Classifying livestock production systems for targeting agricultural research and development in a rapidly changing world

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Abstract

A myriad of agricultural and livestock production systems co-exist in the developing countries. Agricultural research for development should therefore aim at delivering strategies that are well targeted to the heterogeneous landscapes and diverse biophysical and socioeconomic contexts the agricultural production system is operating in. To that end, in the recent past several approaches to spatially delineate landscapes with broadly similar production strategies, constraints and investment opportunities, have been applied. The mapped Seré and Steinfeld livestock production classification, for example, has been widely used for the targeting of pro-poor livestock intervention within ILRI. In this paper we describe potential methodologies for the inclusion of crop-specificity and intensification in the existing Seré and Steinfeld livestock systems classification. We also present some first broad-brush future projections of these detailed crop-livestock production systems. A number of example applications are discussed and recommendations for future improvement and use are made. While the production system classifications are especially useful for bio-physical applications such as livestock-environment interactions and feed assessments, the links with socio-economic factors still need to be explored further. Also, it is only one of the necessary building blocks for better targeting of research and development efforts. We, however, believe that the proposed system classifications will be of use to a variety of agricultural and livestock scientists and development agents alike. In addition, they serve as practical examples making the case for the use of spatial stratification when targeting agricultural research and development.

1. Background

Globally, agriculture provides a livelihood for more people than any other industry (FAOSTAT, 2008). Agriculture also has a key role in poverty reduction: most of the world's poor live in rural areas and are largely dependent on agriculture, while food prices determine the cost-of-living for both rural and urban poor (OECD, 2006). Together with the fresh focus on agricultural development triggered by amongst others the latest world development report (WB 2007), the millennium development goals of reducing hunger and poverty, and many regional initiatives such as NEPAD's Comprehensive Africa Agricultural Development Programme (NEPAD, 2007), this emphasizes the need for higher investments in agricultural research and development, and more specifically in the developing world.

However, many forms of agricultural production co-exist in developing countries. It is thereby crucial to understand that the characteristics and availability of the environmental and socio-economic assets that agricultural production is dependent upon have important spatial and temporal dimensions. Some geographical areas are endowed with agro-ecological conditions suitable for rain-fed cropping, while in others agricultural activities are limited to irrigation or grazing. Some regions have a well-developed road infrastructure, whilst others suffer from a lack of access to services and markets. Exposure to risk, institutional and policy environments and conventional livelihood strategies all vary over space and time. It is hence very difficult to design intervention options that properly address all these different circumstances (Notenbaert, 2009). Agricultural research for development should, instead, aim at delivering institutional and technological as well as policy strategies that are well targeted to the heterogeneous landscapes and diverse biophysical and socioeconomic contexts the agricultural production is operating in (Kristjanson et al., 2006; Pender et al., 2006).

Development strategies therefore call for approaches that identify groups of producers with broadly similar production strategies, constraints and investment opportunities. Somda et al. (2005), amongst others, propose a characterization of farming systems that can typify similar groups for the purpose of identifying opportunities and constraints for development. Notwithstanding the significant heterogeneity of agricultural production systems, a farming system can be defined as a group of farms with a similar structure, such that individual farms are likely to share relatively similar production functions. A farm is usually the unit making decisions on the allocation of resources. The advantage of classifying farming systems is that, as a group of farms they are assumed to be operating in a similar environment. This provides a useful scheme for the description and analysis of crop and livestock development opportunities and constraints (Otte and Chilonda, 2002). It therefore forms a useful framework for the spatial targeting of development interventions.

For technologies coming out of agricultural research to have real impact on poverty alleviation and development, they must have applicability that has been well documented and goes beyond the local level. Thus, there is and always has been need for research to demonstrate effectiveness and wide applicability (Thornton et al., 2006a). The Paris declaration marked a very clear focus on evidence-based policy making, a process that helps planners make better-informed decisions by putting the best available evidence at the centre of the policy process (OECD, 2006). This evidence includes information produced by integrated monitoring and evaluation systems, academic research, historical experience and "good practice" information. The farming systems classification can form the spatial framework within which to organize research and the monitoring and evaluation of interventions. Random, clustered, or stratified sampling techniques can be used to come up with sampling points or survey areas. Case study sites can be selected within or across farming systems (Notenbaert, 2009). System-specific baseline information can be collected, trends monitored, models parameterized for the different farming systems of interest and impacts assessed, both *exante* and *expost*. This process is, for example, demonstrated in the *exante* impact assessment of dual-purpose cowpea by Kristjanson et al. (2005).

This kind of spatial sampling framework is a precondition for any out-scaling effort. Ideally, the moving of technologies to other places requires knowledge about bio-physical and socio-economic environments. To that effect, the farming systems approach, i.e. a clustering of farms and farmers into farming systems for which similar development strategies and interventions would be appropriate, has been widely applied (Dixon et al, 2001).

For investments in agriculture to have a sustainable impact on food security and poverty, decisions have to be made with respect to the small-holder and their natural environment. Non-sustainable use of available natural capital (soil, water, trees) reduces long-term agricultural productivity. Land degradation, erosion, unsustainable water use and equitable sharing of resources are all important issues. The links between agricultural growth and environmental outcomes depend very much on the type of farming system and a country's economic context. For example, the environmental consequences of intensive farming in irrigated areas are quite different from those of extensive farming in low-potential rainfed areas (Hazell and Wood, 2008). Mapping out these different systems can help policy makers and agricultural and land-use planners visualize and develop strategies targeted towards addressing the underlying constraints.

Clearly, interventions addressing current needs have to be done with potential future impacts in mind. In agriculture and international development contexts, there are often significant delays in the development and implementation of technologies and policies (Nicholson, 2007). In order to make technologies and policies better address future needs, it is therefore necessary to assess potential future scenarios. This will enable development agents to plan and prepare in advance and make long-term evidence-based strategic investment decisions.

In short, a farming systems classification offers a spatial framework for designing and implementing pro-active, more focused and sustainable development and agricultural policies. And ideally, it should be amenable to the modeling of different future scenarios.

The classification of agricultural systems has a long history. The coexistence of many different production systems has been described at a global scale before (e.g. Dixon et al., 2001; Seré and Steinfeld, 1996; Pender, 2004). Dixon et al. (2001) defined commodity-specific regions and assessed their potential for agricultural growth and poverty reduction and the relevance of five different strategy choices (intensification, expansion, increased farm-size, increased off-farm income and exit from agriculture). Seré and Steinfeld (1996) looked at the farming system concept with a "livestock lens" and developed a global livestock production system classification scheme that integrates the notions of crop and livestock interactions with agro-ecological zones (AEZ). Livestock production systems may be classified according to a number of criteria, the main ones being integration with crop production, the animal-land relationship, AEZ, intensity of production, and type of product. Other criteria include size and value of livestock holdings, distance and duration of animal movement, types and breeds of animals kept, market integration of the livestock enterprise, economic specialization and household dependence on livestock. For detailed reviews of the different criteria that have been used, see Jahnke (1982), Wilson (1986), Mortimore (1991) and Seré and Steinfeld (1996). In principle, there can be as many classifications as there are possible combinations of criteria.

Kruska et al. (2003) developed a methodology to map the Seré and Steinfeld classification and since then ILRI has regularly updated the system delineation with new datasets (Thornton et al, 2006b). This spatial system characterization forms the basis of a lot of broad-brush targeting and priority setting within ILRI. We describe the different versions of the Seré and Steinfeld livestock production system maps and their applications in more detail in section 2.

Even while the Seré and Steinfeld systems classification has been used quite widely, it is acknowledged that there are various uncertainties and weaknesses to it. Some of the uncertainties in the scheme are listed in Rosegrant et al. (2009). They mention the considerable uncertainties associated with the land-cover data, particularly related to cropland extent. We discuss this in detail in section 3.1 below. Another major weakness highlighted is that the mixed systems categories are too general for many practical applications, and indeed the treatment of crops in the system is weak. This limits the classification's applicability for development purposes, as it does not always offer key insights to potential interventions that could improve the livelihoods of livestock keepers. This limitation becomes even more crucial as agricultural intensification occurs, because livestock will increasingly depend on crop residues and less on grazing on rangelands, fallows and marginal areas (McIntire et al 1992, Powell and Williams 1995; Smith et al. 1997; Naazie and Smith 1997). The inclusion of crop indicators not only enables an explicit link to feed production, it also allows linkages to agricultural water interventions and facilitates estimation of the total value of agricultural production, among others. It is envisioned that a more crop-sensitive system classification can form a common framework across the different crop-based CG-centres and other research organisations.

