Another product is the GLW[11] (Robinson *et al.*, 2007; FAO, 2007a), which provides modelled distribution data in raster format for cattle, buffalos, sheep, goats, pigs, chickens and other poultry. The map values are animal densities (i.e. number of animals per square km), at a resolution of 3 arc minutes (approximately 5 km at the Equator). These maps are updated regularly, more recently at a spatial resolution of *c*. 1 km, using the method summarized below (also described in detail in FAO 2007a).

First, the best available subnational data on livestock populations, at a range of spatial resolutions depending on availability, are collected and standardized. These are converted to densities and adjusted to account for the area of land deemed suitable for livestock production. The suitability adjustments are based on environmental, land cover and land use criteria. For example, livestock are excluded from areas where satellite-derived vegetation indices indicate there is insufficient grazing (for ruminant species) and where topographic features such as elevation and slope would preclude livestock production. They are also excluded where land cover is unsuitable, such as in dense forests and urban areas, and where prevailing land use would not permit livestock to be found, such as in protected areas.

The resulting suitability-adjusted livestock densities are then used to establish robust statistical relationships between livestock densities and an extensive suite of predictor variables, summarized in Table 4.1. Details and references to the data sources are provided in Robinson *et al.* (2007) and FAO (2007a).

[9] GAUL (available through Geonetwork): http://www.fao.org/geonetwork/srv/en/main.home
[10] GLIPHA: http://kids.fao.org/glipha
[11] GLW: http://www.fao.org/ag/againfo/resources/en/glw/home.html

TABLE 4.1 GENERIC LIST OF VARIABLES USED IN LIVESTOCK DISTRIBUTION MODELLING

Generic type	Variables
Locational	Longitude, Latitude
Anthropogenic	Distance to roads Distance to city lights
Demographic	Human population
Topographic	Elevation
Land cover	Normalized difference vegetation index
Temperature	Land surface temperature Air temperature Middle-infrared
Water and moisture	Vapour pressure deficit Distance to rivers Cold cloud duration Potential evapotranspiration
General climatic	Modelled length of growing period
Other	Tsetse distributions (for Africa)

Source: adapted from Robinson *et al.* (2007)

Since the best predictors of animal densities are unlikely to be the same from region to region or across different agro-ecological zones, models are developed separately for different regions and for different ecological zones (defined empirically by cluster analysis of remotely-sensed climatic variables). A series of stepwise multiple regression analyses are performed between the livestock densities and the predictor variables. The models are developed at several different spatial scales – continental; subregional; for 50 ecological zones; for each ecological zone within each region – and using a variety of data transformations (no transformation; logarithmic; exponential; and power) to accommodate non-linear relationships. The best relationship for any point (pixel) is selected according to coefficients of determination (R^2). If the statistical relationship for the analysis at the level of ecological zone by region has an R^2 value in excess of 40 percent then it is used; if it is less than 40 percent those equations are discarded and the relationship at the next level up, i.e. the ecological zone, is evaluated. If that relationship has an R^2 value of greater than 40 percent it is used; if not then it is discarded and the regional equations evaluated. In the few cases that these still fail to attain R^2 values better than 40 percent, the continental equation is used. Typically, R^2 values range between 50 and 80 percent and all the predictive equations are statistically highly significant ($P < 0.001$).

The selected equations are then applied back to the images of predictor variables to generate a map of modelled density for each species. To avoid spurious predictions the modelled numbers for each administrative unit are adjusted to equal those reported and further products are then generated, adjusting the modelled national totals to match FAO's official national statistics, providing time-standardized datasets (so far for the years 2000 and 2005).

This modelling approach has the major dual advantages of predicting livestock densities in areas with no livestock data, and disaggregating livestock density data that are available originally only at a coarse spatial resolution. Since the original global datasets were produced (FAO, 2007a) work has been ongoing at FAO to develop the GLW methodology further, and to improve and update both the predictor variables used and the quality of the reported, subnational statistics on which the modelled outputs are based. These improvements have been applied initially to poultry distributions in Asia (Prosser *et al.*, 2011; Van Boeckel *et al.*, 2011) and new, global, 1 km resolution datasets for all livestock species are also under construction. Figure 4.1 shows the global modelled livestock distributions for cattle and pigs, standardized to FAOSTAT 2005 national totals.

