A production system map for Africa

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Content

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Rationale

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 2009), 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 depending upon have an important spatial and temporal dimension. 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 (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- a need for research to demonstrate effectiveness and wide applicability (Thornton et al., 2006). 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 ex-ante and ex-post. This process is, for example, demonstrated in the ex ante impact assessment of dual-purpose cowpea by Kristjanson et al. (2002).

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 the investments in agriculture to have a sustainable impact on food security and poverty, decisions have to be made with respect for the small-holder and the natural environment. Non-sustainable use of the natural capital reduces the 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).

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, should be amenable to the modeling of different future scenarios.

Existing classification systems

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 5 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. 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.

Seré and Steinfeld (1996) 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. 2006).

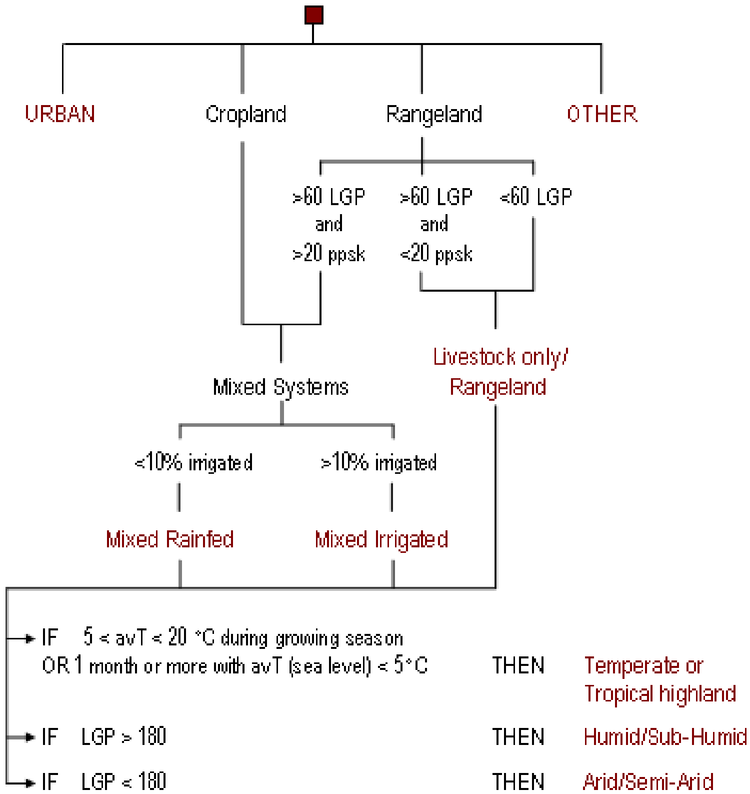
The original systems map has since been updated in various ways. As in any GIS application the key to success is the availability of accurate input data. Most of the updating of the systems maps has therefore been associated with the use of new datasets. Table 1 indicates the data sources that were used.

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

Data Inputs	**Original version**	**Latest version**
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, 1996); 2000 for Asia (CIESIN, 2001)	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. This differentiation was done on the basis of land cover products. 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.

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



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Inclusion of crop-specificity and intensification in the existing classification

The classification system proposed by Seré et al. (1996) and expanded by Thornton et al. (2002) and Kruska et al. (2003) is amenable in identifying priorities at a regional (e.g. South Asia, West Africa, etc.) and country (e.g. India, Nigeria, etc.) level. This classification has been used previously in poverty and vulnerability analyses (Thornton et al. 2002, 2006), for prioritising animal health interventions (Perry et al. 2003) and for studying systems changes in West Africa (Kristjanson et al. 2004). In addition to that it has been used for disaggregating methane emissions by production system, as they all have different land areas, population densities, number of animals, diets for ruminants and may evolve at different rates (Herrero et al 2008).

However, an important shortcoming of this typology is that it does not take into account the dominant crops in the various locations as key determinants of mixed farming systems. This shortcoming limits greatly its applicability for development purposes, as it does not offer 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 range, 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, facilitates estimation of the total value of agricultural production and others. It is envisioned that a more crop-sensitive system classification can form a common framework across the different crop-based CG-centres. More details about the inclusion of crops in Sere and Steinfeld is provided in paragraph 1 below.