The growing demand for high-value products and animal-based foods is having implications for agricultural production systems and producers in many poor rural areas. Farmers and livestock keepers will have to adapt to the changing social, economical, market and trade circumstances (Parthasarthy Rao et al., 2005). This adaptation can take place in different forms: expansion of cultivation area, intensification of systems of production and closer integration of crop and livestock (Powell et al., 2004). Large regional differences exist. In Africa, the increases in production have been mostly through increases in area planted, while in Asia's mixed systems, population densities are so high that increases in production through area expansion are not possible (FAOSTAT, 2008; Herrero et al., 2008b). In a dramatic break with historical patterns, expansion of the total cropped area in most parts of the world has played a remarkably small role in increasing agricultural production in recent decades, to the point that growth in the global extent of cropland has virtually stagnated (Hazell and Wood, 2008). The intensification of production has been primarily achieved with a technological revolution that has increased yields through increases in modern inputs— irrigation, improved seeds, fertilizer, tractors and pesticides. The Seré and Steinfeld livestock system classification does not map the intensive or potentially intensifying agricultural systems. This distinction is, however, very important for several reasons: these are systems that may be expected to undergo rapid technological change, exhibit rapid uptake of technology and need for increased investments in input supply, they are particularly prone to environmental degradation and they might be exceptionally susceptible to the emergence of new disease risks, and so on.

The Seré and Steinfeld classification is a useful start and baseline, but there are clear demands for more information or different system cuts. Issues of how intensified systems are, whether there is potential for intensification, what the scale of production of commodities in particular places are, which major crops are grown in these areas, these are all examples of valid questions that an evolving classification scheme needs to move towards answering. Sections 3 and 4 describe a proposed methodology for inclusion of crop indicators and an attempt to include a simple intensification proxy into the Seré and Steinfeld classification.

The paper also assesses the suitability of the different datasets used in the construction of the classification systems. Potential uses of the resulting systems are demonstrated and discussed using examples and recommendations for future improvements.

2. The Seré and Steinfeld livestock production systems classification

As articulated by Seré and Steinfeld (1996), livestock make an important contribution to most economies. Livestock produce food, provide security, enhance crop production, generate cash incomes for rural and urban populations, provide fuel and transport, and produce value-added goods which can have multiplier effects and create a need for services. Furthermore, livestock diversify production and income, provide year-round employment, and spread risk. They conclude that the interdependence of crops and livestock in mixed farms and the different contributions made to livelihoods suggest that these two aspects of farming should be considered together. Seré and Steinfeld (1996) therefore developed a global livestock production systems classification building on this notion of livestock-crop integration and the agro-ecological zone concept used by FAO. In this classification livestock systems fall into four categories: landless systems (intensive industrial systems), livestock only/rangeland-based systems (areas with minimal cropping), mixed rainfed systems (mostly rainfed cropping combined with livestock) and mixed irrigated systems (a significant proportion of cropping uses irrigation and is interspersed with livestock). All but the landless systems are further disaggregated by agro-ecological potential as defined by the length of growing period, resulting in 11 categories in all. A method was devised to map this classification in the developing world based on LGP, land cover, and human population density (Thornton et al. 2002; Kruska et al., 2003). Because climatic and population variables are used as input data, this has enabled the classification to be re-evaluated in response to different scenarios of climate and population change in the future (Thornton et al. 2006b).

The original systems map has since been updated in various ways. The basic model has been expanded to version 2, by making additions to the original LGP breakdown to include hyper-arid regions, defined as areas with zero growing days. This was done because livestock can be found in some of these regions during wetter years when the LGP is greater than zero.

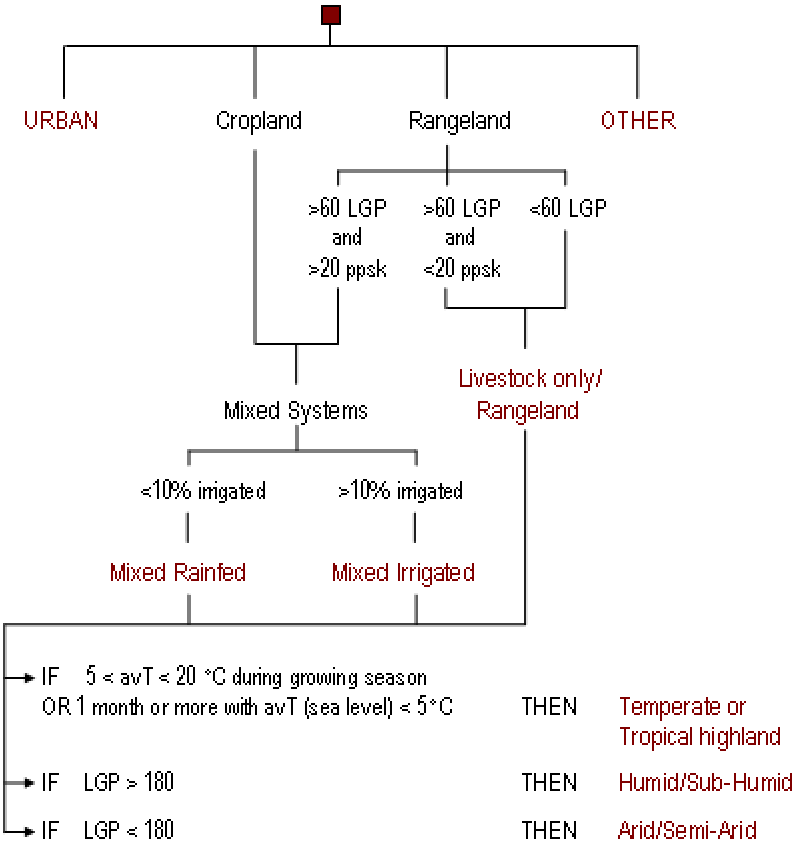
As in any GIS application the key to success is the availability of accurate input data. Most of the updating of the systems maps for version 3 has therefore been associated with the use of new datasets. For human population, the 1-km Global Rural-Urban Mapping Project (GRUMP) data (CIESIN, 2004) was used. Length of growing period data were developed from the WorldClim 1-km data for the year 2000 (Hijmans et al., 2005), together with a new "highlands" layer for the same year based on the same dataset (methods are outlined in detail in Thornton et al., 2006b). Cropland and rangeland were defined from GLC 2000, and areas classified as rock or sand were included as part of rangelands. The landless systems remain problematic and were not included in this version of the classification. Table 1 indicates the data sources that were used in the different versions.

Table 1: Data sources for versions 1 and 3 of the Seré and Steinfeld livestock production systems

Data Inputs	**Version 1**	**Version 3**
Land Use/Cover	USGS Global Land Cover Characterization (1 Km resolution at Equator)	JRC GLC2000 Global Land Cover (1 Km resolution at Equator)
Length of Growing Period	Length of Growing Period 2000, 2050 for Africa (18.5 Km resolution) Jones and Thornton	Length of Growing Period 2000, 2030 (1 Km resolution) (Jones and Thornton/Worldclim)
Highland/Temperate Areas	Highland/Temperate regions 2000, 2050 for Africa (18.5 Km resolution) Jones and Thornton	Highland/Temperate regions 2000, 2030 (1 Km resolution) (Jones and Thornton/Worldclim)
Population	Population density 1990 (5.6 Km resolution) (Deichmann, 2001); 2000 for Asia (CIESIN, 2000)	Population density 2000 (1 Km resolution) CIESIN Global Rural Urban Project (GRUMP – CIESIN 2004)
Population Projections	Population density 2000-2050 (5.6 Km resolution) (ILRI, 2001)	Population density 2030 (1 Km resolution) GRUMP (ILRI, 2005) includes rural/urban breakdown
Irrigation	Global Irrigation Database version 1.0 (56 Km resolution) from the University of Kassel (Siebert et al, 2001)	Global Irrigation Database version 3.0 (5.6 Km resolution) (FAO Aquastat, 2005)

The flow chart in figure 1 shows the process of deriving the different production systems. At the basis of the methodology is the differentiation between mixed systems and livestock grassland-based systems. Cropland extent can be derived from various land cover products, but there is still wide variation in estimates of cropland extent (see section 3.1 for a more detailed discussion of this problem). Largely as a result of the problems of under-estimation of cropland extent, the mapping scheme assigns part of the rangelands to the mixed system category. The rangelands are divided into "cultivatable" and "non-cultivatable", on the basis of a length of growing period threshold of 60 days. All cultivatable rangelands with a population density greater than 20 people per square km are added to the cropland category, to define the mixed production system category. The remaining area under the rangelands category defines the rangelands/livestock-only category. The rationale for using population density is based on the effect of human population density on crop-livestock interaction first described by McIntire et al. (1992). At low levels of population density, crop and livestock production systems are extensive and the sole interactions are through markets and contracts (e.g. manure contracts). With population growth, systems intensify due to changing relative factor prices. Both the net demand for agricultural products and the opportunity costs of land increase, bringing about the need for on-farm crop-livestock interactions, mainly through more efficient exploitation of nutrient resources, crop residues and manure. The threshold density of 20 people km^2 was based on comparisons of maps depicting different thresholds with higher resolution land-cover data for Latin America, West Africa and East Africa, and expert opinion. Human population has been shown to be strongly related to the amount of land cultivated (Reid et al., 2000).