Crop distributions

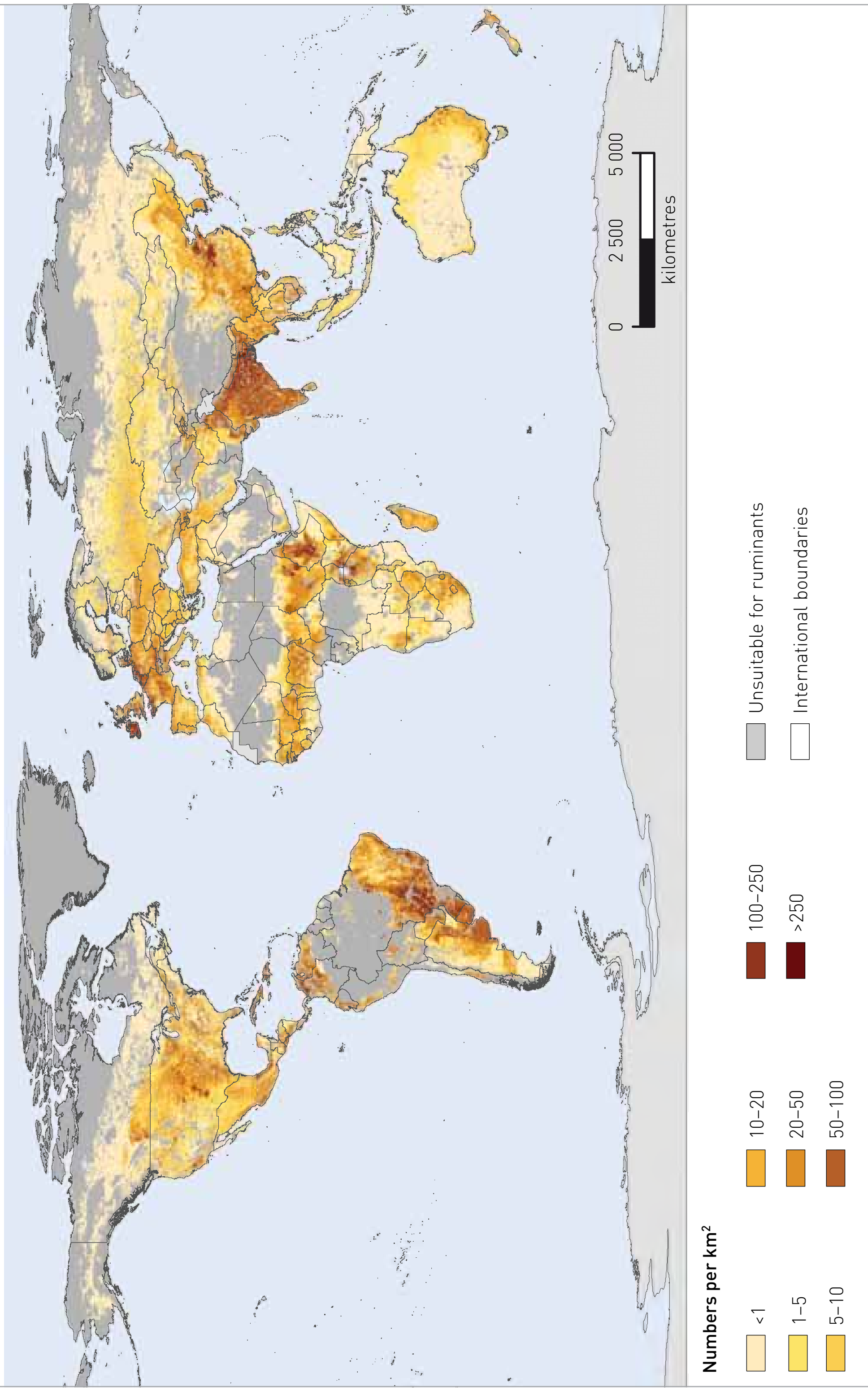
Similarly, though using a different modelling approach, work has been undertaken at the International Food Policy Research Institute (IFPRI) to disaggregate reported crop production statistics (You and Wood, 2004; 2006; You *et al.*, 2006; 2009). Crop production data from large reporting units (usually national or administrative level 1) are allocated spatially to a raster grid at a spatial resolution of 5 arc minutes (approximately 9 km at the Equator). These modelled crop layers are referred to as the Spatial Production Allocation Model (SPAM) dataset, and can be freely downloaded from the MapSPAM web site[12] (the version current at the time of writing was SPAM 2000 Version 3.0.2, produced in April 2010).

The allocation model works by inferring likely production locations from multiple indicators including farming systems, land cover, crop-specific biophysical suitability, commodity prices, and local market access. The model employs a cross-entropy approach (Shannon, 1948) – essentially, a statistical estimation procedure designed to make the most of the informational content of specific data – to manage inputs with different levels of likelihood in indicating the specific locations of agricultural production. No attempt is made in this book to describe in detail the rather complex approach involved; for the interested reader a recent description of the data sources and methodology can be found in You *et al.* (2009). In essence though, crop areas at the national level are first broken down by four different management intensities: 1) irrigated; 2) high-input rainfed; 3) low-input rainfed; and 4) subsistence. Initial, plausible, spatial allocations of each crop are then generated using subnational reported data from a variety of sources, including Agro-MAPS (George *et al.*, 2009) and crop suitability surfaces (Fischer *et al.*, 2001). A cross-entropy approach (Shannon, 1948) is then used to optimize the initial crop allocations with respect to minimizing the cross-entropy distances between different probability distributions of the variables in the analysis, under different spatial constraints. By minimizing cross-entropy, the estimation procedure ensures that uncertainty – information entropy is a metric that measures the uncertainty of expected information – is minimized. Specifically, these constraints are as follows:

- Total agricultural land in a given pixel is estimated by merging the two different