In addition to that, the Seré and Steinfeld livestock system classification has nothing much to say about the location of intensive and/or industrial 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, or be particularly susceptible to the diseases of intensification and/or the emergence of new disease risks, and so on. Parallel to the inclusion of crops, an attempt was made to include a simple intensification proxy into the Sere and Steinfeld classification. Paragraph 2 below describes how this was done.

1. Inclusion of crops in Seré and Steinfeld

In order to disaggregate the mixed systems category, we integrated 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 spun from it.

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.

The 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 refer to 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.

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 are 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 3.

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. 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 2: 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.

Table 3: 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

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+

		Coffee+
		Oil Palm
		Oil Palm+
		Banana
		Banana+
		Cotton
		Cotton+
	MR/Rootcrops	Potato
	MR/Rootcrops+	Potato+
		Yam
		Yam+
		Cassava
		Cassava+
		Sweet Potato
		Sweet Potato+
	MR/Legumes	Beans
	MR/Legumes+	Beans+
		Cowpea
		Cowpea+
		Soybean
		Soybean+
		Groundnut
		Groundnut+

		Banana
		Banana+
		Cotton
		Cotton+
	MI/Rootcrops	Potato
	MI/Rootcrops+	Potato+
		Yam
		Yam+
		Cassava
		Cassava+
		Sweet Potato
		Sweet Potato+
	MI/Legumes	Beans
	MI/Legumes+	Beans+
		Cowpea
		Cowpea+
		Soybean
		Soybean+
		Groundnut
		Groundnut+
URBAN	Urban	
	Peri-Urban	
OTHER	Other	

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. 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.

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.