Figure 1: Flow chart of the process used in establishment of the production systems (adapted from Thornton et al. 2002)



2.1 The livestock production systems of the world

The resulting maps and some summary statistics are shown in Annex 1. Almost one third of the global area is occupied by rangelands. Due to the very low human population densities here, they are home to only 4% of the world population. Still, they can be of major importance. In some regions they support substantial populations in their livelihoods and contribute considerable amounts to the national budgets through livestock production, but also wildlife and eco-tourism. In Africa, for example, about a quarter of the cattle are kept in a livestock production system mainly depending on rangelands and almost half of that production happens in the arid and semi-arid lands. In view of the ever-growing population pressure, increasing demand for livestock products, and environmental threats associated with un-controlled intensification, it will become increasingly important to utilize the rangelands sustainably and to their full potential. It has been recognised that these rangeland based systems are ecosystems with many functions and some alternative development options. Some of these options might turn into economically viable livelihood strategies if the right systems of incentives and policies are put in place. For poor households this will mean alternatives beyond traditional livestock production such as payments for ecosystem goods and services like water, carbon sequestration and others, tourism, bio-fuel production and the development of niche markets (Seré et al., 2008).

The largest human (and cattle) populations are supported by mixed systems. More than 80% of the global population lives in these systems, though they only occupy about 30% of the land area. As a consequence, high population densities can be observed in many of the mixed crop-livestock systems. The irrigated systems, especially in Asia, expand over large areas and exhibit the highest population densities of the world. In East-Asia, for example, 58% of the population lives on the 12% of land which is under irrigation; in South-East Asia, 40% of the population lives in areas with irrigated agriculture, covering about 10% of the land area. This results in average population densities of 555 and 430 people per square kilometer respectively.

Clearly, huge regional differences exist. The importance of different systems in terms of areas covered, human and animal populations supported by them, contribution to the country's or region's economy varies considerably. In addition, the characteristics and associated challenges and opportunities are quite different from system to system but also from region to region.

2.2 Looking Ahead

The spatial distribution of the production systems defined by Seré and Steinfeld (1996) and mapped by Kruska et al. (2003) will evolve by 2030 (see Herrero et al., 2009). Land areas under each production system will change significantly as a result of climate change (changes in LGP) and also due to increased population density. Our projections in Africa show that there will be an expansion of the arid production systems at the expense of humid and temperate/tropical highlands systems. At the same time, the results show a transition from livestock grazing systems to mixed systems. The largest changes from rangeland-based to mixed systems are in areas where population densities are rapidly increasing. In addition, livestock numbers will increase significantly by 2030. These increases vary depending on the production system and environment. In general terms, higher increases can be observed in mixed systems compared to rangeland systems..

2.3 Uses of the Seré and Steinfeld Classification

The original FAO Seré and Steinfeld livestock production system classification was set up to be used for environmental impact assessment by production system and as an analytical framework of the livestock-environment study. They also envisioned its use by a wider public for priority setting and as a basis for a general discussion on livestock development (Seré and Steinfeld, 1996). The mapped version of this system characterization forms the basis of a lot of broad-brush targeting and priority setting within ILRI and beyond. Livestock production varies across different livestock production systems, and it can provide a stratification by which to parameterize livestock growth and off-take models (e.g. Otte and Chilonda, 2002; Wint and Robinson, 2007). Herrero et al. (2008a) estimated methane emissions from domestic ruminants in Africa for a range of production systems. The classification has also been used successfully in poverty and vulnerability analyses (Thornton et al. 2002, 2006b), for prioritising animal health interventions (Perry et al. 2002) and for studying systems changes in West Africa (Kristjanson et al. 2004). In addition, the systems classification has been used to investigate the role of agricultural science and technology on economic growth and poverty alleviation to the middle of the current century (Rosegrant et al., 2009), and to assess the potential impacts of change in crop-livestock systems on agro-ecosystems services and human well-being (Herrero et al., 2009). The classification forms a practical framework for priority setting exercises at both a regional and country level. Peden et al. (2006) used the farming systems in combination with measures of market access, population density and water availability to assess investment options for integrated water-livestock-crop production in sub-Saharan Africa, while Van de Steeg et al (2008) gave input into the ASARECA strategic plan on climate change in East and Central Africa. As it entails a landscape-level review, it is however not meant to assess interventions at the household level.

3. Moving forward: Including crop indicators in the Seré and Steinfeld classification

Mixed crop-livestock systems in the developed world are very heterogeneous. In general terms they can be distinguished by the type of main crops grown in them and the type of livestock prevailing. Fernández-Rivera et al. (2004), for example, define 13 different crop-livestock systems in West-Africa, such as maize-sorghum-livestock and cassava-yam-livestock. The main crops grown largely define the types of technologies (crop varieties and management, feeding practices for animals, intensity of production and others) applicable in them. The "mixed" crop/livestock systems of the Seré and Steinfeld classification, on the other hand, only include areas known to be cropped with no attempt to distinguish the variety of crops and crop types covered within the distribution. It groups a vast range of crops, ignoring the diverse types of production systems that exist. In order to address this gap, and disaggregate the mixed systems category, we integrated the latest global crop data layers with the Seré and Steinfeld system classification. This work was originally done for identifying systems types

and feed interventions across the regions where CG centres could jointly work (Herrero et al 2007), although many other applications have sprung from the initial effort.
We used the Spatial Allocation Model (SPAM) dataset (You et al., 2009), which shows the global distribution of the following major crops: rice, wheat, maize, sorghum, millet, barley, groundnuts, cowpeas, soybeans, beans, cassava, potato, sweet potato, coffee, sugar cane, cotton, bananas, cocoa, and oil palm. The combination of both layers allowed us to develop a new hierarchical systems classification that gives a clear indication of the main crops grown. In addition it differentiates between pastoral and agro-pastoral as well as between urban and peri-urban areas.

3.1 The SPAM dataset

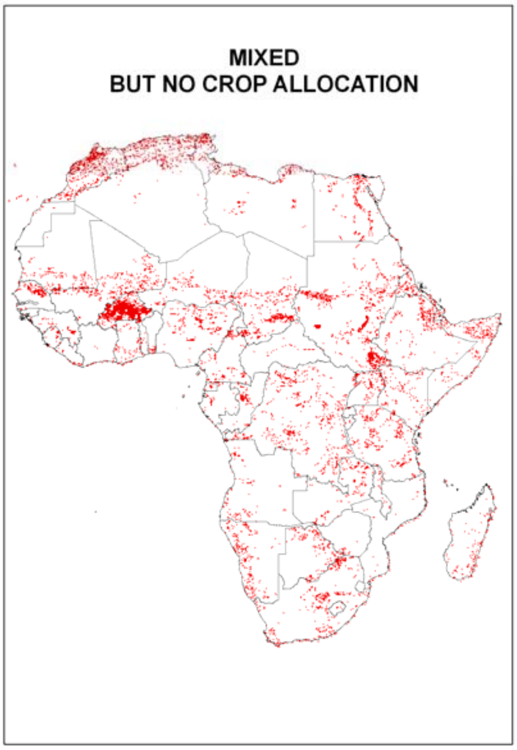
The Spatial Allocation Model (SPAM) methodology uses a cross-entropy approach to make plausible allocations of crop production statistics for geopolitical units (country, or state) into individual pixels, through judicious interpretation of all accessible evidence such as farming systems, satellite imagery, crop biophysical suitability, crop price, local market access and prior knowledge. For a detailed description of the data sources and the spatial allocation methodology see You et al. (2009). The resulting dataset contains 5x5 minutes (about 9x9 km2 on the equator) crop distribution maps of 20 major crops, covering over 90% of the world crop land. In addition to these area distribution maps, the dataset includes production and harvested area distribution maps as well as the sub-crop type maps split by production input levels (irrigated, high-input rainfed, low-input rainfed and subsistence). To the best of our knowledge these are the finest resolution global crop distribution maps for the year 2000 available in the public domain.