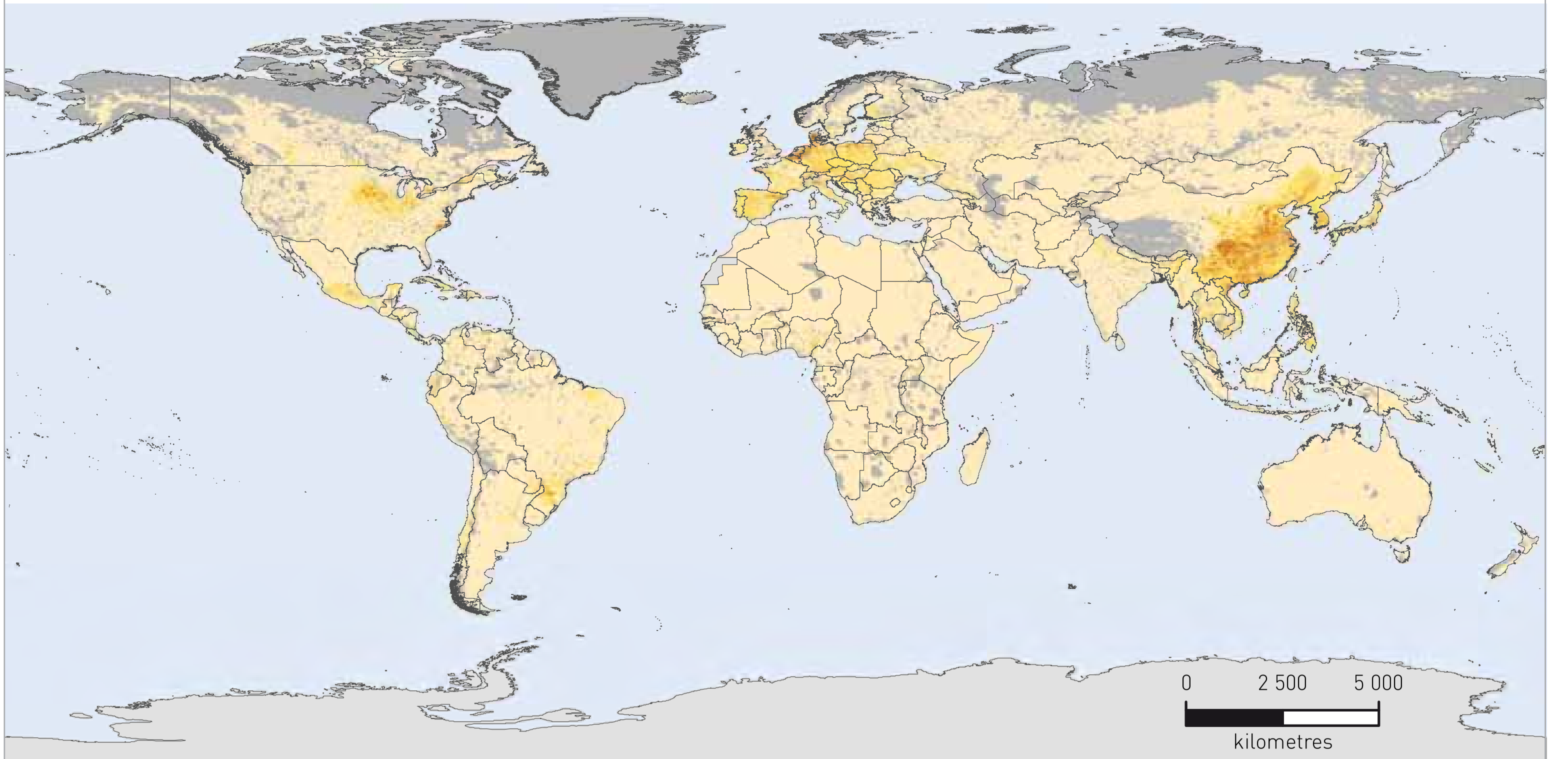
[12] MapSPAM: http://mapspam.info

4.1a ESTIMATED GLOBAL DISTRIBUTIONS OF CATTLE, ADJUSTED TO MATCH TO FAOSTAT 2005 NATIONAL TOTALS



Source: adapted from FAO (2007a).

4.1b ESTIMATED GLOBAL DISTRIBUTIONS OF PIGS, ADJUSTED TO MATCH TO FAOSTAT 2005 NATIONAL TOTALS



Numbers per km²

<10
10–50
50–100
100–200
200–500
500–1 000
1 000–2 500
>2 500
Unsuitable for monogastrics
International boundaries

Source: adapted from FAO (2007a).

satellite-derived products: Boston University's MODIS-derived land cover product and the GLC 2000 dataset (Ramankutty *et al.*, 2008). In addition to a mean cropland estimate, Ramankutty *et al.* (2008) also calculated 5th percentile and 95th percentile values of the cropland. A consistency index is estimated to account for the uncertainty and inconsistency of cropland estimates.

- Crop suitability is estimated building on an approach initially developed by FAO (1981) that used location-specific data on elevation, temperature, and rainfall to assess agroclimatic suitability for a series of crops under low- and high-input rainfed conditions. The approach has since been extended in many ways and the data used for the crop allocation are the most recent versions of the crop suitability data, available globally at a spatial resolution of 5 arc minutes (Fischer *et al.*, 2001).
- The irrigated area in each pixel is taken from the FAO Aquastat map Version 4.0.1. (Siebert *et al.*, 2007). Aquastat provides a global map of irrigation that shows the amount of area equipped for irrigation as a percentage of the total pixel area, at a spatial resolution of 5 arc minutes.
- Transaction costs and market access are implied by a market access proxy estimated by using a normalized rural population density measure, described in You *et al.* (2009). Population data are taken from the Gridded Population of the World Version 2, which provides global estimates of population counts and population densities (CIESIN *et al.*, 2000). Urban areas, which do not normally produce any crops, are eliminated using the urban mask from the GRUMP dataset (CIESIN *et al.*, 2004). National figures are reconciled with UN population estimates for 1990 and 1995.

The allocated crop areas are finally converted into production by considering both the broader production systems and the spatial variation within the systems. An average potential yield within each spatial allocation unit is estimated for each crop using the allocated areas as a weight. The yield of each crop in each production system is then estimated by multiplying the suitability by the reported yield, and dividing by the potential yield. Production is estimated by multiplying yield by the allocated area and the cropping intensity. A validation of the approach in Brazil has shown that the disaggregated coarse resolution data agree well with available data from smaller reporting units (You and Wood, 2006).

Figure 4.2 shows the resulting crop distribution maps for maize and sorghum. Similar maps have been generated for an additional 18 major crops (see Table 4.2) covering over 90 percent of the world's crop land. In addition to these area distribution maps, the model results include production and harvested area distribution maps, as well as the subcrop type maps split by the four production input levels.