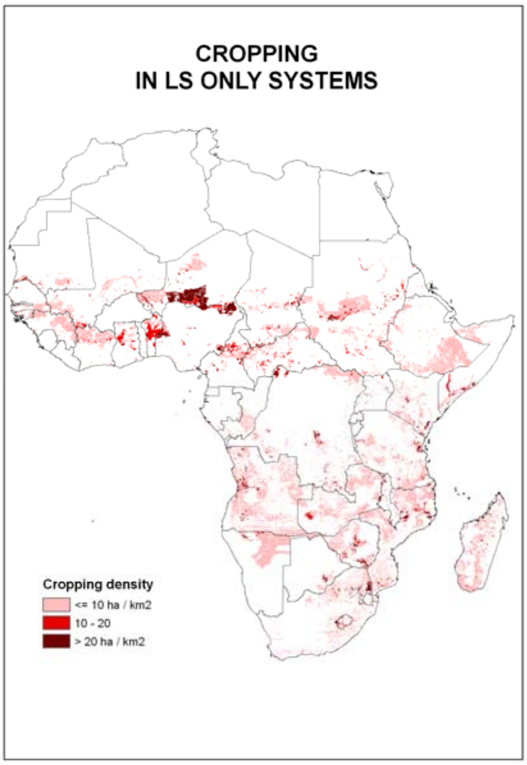
Satellite-based land cover data play an important role in the allocation model. They serve to provide detailed spatial information on cropland extent – distinguishing cropland from other forms of land cover such as forest, grassland, and water bodies and, therefore, delineating the geographical extents within which crop production must be allocated. As outlined by You et al. (2008), one of the greatest challenges when working with existing land cover datasets is the lack of consistent and reliable data on the location and area intensity of cultivation. Agricultural areas are generally difficult to map because of the heterogeneity, the spectral similarity with grassland in the dry areas, the inter-annual variability due to rotation, fallow, and growing seasons (Rembold, 2007).

In line with version 3 of the Seré and Steinfeld map, the SPAM crop allocation uses the data from the Global Land Cover 2000 project (GLC2000 from JRC, 2005). As a result of the problems associated with the land cover data, the need arose for allocating crops beyond the remotely sensed cropland extent of GLC2000. The SPAM methodology however, uses different rules in contrast to those used by Kruska et al. (2003). As noted before, Kruska et al. (2003) assumed that the all rangelands with adequate growing periods and high population densities can actually be assumed to be under a mixed crop/livestock system. Human population has been shown to be strongly related to the amount of land cultivated (Reid et al., 2000), and it was estimated that the threshold of 20 people per square km is generally equivalent to 15-25 percent of the land cultivated. The resulting classification may thus slightly overestimate the cover of cropland, but it should appropriately classify mixed crop-livestock systems (Kruska et al., 2003).

The SPAM model distributes crops to highly suitable rangeland pixels if and where the cropland pixels do not suffice to share out the total crop production reported for that area. This results in quite different final cropland boundaries. In figure 3, a comparison between the Seré and Steinfeld classification and the SPAM crop extents is shown . The huge differences indicate the need for a more accurate or better harmonized definition of cropland extent. Currently, a number of global land cover datasets exist but the accuracy and extent of the areas classified as cultivated vary widely (Fritz et al. 2008). These datasets include: IFPRI's (International Food Policy Research Institute) extent of cultivated area, which was derived from the Global Land Cover Characterization Database (GLCCD) and is based on 1992/93 AVHRR satellite data; GLC2000 which was derived from year 2000 SPOT satellite data; Boston University's Global Land Cover dataset based on year 2000 MODIS data; the SAGE cropland database (Leff et al., 2004); and the GLOBCOVER2005 products. Each of these datasets includes classes related to cultivated areas but each were derived using different criteria, thresholds, etc and none of them stands out as fully encompassing the areas across the globe that are characterized by cultivation particularly those characterized by a mosaic of cultivation and other natural land covers. Each land cover dataset has its strengths and weaknesses, and some researchers (e.g. Jung et al. (2006)) are exploring the option of merging individual remote sensing products in order to provide a higher quality, integrated land cover data sets. A concerted research effort involving experts from different fields and incorporating extensive field validation could increase the accuracy of this crucial dataset considerably.

Figure 3: The rangeland extent according to the Seré and Steinfeld livestock systems classification compared with You and Wood's spatial crop allocations





3.2 A new hierarchical system classification providing more detail for the mixed systems

The combination of the original Seré and Steinfeld classification, as in Kruska et al 2003, with the SPAM crop distribution layers allowed us to develop a new hierarchical systems classification that greatly improves the amount of information of the mixed categories. It was decided not to include any indication of agro-ecology. The number of classes in a map should be possible to deal with by the reader. Maps with more than 9 classes are too complex for most users (Olson, 1981). In any classification system, there is therefore the trade-off between clarity, readability and the variety of criteria to include. In some cases it is important to know which specific crops are grown, while in others it is the bio-physical conditions that are of interest. It would be too crowded to include crops, intensification and AEZs all in one classification scheme. In addition to the crop differentiation, the proposed classification distinguishes between pastoral and agro-pastoral as well as between urban and peri-urban areas.

The first level remains unchanged from Kruska et al's methodology (2003) and splits the land area in rangeland-based systems, mixed rainfed, mixed irrigated, urban and other systems. A second level provides sub-divisions for four of these categories. A third and final level provides information about the major crops in the mixed systems only. These different levels are illustrated in table 2.

Table 2: Overview of the different classification levels

Broad Class	Crop Group	Detail
Rangeland Based	LG/Pastoral	/
	LG/Agro-Pastoral	/
Mixed-Rainfed	MR	/
	MR/Cereals	Barley
	MR/Cereals+	Barley+
		Millet
		Millet+
		Maize
		Maize+
		Rice
		Rice+
		Sorghum
		Sorghum+
		Sugar Cane
		Sugar Cane+
		Wheat
		Wheat+
	MR/Treecrops	Cocoa
	MR/Treecrops+	Cocoa+
		Coffee
		Coffee+
		Oil Palm
		Oil Palm+
		Banana
		Banana+
		Cotton
		Cotton+
	MR/Rootcrops	Potato
	MR/Rootcrops+	Potato+
		Yam
		Yam+

Broad Class	Crop Group	Detail
Mixed Irrigated	MI	Barley
	MI/Cereals	Barley+
	MI/Cereals+	Millet
		Millet+
		Maize
		Maize+
		Rice
		Rice+
		Sorghum
		Sorghum+
		Sugar Cane
		Sugar Cane+
		Wheat
		Wheat+
	MI/Treecrops	Cocoa
	MI/Treecrops+	Cocoa+
		Coffee
		Coffee+
		Oil Palm
		Oil Palm+
		Banana
		Banana+
		Cotton
		Cotton+
	MI/Rootcrops	Potato
	MI/Rootcrops+	Potato+
		Yam
		Yam+
		Cassava
		Cassava+
		Sweet Potato

		Cassava
		Cassava+
		Sweet Potato
		Sweet Potato+
	MR/Legumes	Beans
	MR/Legumes+	Beans+
		Cowpea
		Cowpea+
		Soybean
		Soybean+
		Groundnut
		Groundnut+
		Sweet Potato+
	MI/Legumes	Beans
	MI/Legumes+	Beans+
		Cowpea
		Cowpea+
		Soybean
		Soybean+
		Groundnut
		Groundnut+
URBAN	Urban	
	Peri-Urban	
OTHER	Other	

The two mixed classes -mixed rainfed and mixed irrigated- were subdivided according to the major crop groups present. The SPAM crop data provides information about harvested area of 20 commodities on a ha/pixel basis: yam, rice, wheat, maize, sorghum, millet, barley, groundnuts, cowpeas, soybeans, beans, cassava, potato, sweet potato, coffee, sugar cane, cotton, bananas, cocoa, and oil palm. As the pixel sizes vary with longitudes, we converted these harvested areas to crop densities, expressed in ha/km2. We then classified these 20 crops into 4 crop functional groups: cereals, legumes, root crops and tree crops (Table 3). Total crop group densities (ha/km2) were calculated by adding up the densities of the constituting crops. The grouping of crops was done to simplify the classification. In a third hierarchical level details about the actual crops are incorporated.

Table 3: combination of crops in crop groups

CROP GROUPS	
Cereals	maize, millet, sorghum, rice, barley, wheat
Legumes	Beans, cow peas, soy beans, groundnuts
Root crops	Cassava, (sweet) potato, yams
Tree crops	Cocoa, coffee, cotton, oil palm, banana

All commodities were added up to calculate a total crop density per pixel. For each of the crop groups their importance as compared to the other crop groups was calculated and expressed as a percentage of total crop densities taken up by this specific crop group. This allowed us to establish which of the four crop groups covered most of the cropped area. This major crop group was then used as the crop identifier in the new system classification. In case this crop group adds up to more than 60% of the cropped area, it dominates and is directly referred to, otherwise it is referred to as e.g. cereals+. The data behind the map in figure 5 contains the details of exactly what other crop groups had to be included to reach the 60% threshold but this information was not included on the map for clarity.

Further detail was developed within the crop group classes. For example, for each of the main crop groups, the main crop per crop group was identified. Parallel to what was done for the crop groups, also here differentiation was also made between more or less “pure” crop systems. For example, it was established if the major crop constitutes more or less than 70% of the agriculture within its crop group.

Apart from this sub-division of the mixed systems on the basis of crop groups, also sub-division on the basis of crop types and crop categories was done to identify crops of different economic or food security importance and to identify those that could be used as feed resources (*Herrero et al 2007*) (see table 4). The groupings of crops are different, the methodology however exactly the same.

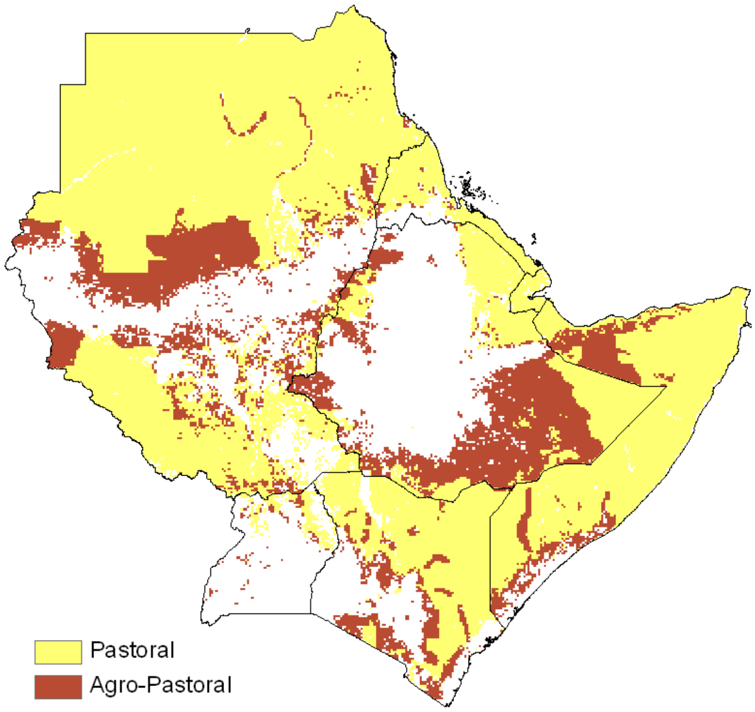
Table 4: combination of crops in crop types and categories

*CROP TYPES**	
Cash crops	Cocoa, coffee, cotton, oil palm, sugar cane, soybeans, groundnuts
Food crops	Banana, maize, millet, sorghum, rice, barley, wheat, potato, sweet potato, yams, cassava, beans, cow peas
CROP CATEGORIES	
Food/Feed crops	Banana, cow pea, maize, sorghum, millet, barley, wheat, rice, beans, soybeans, groundnuts
Feed crops	Sugar cane

** A second version of crop types was also constructed, the difference being the inclusion of groundnuts with the food crops instead of cash crops*

The rangeland-based systems are subdivided into purely livestock based or pastoral system and agro-pastoral systems where livestock keeping is to a certain extent mixed with crop agriculture. As already noted earlier, the SPAM model assigns crops to pixels that are classified as “Livestock only”. Mostly these have less than 10% of the total available land cropped. These areas are now reclassified as agro-pastoral (see figure 4). In sub-Saharan Africa, these agro-pastoral areas cover 19% of the land, are home to almost 10% of the population and house more than 15 million cattle.

Figure 4: The rangelands sub-divided in pastoral and agro-pastoral areas in the greater horn of Africa



The GRUMP (Global Rural Urban Mapping Project) dataset was used to expand the "urban" areas in the S&S classification. One of the GRUMP layers contains the extent of all urban areas with a population of more then 5000 people. The extent of urban settlements with a population of more than 100,000 was selected and classified as peri-urban, whereas the actual build-up areas showing up on the GLC (Global Land Cover) satellite imagery remained classified as urban.

3.3 Examples of the inclusion of crop-indicators

Figure 5 shows level 2 of the hierarchical system classification for sub-Saharan Africa. It clearly indicates the huge variety of crop and livestock mixes that can be found in sub-Saharan Africa (SSA). About 60% of the land area of SSA is under rangeland systems, making it by far the most wide-spread land use system in this region (see table 5). It supports a population of more than 100 million pastoralists. One third is estimated to be under an agro-pastoral management system i.e. pastoralists are also in the rangeland area growing some crops. Rainfed crop production, often mixed with livestock production, occupies about 20% of the land area in SSA. The cropping systems where cereals dominate occupy most of this area (12%), followed by treecrops (3%) and legumes (2%). Large-scale irrigation is rare to find in SSA and only 0.1% of the area is under such management, supporting only a fraction of the human as well as animal population.

Across SSA, the cereal-dominated systems are the most widespread cropping system. The relative importance does, however, differ between the regions. In eastern Africa, more than 70% of the area is under cereal systems with very small areas dominated by root- or treecrops. In central and western Africa, however, the tree- and rootcrops also dominate considerable areas. The rootcrop systems, for example, cover more than a quarter of central African mixed rainfed areas (table 5).

Also striking is the fact that across SSA, most of the land is used for some kind of agricultural activity, be it pastoralism or crop-based agriculture. The only region which has large tracks of non-agricultural land is central Africa.