Crop and livestock characteristics of the global livestock production systems

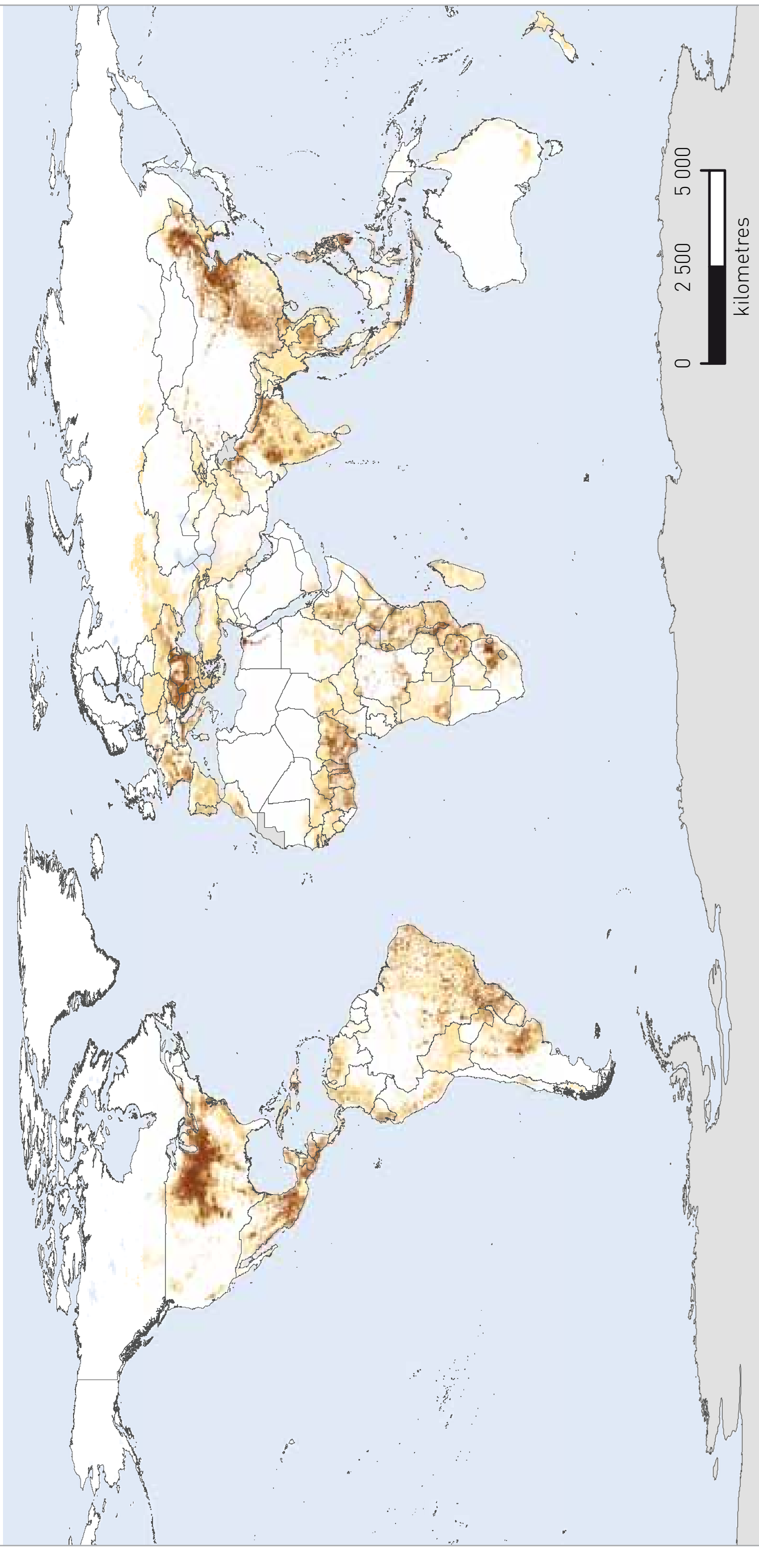
Neither the original Seré and Steinfeld (FAO, 1996) classification, nor any of the subsequent efforts

TABLE 4.2 CROPS WHOSE DISTRIBUTIONS HAVE BEEN MODELLED BY IFPRI

Hierarchy	Input data
Cereals (6)	Wheat, rice, maize, barley, millet, sorghum
Roots and tubers (3)	Potato, sweet potato and yams, cassava
Fruits (1)	Banana and plantain
Pulses (2)	Dry beans, other pulse
Sugar crops (2)	Sugar cane, sugar beets
Fibre crops (2)	Cotton, other fibres
Oil crops (3)	Soybean, groundnuts, other oil crops
Stimulant crops (1)	Coffee

Source: adapted from You *et al.* (2006).

4.2a ESTIMATED CROP DISTRIBUTION MAPS OF THE WORLD: HARVESTED AREA OF MAIZE



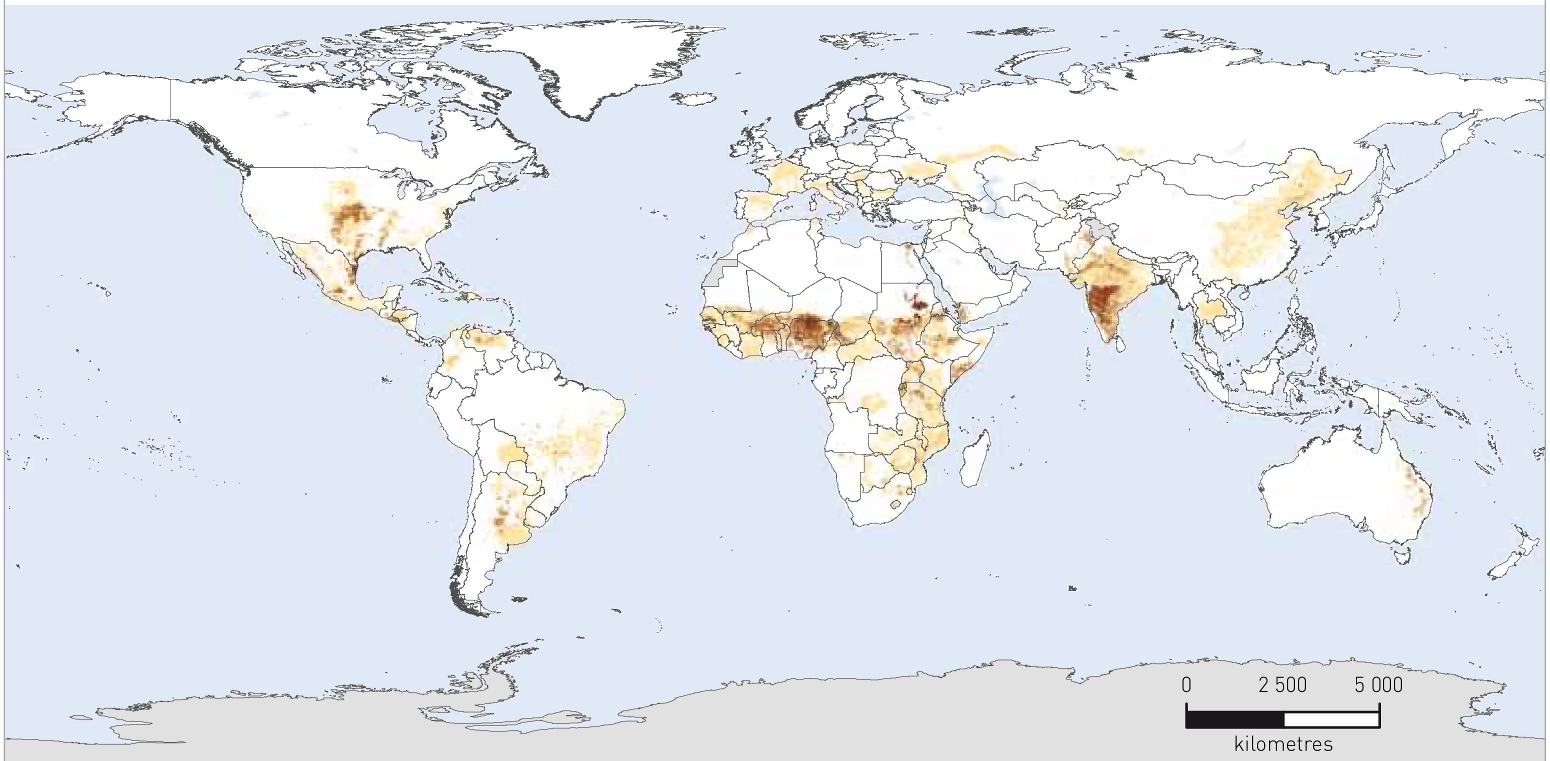
Harvested area (hectares per cell[*])