Figure 5: The huge heterogeneity of production systems in SSA

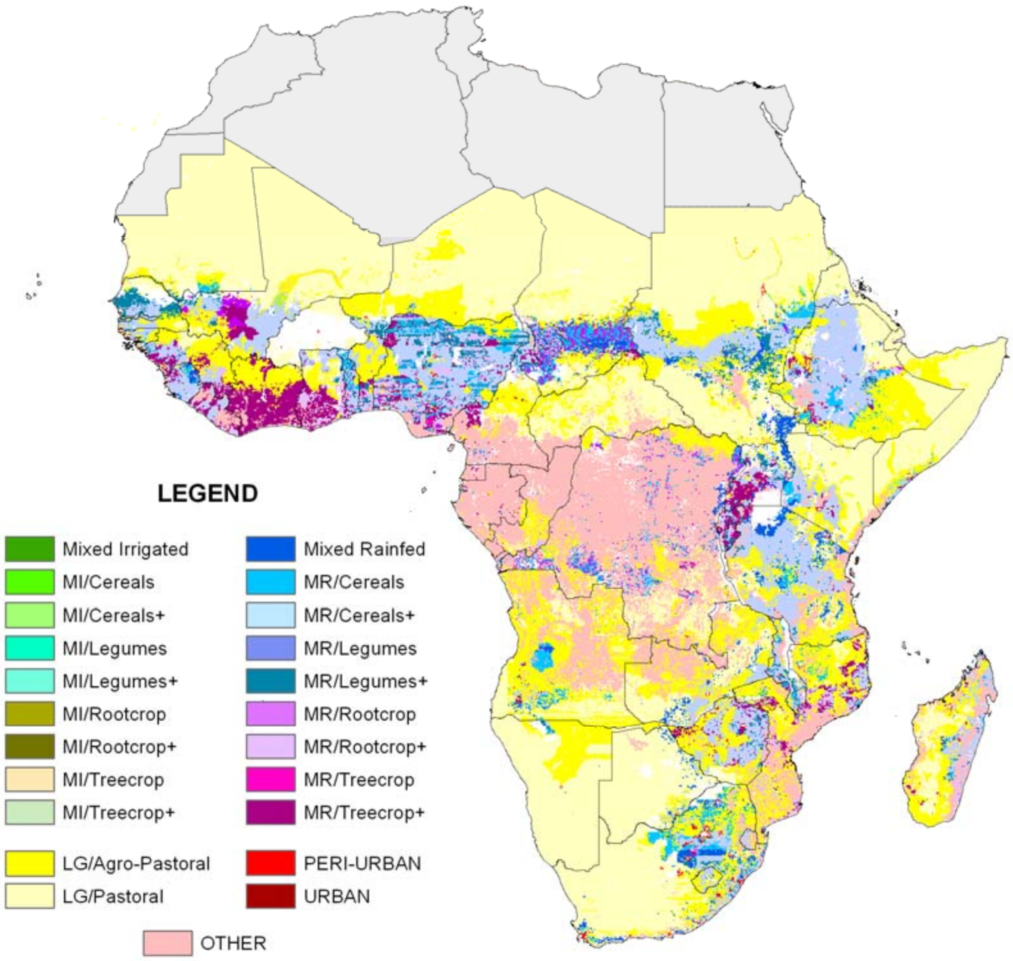


Table 5: Land areas of the different systems in thousands of square kilometer

System class *	Central Africa	%	Eastern Africa	%	Western Africa	%	Southern Africa	%	Grand Total	%
Pastoral	689	*17.2*	2,823	*46.7*	3,659	*50.8*	2,397	*37.3*	9,568	*40.4*
Agro-pastoral	508	*12.7*	1,093	*18.1*	983	*13.6*	1,883	*29.3*	4,468	*18.9*
MR**	18	*0.4*	140	*2.3*	39	*0.5*	94	*1.5*	291	*1.2*
MR cereals	46	*1.2*	1,106	*18.3*	801	*11.1*	511	*8.0*	2,464	*10.4*
MR cereals+	56	*1.4*	94	*1.6*	177	*2.5*	143	*2.2*	470	*2.0*
MR treecrops	41	*1.0*	107	*1.8*	449	*6.2*	114	*1.8*	711	*3.0*
MR treecrops+	12	*0.3*	1	*0.0*	36	*0.5*	2	*0.0*	50	*0.2*
MR rootcrops	29	*0.7*	48	*0.8*	177	*2.5*	78	*1.2*	332	*1.4*
MR rootcrops+	48	*1.2*	6	*0.1*	79	*1.1*	2	*0.0*	135	*0.6*
MR legumes	13	*0.3*	168	*2.8*	212	*2.9*	65	*1.0*	458	*1.9*
MR legumes+	24	*0.6*	2	*0.0*	53	*0.7*	7	*0.1*	87	*0.4*
MI**	0	*0.0*	0	*0.0*	0	*0.0*	1	*0.0*	1	*0.0*
MI cereals	1	*0.0*	5	*0.1*	10	*0.1*	0	*0.0*	16	*0.1*
MI cereals+	0	*0.0*	1	*0.0*	1	*0.0*	0	*0.0*	2	*0.0*
MI treecrops	0	*0.0*	1	*0.0*	1	*0.0*	0	*0.0*	2	*0.0*
MI treecrops+	0	*0.0*	0	*0.0*	0	*0.0*	0	*0.0*	0	*0.0*
MI rootcrops	0	*0.0*	0	*0.0*	0	*0.0*	0	*0.0*	0	*0.0*
MI rootcrops+	0	*0.0*	0	*0.0*	0	*0.0*	0	*0.0*	0	*0.0*
MI legumes	0	*0.0*	1	*0.0*	1	*0.0*	0	*0.0*	3	*0.0*
MI legumes+	0	*0.0*	0	*0.0*	0	*0.0*	0	*0.0*	1	*0.0*
Urban	0	*0.0*	1	*0.0*	2	*0.0*	3	*0.0*	5	*0.0*
Peri-urban	4	*0.1*	7	*0.1*	14	*0.2*	20	*0.3*	45	*0.2*
Other	2,517	*59.9*	443	*4.8*	511	*2.3*	1,107	*15.7*	4,579	*16.3*
TOTAL	***4,008***		***6,048***		***7,206***		***6,428***		***23,690***	

**MR = Mixed Rainfed / MI = Mixed Irrigated*

***Mixed areas with missing crop data don't have any indication of major crop group*

Zooming into West Africa, figure 6 shows the geographical spread and details of the cereal systems in use there. These are mainly dominated by millet, with large areas (30%) comprising over 70% of the crops grown (see table 6). The second most dominant cereal in West Africa is sorghum, which dominates in Benin, Cameroon, Ghana, Mali, Mauritania and

Togo. Rice follows closely, with extreme importance in Ivory Coast, Guinea, Liberia and Sierra Leone.

Figure 6: The production systems in West-Africa and details of the cereal-based systems

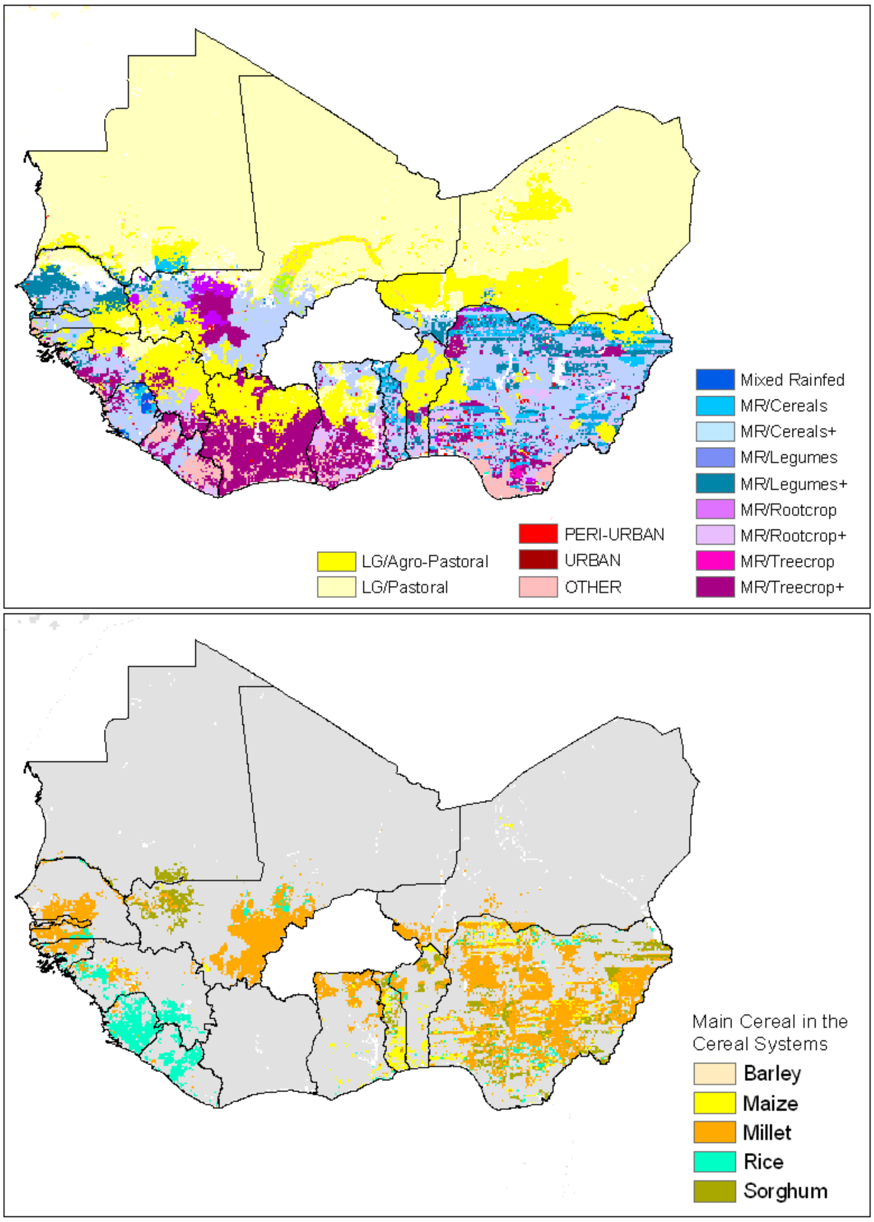


Table 6: Percentages of cereal system areas in West Africa

Country name	Maize	Millet	Rice	Sorghum	Sugar Cane
Benin	28.3	14.9	14.1	42.7	
Cameroon			33.3	66.7	
Cote d'Ivoire			100.0		
Gambia		55.8	7.0	37.2	
Ghana	18.9	33.0	14.1	34.0	

Guinea	15.1	4.9	80.1		
Guinea-Bissau	14.7	15.3	64.0	6.0	
Liberia			98.7		1.3
Mali	11.3	30.8	23.4	34.1	0.3
Mauritania	0.8	1.5	3.8	94.0	
Niger		97.1		2.9	
Nigeria	23.3	35.5	9.4	31.8	
Senegal		59.5	23.9	15.3	1.3
Sierra Leone		0.2	98.7	1.1	
Togo	57.1	9.2	8.9	24.8	
Total	**17.9**	**30.1**	**24.7**	**27.1**	**0.2**

In figure 6, it can be seen that there are still some problems with the spatial allocation of crops, resulting in a big data gap in Burkina Faso and a pattern of parallel stripes in e.g. Nigeria. The beta version of the spatial allocation that was used to produce the maps is currently being revised. Apart from more detailed input data in terms of higher resolution statistics and ground-truthing, some methodological problems in the spatial allocation algorithm are under review. Although some of the spatial patterns might change, it is expected that the general picture will remain and overall statistics will only change marginally. In addition to that, it is important to keep in mind that each of the production system classes harbours a lot of heterogeneity within. The system classification is a landscape level assessment; the application of this classification is therefore limited in scale. It is however useful for regional, continental and global targeting work. It can further serve as a spatial framework for broad-scale analysis of, for example, nutrient cycles dependent on the farming system, ecosystem functioning and services in agricultural lands, and diets and productivity of livestock.

4. Distinguishing mixed extensive from potentially intensifying systems

The distinction between extensive and intensive agricultural systems is very important as intensification partly determines the use, regulation and provision of agro-ecosystems services in different production systems, and the consequences for human wellbeing and the environment. It also helps targeting the existing policy and technical options to ensure the sustainability of global food production and ecosystems functioning as human population increases. These issues were recently addressed by a CG-wide global integrated assessment of the future of livestock and crop livestock systems (Herrero et al. 2009). This study required a simple but robust systems classification for easily communicating results to a range of diverse stakeholders.

We therefore implemented a classification scheme that included a measure of intensification potential and separated the areas with a high potential for intensification from the pastoral and more extensively managed mixed systems. We thereby ended up with 4 broad classes:

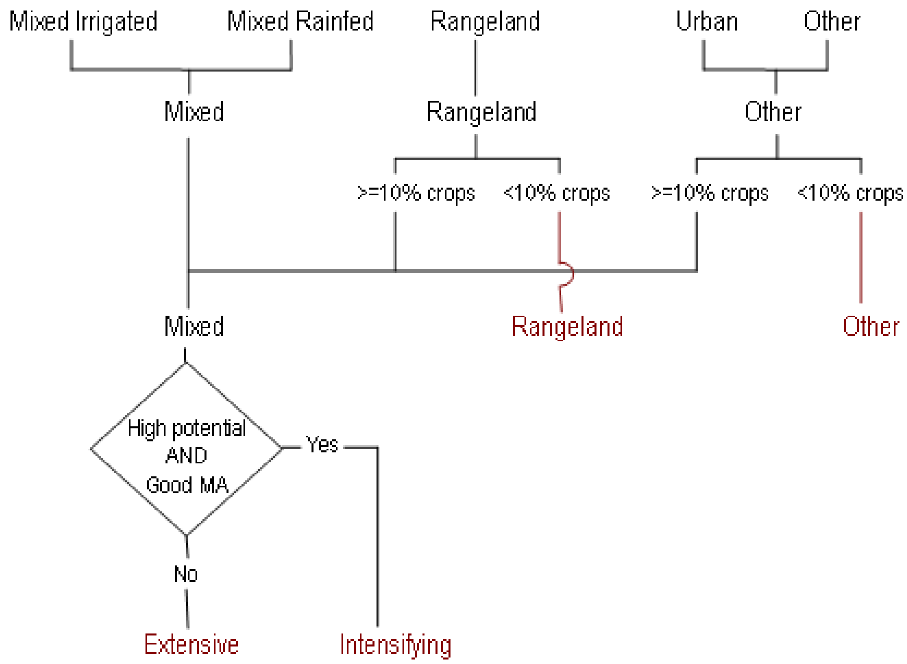
- Pastoral systems
- Mixed crop-livestock systems in which natural resources are most likely to be extensively managed
- Mixed crop-livestock systems in which natural resources can be managed to intensify the productivity of the system.
- Others, which include the amalgamation of all the others, e.g. urban, forest based and landless systems

The pastoral systems correspond to the three rangeland-based (LGA, LGH, LGT) categories of Seré and Steinfeld where there is at the same time less than 10% of the total land area covered by crops (according to the SPAM crop layers). Examples include the arid zones of Burkina Faso, Mali, and Niger extending to the Atlantic Ocean through the northern parts of Senegal and the dry pastoral areas in the Greater Horn of Africa. Cases in temperate zones include parts of China and Mongolia.

The crop-livestock systems correspond to the mixed rainfed (MRA, MRH, MRT) and mixed irrigated (MIA, MIH and MIT) categories of S&S together with all the areas that have more than 10% of the area under crop (according to the SPAM crop layers).

To determine the mixed "intensifying" systems, we added two indicators, one to do with relatively high agricultural potential, and another one related to market access. The assumption we made was that mixed systems that are in high-potential areas and are close to large population centres and markets, will have a high potential for intensifying production. Areas with high agricultural potential were defined as being equipped with irrigation (as in S&S) or having a length of growing period of more than 180 days per year. Good market access was defined using the time required to travel to the nearest city with a population of 250,000 or more (JRC, 2005). We applied a threshold of 8 hours. The flow chart below (figure 7) shows the process of deriving the different production system categories starting from S&S.

Figure 7: Flow chart of the process used in establishment of the production systems



Considerable parts of Asia fall in the "intensifying" category, one such example being the Indo-Gangetic plains in India. Cases in Africa include the easily accessible highlands of Uganda, Rwanda and Burundi and some of the cash-crop oriented farming in West Africa.

The resulting maps and some summary statistics can be found in annex 3 (a more comprehensive description of these results can be found in Herrero et al, 2009). Globally, almost half of the land area is estimated to be under a pastoral production system. Sub-Saharan Africa (SSA) and West Asia and North Africa (WANA) have the largest areas of pastoral systems but these are mostly in arid regions of very low or low productivity. Their carrying capacities are inherently low. Central and South America have important cattle producing areas based on grasslands of moderate potential.

Together the mixed crop-livestock systems occupy slightly more than 30% of the global land area. Although the majority of these systems are estimated to be under extensive management (60%), most of the population inhabiting the mixed systems can be found in the areas with high intensification potential (70%). The big exception is sub-Saharan Africa, where only 40% of the population of the mixed areas (and 27% of the total population) can be found in these intensifying systems. Also in terms of areas, SSA has a much lower percentage of the mixed areas classified as potentially intensifying, i.e. 23% as compared to 40 to 57% for the other regions. This is due to both large areas with short lengths of growing periods and limited infrastructural developments in the region.

In terms of human population density, clearly the mixed intensive systems have the highest densities. The high population densities in these systems place and will keep on exerting, a very high pressure on agro-ecosystems services, notably on food production, water resources, biodiversity, and others. The highest population density can be found in South-Asia (SA). The areas with the lowest population density are found in the rangelands of SSA.

Also cattle numbers can be found at the highest densities in the mixed intensive system. In contrast, agro-pastoral systems have a large number of cattle but they are distributed in a much larger area. Animal densities in mixed systems are close to 5-6 fold those of the pastoral areas. Again, SA has the most dense cattle population, this time followed by CSA. SSA is the only region where the extensive mixed areas are more densely populated with cattle than the areas with high intensification potential. This is mainly due to the large humid and sub-humid areas in West Africa with good cropping potential but where the major tsetse challenge is preventing a more intensified livestock production. Intensification in these areas is rather crop-based and driven by the demand for food in the highly populated coastal areas and the production of cash crops for export.

Other systems such as forests occupy significant land areas, notably in Latin America and sub-Saharan Africa. As demand for food, feed, energy and other resources increases, these areas, will be under significant pressure for conversion to agriculture and livestock production to satisfy the demands of people living in other rural systems or in the increasingly populated urban areas. This is supported by the findings of for example Rosegrant at al. (2009). They suggest increases of cropland extent of 28% in SSA and 21% in Latin America by 2050. However, expansion in area is not expected to contribute significantly to future production growth in other regions. Overall, this implies that the projected slow growth in crop area places the burden to meet future cereal demand on crop yield growth.

There are large differences between regions and systems. These reflect the variability in livestock-crop variation, agricultural potential, population densities, access to markets and other variables in the different regions. On the one hand, mixed intensive systems in fertile areas with suitable lengths of growing period and relatively low population densities abound in CSA, while in others places like in South and East Asia, land availability per capita is a constraint. Sub Saharan Africa, on the other hand, still has suitable land for increased intensification but faces constraints like huge population increases, weak institutions and unequal distribution of land. Also the lack of investment and service provision prevent a better utilisation of the natural resources. It is essential to acknowledge these structural differences, as options and opportunities for sustainable growth in productivity and poverty reduction are largely dependent on them.

5. Conclusions and recommendations

All that is presented in this document is work in progress. It is the result of many years of working on livestock issues taking a systems perspective. Different system classifications have been developed and subsequently applied in a variety of analytical studies. Below we present some of the lessons learned, remaining knowledge gaps, major challenges and opportunities. We thereafter conclude by highlighting the future direction this type of work could take for continued and improved applicability of the spatially delineated livestock production systems framework.

Farming systems classifications provide an analytical framework for targeting agricultural R&D efforts and guiding investment decisions for agricultural poverty reduction

Agricultural research and development agencies, such as FAO, CGIAR, donors and NGOs, all face the need to target their investments and measure impacts on their target groups. At the same time, it is crucial to acknowledge that a huge heterogeneity of agricultural production, livelihood challenges and opportunities for poverty reduction exists within regions and countries. How can we identify a level of agricultural systems homogeneity to simplify the task of identifying priority investments and communicating effective agricultural R&D messages? Global spatially disaggregated datasets have been and are becoming ever more important in priority setting and strategy development exercises. One of the crucial datasets for this spatial targeting work is an agricultural systems classification that provides adequate detail on crops and livestock. We believe that the system classification schemes presented in this paper will partially help filling this gap. They can be used as a sampling framework for data collection and monitoring and evaluation efforts. In addition they can spatially stratify research and development efforts in a wide array of subject areas, such as pest and diseases, climate change vulnerability and adaptation, nutrient cycling, agricultural productivity, sustainable intensification, and assessment of agro-ecosystem services. We think they provide adequate detail while at the same time being sufficiently generic to be useful to many different agricultural research and development actors. It will however be necessary to continue the discussion on how to improve the usefulness for livestock as well as non-livestock focused users, to keep them continuously updated with the latest available datasets and develop future projections according to different relevant scenarios.