- 1–100
- 100–200
- 200–400
- 400–800
- 800–1 600
- 1 600–3 200
- >3 200

* Harvested areas of less than 1 hectare per cell are not shown on the map.

Source: drawn from SPAM data (You *et al.*, 2009).

4.2b ESTIMATED CROP DISTRIBUTION MAPS OF THE WORLD: HARVESTED AREA OF SORGHUM



Harvested area (hectares per cell*)

1–100
100–200
200–400
400–800
800–1 600
1 600–3 200
>3 200

* Harvested areas of less than 1 hectare per cell are not shown on the map.

Source: drawn from SPAM data (You *et al.*, 2009).

to map it (Thornton *et al.*, 2002; Kruska *et al.*, 2003; Kruska, 2006), make any explicit attempt to investigate the actual composition of crop or livestock production in the different systems identified. However, given that global and detailed spatial data are now available for many of the major crop and livestock species, we are in a position to look at how these are distributed across the different systems and in what combinations they tend to occur in different places.

An obvious reason to incorporate empirical crop and livestock data in the classification of Thornton *et al.* (2002) is to make adjustments to the areas designated livestock only, grasslands (LG), mixed rainfed (MR) and mixed irrigated (MI), based on the modelled distributions of crops and livestock. Areas classified as rangeland (LG), but where reported statistics suggest that cropping also occurs, can be reassigned to the mixed rainfed category (MR). A further 'crops only' category can be introduced in areas where empirical data suggest that few if any livestock occur in potentially mixed farming areas. Table 4.3 lists the main adjustments that could result from including reported or modelled crop and livestock data with the livestock production system maps. Three of the potential adjustments reflect inconsistencies in the crop cover data layers; if the livestock production system and SPAM mapping approaches were harmonized to the extent that they used exactly the same estimates of agricultural land cover, then these adjustments would not occur.

Notenbaert *et al.* (2009) have made such adjustments to the livestock production systems maps, using a threshold of 10 percent, and shown that the discrepancies are quite extensive.

A second reason for incorporating empirical crop and livestock data is to classify the livestock production system classes further, and in particular to break down the mixed farming areas. Notenbaert *et al.* (2009) have included the SPAM crop data following the adjustments to mixed farming areas discussed above. They classified the 20 SPAM crops into 4 functional groups: 1) cereals

TABLE 4.3 MAIN ADJUSTMENTS THAT COULD RESULT FROM INCLUDING EMPIRICAL CROP (SPAM) AND LIVESTOCK (GLW) DATA WITH THE GLOBAL LIVESTOCK PRODUCTION SYSTEMS CLASSES, AND THE CONDITIONS REQUIRED FOR THE ADJUSTMENTS TO BE MADE