Farming systems classifications are an essential building block for identifying environmental impacts of agricultural growth

Environmental problems associated with agriculture also vary according to their spatial context, ranging from problems associated with the management of modern inputs in intensively farmed areas to problems of deforestation and land degradation in many poor and heavily populated regions with low agricultural potential. In general, the impacts of agricultural production on natural conditions strongly depend on specific local conditions. Changes in water or nutrient cycles, for example, are related to soil conditions, terrain type and local climate condition (Lotze-Campen et al., 2005). The diets of ruminants vary a lot between different types of livestock systems, enabling the development of system-specific methane emission factors (Herrero et al., 2008a). In crop–livestock systems the feed supply is defined to a large extent by the biomass produced by crops that could be available for use as livestock feed (Fernández-Rivera et al. 2004). Estimations of feed surplus and deficit areas linked to potential stocking capacity, can give an indication of current and probable future pressure on the natural resource base. Other potential applications include manure calculations, nutrient cycling and land degradation.

Livestock classification systems require temporal dynamics to project changes and help identify future agricultural R&D priorities

For two of the three proposed schemes, projections for the year 2030 have been developed. This forward looking potential is very important. The acceleration of economic, technological, social, and environmental change challenges decision-makers to learn at increasing rates, and at the same time, the complexity of the dynamic systems in which we live is growing (Sterman, 2000). In agriculture and international development contexts, there are often significant delays in the development and implementation of technologies and policies, and agriculture-based livelihood systems are in constant and sometimes rapid evolution. In order to make technologies and policies better match the future state of these systems, it is necessary to better understand their likely evolution (Nicholson, 2007). One of the interesting aspects of the Seré and Steinfeld and the “intensification potential” schemes is that the systems are in part defined in terms of population density and length of growing period (LGP), two variables for which future projections exist. This means that we can recreate the classification using different scenarios for population and LGP in the future, so that we can make broad-brush assumptions about how the production systems may change in the future.

Concerted effort towards the development and integration of high quality global data sets and forward looking projections is an essential step to improve the farming system classifications

As in any GIS application, the key to success is the availability of accurate spatial input data. With the advent of more accurate baselines and better projections of all of the building blocks of the classification schemes, improvements of the production systems classifications and projections according to a variety of scenarios will become possible.

One of the key input datasets in all of the classification systems described in this paper is land-use data. In paragraph 3.1 we already highlighted the problems associated with the baseline cropland and rangeland extent. In order to come up with more realistic future projections, it will not only be necessary to improve the baseline but also to incorporate the output of land-use models. Many different groups are working on spatially-explicit models of land-use and land-cover change. A wide array of examples is described in Pontius et al. (2007). The GLOBIO (Global Methodology for Mapping Human Impacts on the Biosphere) consortium, for example, aims to develop a global model for exploring the impact of environmental change on biodiversity. Other global land-use models include the GTAP models, the AgLU model, the coupled IMAGE-GTAP/LEI model and the FARM model (Müller et al., 2007).

Additional input data of interest includes projections of length of growing period, human and livestock populations, crop distribution, market accessibility and intensification. In the framework of the IPCC (2007), future climate projections according to different models and scenarios are becoming more widely available. Several researchers and institutions in recent years have used new methods and data to map the global distribution of human population. The first major effort to generate a consistent global geo-referenced population dataset was the Gridded Population of the World (Balk and Yetman, 2004), updated by CIESIN in 2000 (Deichmann et al., 2001). Other efforts then followed, as there are for example the LandScan database (Dobson et al, 2000) and GRUMP (Balk et al, 2004). Most of these groups are developing future projections too. FAO has recently developed the "Gridded livestock of the world" database: the first standardized global, subnational resolution maps of the major agricultural livestock species. These livestock data are now freely available for download via the FAO web pages (Wint and Robinson, 2007). Notable efforts have been put into global crop distribution maps. The FAO, in collaboration with the International Institute for Applied Systems Analysis (IIASA), estimated the global land suitability for growing different crops (Fischer, 2001). Although valuable, this product only indicates where crops could potentially be grown, and is not a representation of where crops are actually grown today. Examples of modeled crop distribution maps include the SPAM dataset for the year 2000 (You et al. 2009) and the global data sets of the distribution of 18 major crops representative of the early 1990s by Leff et al. (2004). In the framework of for example the IAASTD (Rosegrant et al, 2009) and the SLP-funded study on drivers of change in the crop-livestock systems (Herrero et al., 2009), a first effort to develop spatially disaggregated projections of crop and livestock data was made. In summary, the global change community is putting increased effort in developing future projections of a variety of variables.

However, major data gaps still exist to represent measures of agricultural intensification and market access

Major data gaps still remain, such as measures of intensification and projections of market accessibility. Continued effort from the ever growing number of data providers in the international arena and improved linkages and data sharing between them, will enable this type of classification to be improved further in future (see for example Uchida and Nelson, 2008).

Farming system classifications present a methodological approach adaptable to multiple scales of analysis

The datasets described in this paper have huge scale-related limitations. The resulting layer of information of any GIS operation is only as accurate as the least accurate dataset used in the analysis. The use of global datasets in all of the classifications schemes presented, many of which are based on national and state level data, makes the data appropriate only for regional- to global-scale studies. The same concepts or variations thereof can, however, be implemented with more detailed datasets.

Increased application of farming systems classifications and concepts requires simple open source databases and tools for improved dissemination

The design of any characterization schema should be based on several key principles, including clear objectives of use, relevance to a known set of problems, and reliance on a feasibly measurable and manageable set of characterizing variables. Even these, seemingly trivial, requirements provide sufficient grounds to believe that a generic schema would be impractical (Wood et al., 1999). It seems that predetermined (i.e., pre-selected and pre-aggregated) generic schemas are likely to impose unnecessary restrictions of analytical scope and geographic scale. With the wide availability of GIS tools and the ever growing range of ancillary datasets currently available, the system classification schemes described in this paper could easily be tailored to specific needs, to include more detail or other criteria on an ad-hoc basis.

The best way forward might therefore be to provide a database and user-friendly tool that combines everything in easily accessible format so that users can not only access the standard and pre-defined system classification but also make their own selection of criteria. ILRI developed such a tool using open-source software. GOBLET (Geographic Overlaying dataBase and query Library for Ex-anTe impact assessment) brings together a considerable amount of spatial data from many sources, and allows the user to overlay these spatial datasets to identify target domains. GOBLET is designed for a broad range of stakeholders that, although they may benefit from GIS processing for better targeting and resource allocation, have little or no GIS expertise to do so (Quiros et al. 2009). The different aspects that go into the production systems classifications, one or more standard classifications, together with other relevant datasets could be packaged and distributed in a similar way.

A farming system classification is not the only dataset required for evidence-based, well targeted and sustainable agricultural development

Even with the highest quality production system map, it is important to note that the production system is only one of the necessary building blocks to target research and development. Omamo et al. (2006) argue that agricultural performance both derives from and conditions deeper socio-economic and bio-physical realities. Factors that distinguish the various trajectories of agricultural development exhibit significant spatial variability, such as differences in farming systems and productive capacity, but also population densities and growth, evolving food demands, infrastructure and market access, as well as the capacity of countries to import food or to invest in agriculture and environmental improvement. Characteristics like the share of contribution of agricultural/livestock activities to household income also play an important role in the effectiveness and potential impact of rural and agricultural interventions. Agricultural development strategies must recognize such heterogeneity when devising interventions and investments. Areas exhibiting different combinations of these characteristics are often associated with different management practices and livelihood strategies, and thus overall agricultural performance (Omamo et al., 2006). By matching conditions favoring the successful implementation of a development strategy with a spatially referenced database, it is possible to delineate geographical areas where this specific strategy is likely to have a positive impact (Notenbaert, 2009). The variety of variables involved in an analysis like that, could all be integrated in the tool described above.

A lot remains to be done

Although we believe that the various system classifications schemes presented in this paper have proven to be useful for a variety of purposes, a lot remains to be done. Below we list some of the priorities for further research.

One of the basic building blocks of any farming systems classification is land cover information. One of the priority areas of collaborative research remains therefore land cover classification. This effort should look at solving the spatial inaccuracy as well as addressing the need for temporal comparisons. It should result in an accurate longitudinal land cover dataset that can be updated on a regular basis.

Relatively large land areas continue to be classified under the vaguely named “other” class. This class joins an amalgamation of different land use classes together: from sparse vegetation over water bodies to forested areas. There is a need to provide more relevant detail herein.

As for the other classes, there has never been an effort to appropriately ground-truth any of the classifications nor has any other validation been done. With the advent of freely accessible geo-wiki tools, the application of these in combination with field based validation should be explored.

In the context of the rapidly changing world we’re living in today, it will be important to get a more accurate picture of how the production systems might change in future. More closely integrated methods linked to the outputs of land-use models will be of very high importance here. This should also enable more accurate estimations of the impacts of climate change on crop and livestock production.

Lastly, up to now the farming system classifications have been primarily applied in bio-physical applications. There is an urgent need to have a closer look at associations with socio-economic or cultural issues such as livelihoods, poverty status, land tenure systems and vulnerability.

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