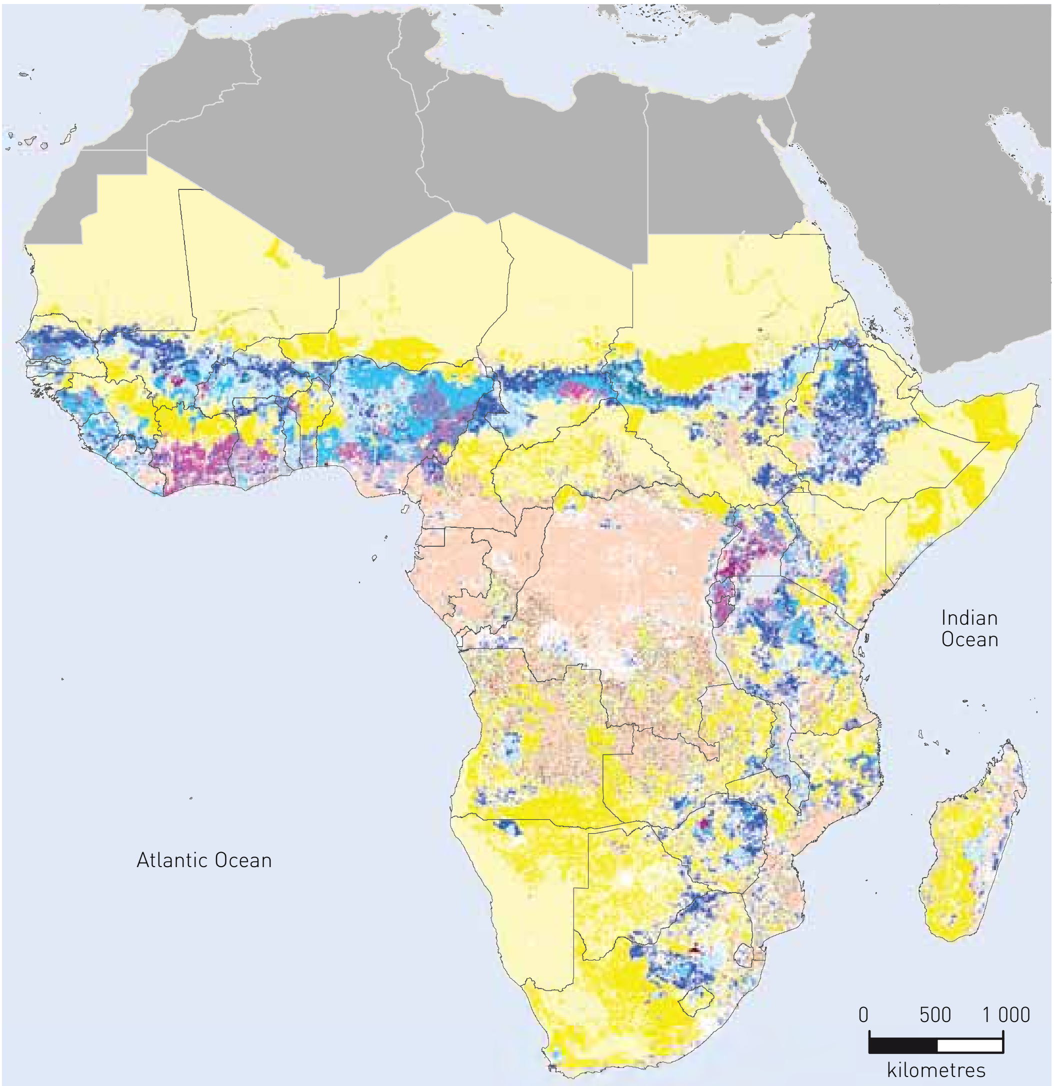
Original system	Revised system	Conditions	Comment
LG	LG	SPAM = no crop GLW = livestock	No change
LG	MR	SPAM = crop GLW = livestock	Reflects inconsistencies in crop cover data layers
LG	Rainfed crop only (CR)	SPAM = crop GLW = no livestock	Reflects inconsistencies in crop cover data layers
MR	MR	SPAM = crop GLW = livestock	No change
MR	LG	SPAM = no crop GLW = livestock	Reflects inconsistencies in crop cover data layers
MR	Rainfed crop only (CR)	SPAM = crop GLW = no livestock	No livestock in potentially mixed (rainfed) areas
MI	MI	SPAM = crop GLW = livestock	No change
MI	Irrigated crop only (CI)	SPAM = crop GLW = no livestock	No livestock in potentially mixed (irrigated) areas

(maize, millet, sorghum, rice, barley and wheat); 2) legumes (beans, cow peas, soy beans and groundnuts); 3) root crops (cassava, (sweet) potato and yams); and 4) tree crops (cocoa, coffee, cotton, oil palm, banana). They then estimated the densities of each group as a whole, and subcategorized the livestock production systems to include the major functional crop grouping(s). Notenbaert *et al.* (2009) further used the SPAM data to subdivide the rangeland (LG) systems into pastoral (with no cropping) and agropastoral systems (where livestock keeping is supplemented by low levels of crop production). They did this by reassigning rangeland areas to agropastoral where the SPAM layers indicate cropping to occur but at less than 10 percent (areas with more than 10 percent having already been re-classified as mixed farming areas). In sub-Saharan Africa, the resulting agropastoral areas covered 19 percent of the total land area, and were home to almost 10 percent of the human population, plus some 15 million cattle.

Figure 4.3 shows the resulting map for sub-Saharan Africa (a plus sign appended to the major crop group indicates that it covers less than 60 percent of the area, and that other group(s) are also important). The Figure shows the cereal-dominated systems to be particularly prevalent in Eastern Africa, while in central and western Africa, the tree and root crop systems also cover large areas of land.

Table 4.4 shows the average farmed area for the four functional groups (cereals, legumes, roots and tree crops) and the mean livestock density (for bovines, small ruminants, pigs and poultry) across the livestock production systems. Values are summarized by the World Bank regions in 2010. Later in the book the same strata are applied to report the distribution of rural poor livestock keepers across the livestock production systems. Consistent with their definition, the potential livestock-only systems have none or limited areas farmed with legumes, roots and tree crops. However, the land cover information and subsequent adjustments based on climate and human population are less precise in identifying the distribution of the area farmed with cereals. Consequently, cereals cultivation is also found in the livestock-only systems of the different regions. Unsurprisingly, the mixed irrigated areas show the highest proportions of farmed area. Overall mixed farming systems (both rainfed and irrigated) concentrate the highest densities of livestock. The distribution of poultry seems somewhat unrelated to the livestock production systems. As observed earlier, the current mapping method relies heavily on land cover data using *ad hoc* interpretation of land cover categories as a proxy for the potential distribution of livestock. However, poultry might be more loosely associated with land cover aspects compared with cattle or other ruminants. This suggests that the livestock production systems classification is better suited to mapping the distribution of potential systems for ruminants rather than for monogastric species. The climatic distribution (hyper-arid, arid and semi-arid, humid and sub-humid, temperate/tropical highland) of the mixed rainfed systems varies across the regions. Nevertheless there is a clear pattern that associates the cultivation of cereals to the distribution of bovines. In the more arid countries of the Middle East and North Africa, bovines are typically replaced by sheep and goats. Eastern and southern Asian regions report significant proportions of farmed area and relatively high livestock densities in urban areas. This calls for refinement of the current method to capture more completely the different urban conditions, as well as peri-urban agriculture, across the regions. It also suggests a need to harmonize the classification and mapping of livestock production systems and the modelling of livestock distributions.

4.3 THE LIVESTOCK PRODUCTION SYSTEMS MAP (VERSION 3) FOR SUB-SAHARAN AFRICA, EXTENDED TO INCLUDE SPAM CROP DATA CLASSES



Mixed Irrigated (MI)	MI/Treecrops	MR/Rootcrops	Peri-urban
MI/Cereals	MI/Treecrops+	MR/Rootcrops+	Urban
MI/Cereals+	Mixed Rainfed (MR)	MR/Treecrops	Other
MI/Legumes	MR/Cereals	MR/Treecrops+	
MI/Legumes+	MR/Cereals	LG/Agro-pastoral	
MI/Rootcrops	MR/Legumes	LG/Pastoral	
MI/Rootcrops+	MR/Legumes+		

Source: adapted from Notenbaert *et al.* (2009).

TABLE 4.4 CROP AND LIVESTOCK GROUPS BY LIVESTOCK PRODUCTION SYSTEM (VERSION 5)*

		LGY	LGA	LGH	LGT	MRY	MRA	MRH	MRT	MIY	MIA	MIH	MIT	Urban	Other
EAP	Cereals	0	0	2	0	6	8	9	8	10	17	32	31	21	3
	Legumes	0	0	1	0	2	8	2	3	3	8	3	8	5	1
	Root crops	0	0	0	0	0	0	2	1	0	0	3	1	2	0
	Tree crops	0	0	0	0	0	1	1	0	0	1	1	3	1	0
	Bovines	2	0	8	2	4	28	18	20	12	37	27	37	27	13
	Small ruminants	39	11	2	29	5	48	10	64	9	40	15	101	61	14
	Pigs	2	0	6	2	23	47	45	57	43	50	100	120	99	39
	Poultry	67	5	94	18	373	337	591	660	764	378	1 169	2 263	1 818	426
EECA	Cereals	0	5	11	1	5	18	17	16	27	31	11	20	11	0
	Legumes	0	0	0	0	0	2	2	1	3	3	1	1	1	0
	Root crops	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Tree crops	0	1	0	0	0	1	0	0	0	5	0	3	1	0
	Bovines	0	11	0	1	1	14	16	9	0	25	41	18	11	2
	Small ruminants	3	51	0	3	2	47	15	8	18	48	74	24	13	2
	Pigs	2	0	0	0	21	1	5	19	0	1	7	8	9	1
	Poultry	13	124	0	9	275	321	364	144	0	306	298	284	237	29
LAC	Cereals	0	1	2	1	1	4	5	5	6	15	12	7	7	1
	Legumes	0	0	2	1	1	3	5	1	2	3	4	2	3	1
	Root crops	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Tree crops	0	0	0	0	0	1	1	1	5	2	2	1	2	0
	Bovines	0	7	37	8	8	20	53	24	148	27	51	30	25	8
	Small ruminants	0	6	9	20	6	12	5	22	0	12	11	38	7	3
	Pigs	0	1	3	3	7	6	8	10	0	21	13	14	10	3
	Poultry	19	41	94	98	55	154	231	291	9	375	358	502	279	80
MENA	Cereals	0	1	0	11	10	14	15	19	27	37	17	27	19	6
	Legumes	0	0	0	1	1	1	7	1	2	4	19	6	2	1
	Root crops	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Tree crops	0	0	0	0	1	0	1	0	3	3	4	2	1	0
	Bovines	0	2	54	7	0	9	31	9	92	25	25	19	17	21
	Small ruminants	1	20	117	62	8	83	60	75	109	76	57	62	66	86
	Pigs	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Poultry	6	85	1 420	248	30	427	1 518	444	873	616	1 638	349	541	689

(Continued)

TABLE 4.4 CROP AND LIVESTOCK GROUPS BY LIVESTOCK PRODUCTION SYSTEM (VERSION 5)* *(Continued)*

		LGY	LGA	LGH	LGT	MRY	MRA	MRH	MRT	MIY	MIA	MIH	MIT	Urban	Other
SA	Cereals	5	2	1	1	25	22	24	9	57	39	61	19	34	11
	Legumes	0	0	0	0	1	12	3	2	4	11	5	1	9	5
	Root crops	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Tree crops	0	0	0	0	1	4	1	0	0	5	1	0	4	1
	Bovines	9	11	29	6	44	88	91	43	136	138	164	69	105	62
	Small ruminants	6	39	5	6	37	74	56	47	187	84	175	91	75	41
	Pigs	0	0	23	3	0	2	9	9	0	5	4	8	4	5
	Poultry	24	48	370	102	381	166	402	520	430	199	821	294	288	247
SSA	Cereals	0	1	2	4	0	8	7	12	0	21	16	14	8	1
	Legumes	0	0	0	0	0	4	2	2	0	4	3	2	2	0
	Root crops	0	0	1	0	0	1	5	1	0	1	6	1	2	0
	Tree crops	0	0	1	0	0	1	2	2	0	2	3	2	1	0
	Bovines	0	6	3	12	4	22	13	55	7	44	35	100	20	8
	Small ruminants	0	15	5	27	8	39	22	55	16	76	36	77	49	11
	Pigs	0	0	0	1	0	1	4	2	1	1	16	2	5	2
	Poultry	3	11	10	26	12	64	98	91	47	105	162	292	487	55
HIC	Cereals	0	1	4	2	2	17	4	22	6	18	13	29	8	1
	Legumes	0	0	1	0	1	1	2	9	0	1	8	10	3	0
	Root crops	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Tree crops	0	0	1	0	0	0	2	0	0	2	9	1	1	0
	Bovines	0	3	24	3	4	11	33	23	8	22	15	32	18	5
	Small ruminants	2	6	30	2	5	58	79	13	5	36	12	7	12	5
	Pigs	1	1	3	1	46	15	26	35	64	23	17	74	23	5
	Poultry	23	34	165	9	213	133	527	410	791	370	356	701	421	109

Developing regions and high income countries are based on 2010 World Bank country classification (World Bank, 2010), listed in Appendix A.

EAP = East Asia and the Pacific; **EECA** = Eastern Europe and Central Asia; **LAC** = Latin America and the Caribbean;
MENA = Middle East and North Africa; **SA** = South Asia; **SSA** = Sub-Saharan Africa; **HIC** = High Income Countries.

* For the crop groups the average farmed area from the SPAM dataset (You *et al.*, 2009) is presented (percentage of each livestock production system area farmed with a given crop group); for the livestock groups the mean livestock density from GLW (FAO, 2007a) is presented (numbers per km^2).

AD HOC EXTENSION OF THE MAPPED LIVESTOCK PRODUCTION SYSTEMS CLASSIFICATION

For some applications, the use of a livestock-based classification such as that of Seré and Steinfeld (FAO, 1996) or those based on it, is not appropriate by itself, simply because there will be situations in which details are needed concerning important communities of people whose livelihoods are not partially dependent on livestock.

An example of a study that involved the rather *ad hoc* extension of the livestock production systems map was that of climate change and vulnerability in Africa (Thornton *et al.*, 2006). In that study the livestock systems were supplemented with some of the farming system categories from Dixon *et al.* (2001). As noted above, this farming systems classification is based on a principal livelihoods approach, and has been used to assess general trends in the poverty levels associated with each system. Because the classification itself is based largely on expert knowledge it is probably not entirely mappable using global- or continental-level datasets. In the vulnerability study an extended systems classification was derived by taking the livestock production system map Version 3 (Kruska, 2006), and for those areas that were classified as 'other' (i.e. non-livestock systems), a digitized version of the Dixon *et al.* (2001) classification was overlain to see which systems were occurring in these non-livestock areas. As a result, the 'other' category in sub-Saharan Africa was supplemented with the following five system categories from the Dixon *et al.* (2001) classification:

- Coastal artisanal fishing-based systems (principal livelihoods include marine fish, coconuts, cashew, banana, yams, fruit, goats, poultry and off-farm work).
- Forest-based systems (cassava, maize, beans and cocoyams).
- Highland perennial-based systems (banana, plantain, enset, coffee, cassava, sweet potato, beans, cereals, livestock, poultry and off-farm work).
- Rice-tree crop systems (rice, banana, coffee, maize, cassava, legumes, livestock and off-farm work).
- Tree crop systems (cocoa, coffee, oil palm, rubber, yams, maize and off-farm work).

The root crop systems and the cereal root crop mixed systems, which also occurred in the 'other' zones but to a smaller extent, were combined into one category and added to all other areas that remained unclassified.

As might be expected given the very different ways in which the two classifications were derived, there are some mismatches between them in terms of areas that are classified inconsistently. For example, the coastal artisanal fishing system also includes goats and poultry (Dixon *et al.*, 2001), although in the global livestock production systems map produced by Kruska *et al.* (2006), these are classified as systems with no livestock. Overall, however, given the continental scale of these data sets, the match between the two systems was found to be reasonably consistent. The full set of systems is provided in Table 4.5, showing for each system the source of the system definition and the source of the mapped system.

These systems were used to assess current and possible future vulnerability to climate change in sub-Saharan Africa. Despite the uncertainties associated with the analysis, results indicated that many currently vulnerable regions are likely to be adversely affected by climate change in sub-Saharan Africa. These include the mixed arid and semi-arid systems in the Sahel (MRA), arid and semi-arid rangeland systems in parts of Eastern Africa (LGA), the mixed and highland perennial systems in the Great Lakes region of Eastern Africa (MRT, PEREN), the coastal regions of Eastern Africa (COAST), and many of the drier zones of southern Africa (LGA, MRA). More details can be found in Thornton *et al.* (2006; 2008).

TABLE 4.5 AGRICULTURAL SYSTEMS USED IN THE AFRICAN CLIMATE CHANGE VULNERABILITY STUDY, SHOWING THE SOURCE OF DEFINITION AND THE SOURCE OF MAPPING

Type	Code	Short system description	Source defined	Source mapped
"Livestock" systems	LGA	Livestock only systems, arid and semi-arid	S	K3
	LGH	Livestock only systems, humid and sub-humid	S	K3
	LGHYP	Livestock only systems, hyper-arid	K6	K6
	LGT	Livestock only systems, highland/temperate	S	K3
	MIA	Irrigated mixed crop/livestock systems, arid and semi-arid	S	K3
	MIH	Irrigated mixed crop/livestock systems, humid and sub-humid	S	K3
	MIHYP	Irrigated mixed crop/livestock systems, hyper-arid	K6	K6
	MRA	Rainfed mixed crop/livestock systems, arid and semi-arid	S	K3
	MRH	Rainfed mixed crop/livestock systems, humid and sub-humid	S	K3
	MRHYP	Rainfed mixed crop/livestock systems, hyper-arid	K6	K6
	MRT	Rainfed mixed crop/livestock systems, highland/temperate	S	K3
"Non-livestock" systems	RITRE	Rice-tree crop systems	D	D
	TREEC	Tree crop systems	D	D
	URBAN	Built-up areas	G	G
	COAST	Coastal artisanal fishing-based systems	D	D
	FORST	Forest-based systems	D	D
	PEREN	Highland perennial-based systems	D	D
	OTHER	Others (including root-crop-based & root-based mixed systems)	S & D	K3

S = Seré and Steinfeld (FAO, 1996); **K3** = Kruska *et al.* (2003); **K6** = Kruska (2006);
D = Dixon *et al.* (2001); **G** = GLC 2000 (Mayaux *et al.*, 2004).

Source: adapted from Thornton *et al.* (2006).

This kind of approach could be extended globally, although there is probably limited utility in attempting to combine classification systems that are not based on the same criteria. Moreover, it assumes that the 'other' category in the mapped livestock production systems does not support livestock, whereas the annexes of FAO (2007a) show this not to be the case: many livestock fall into the areas classified as 'other' according to the modelled livestock distributions. In the example above, this provided a stop-gap means of being able to say something about non-livestock systems in the absence of detailed crop layers. Now that these layers are available it probably makes more sense to pursue a strategy to derive systems maps based on a set of coherent principles and datasets, using the crop and livestock data described above.