Fig. 2: Indication of the main crop group

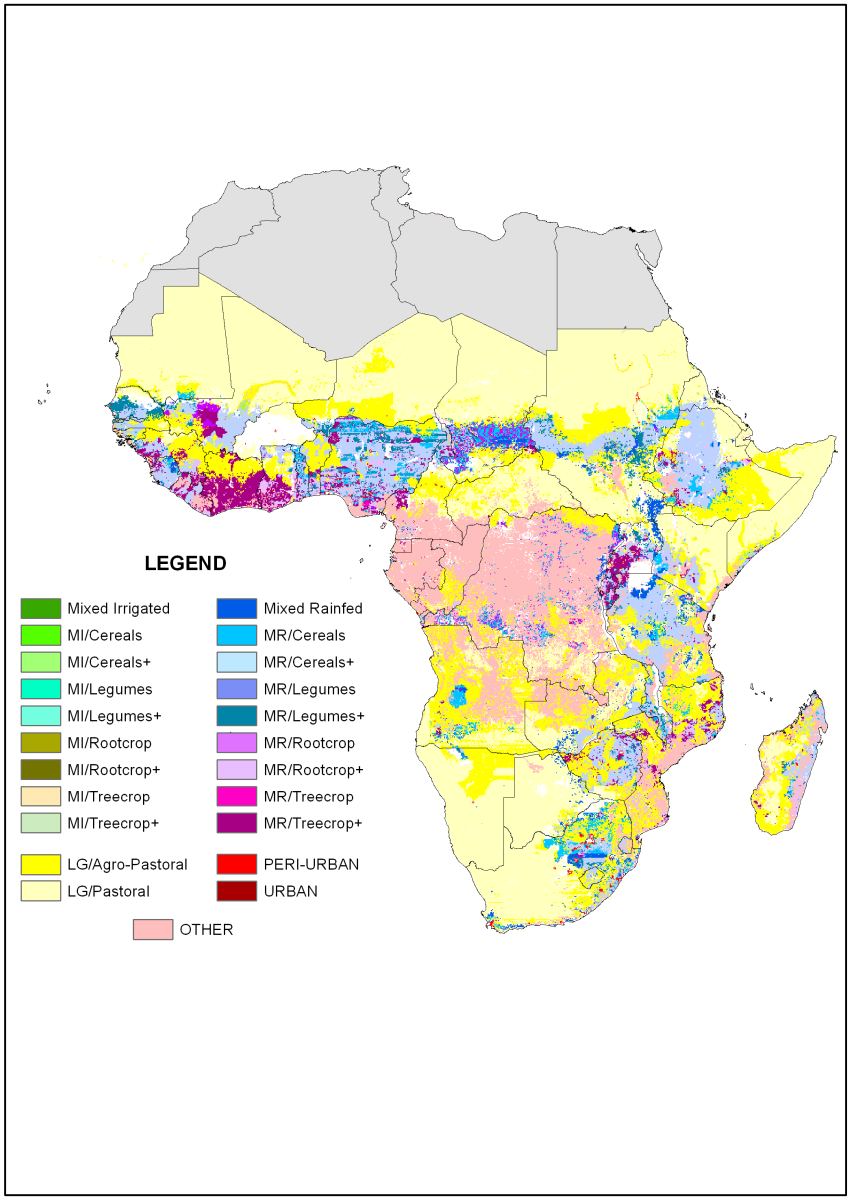


Fig. 3: The most common crop

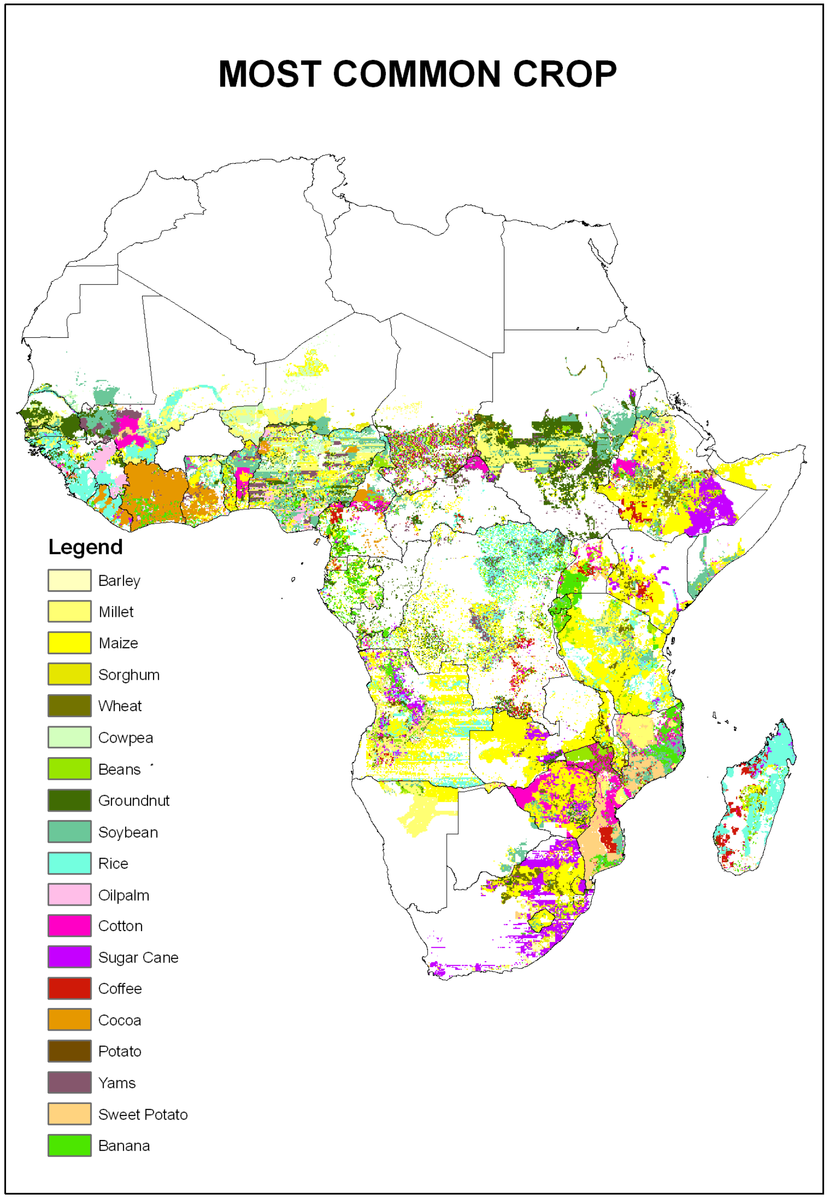
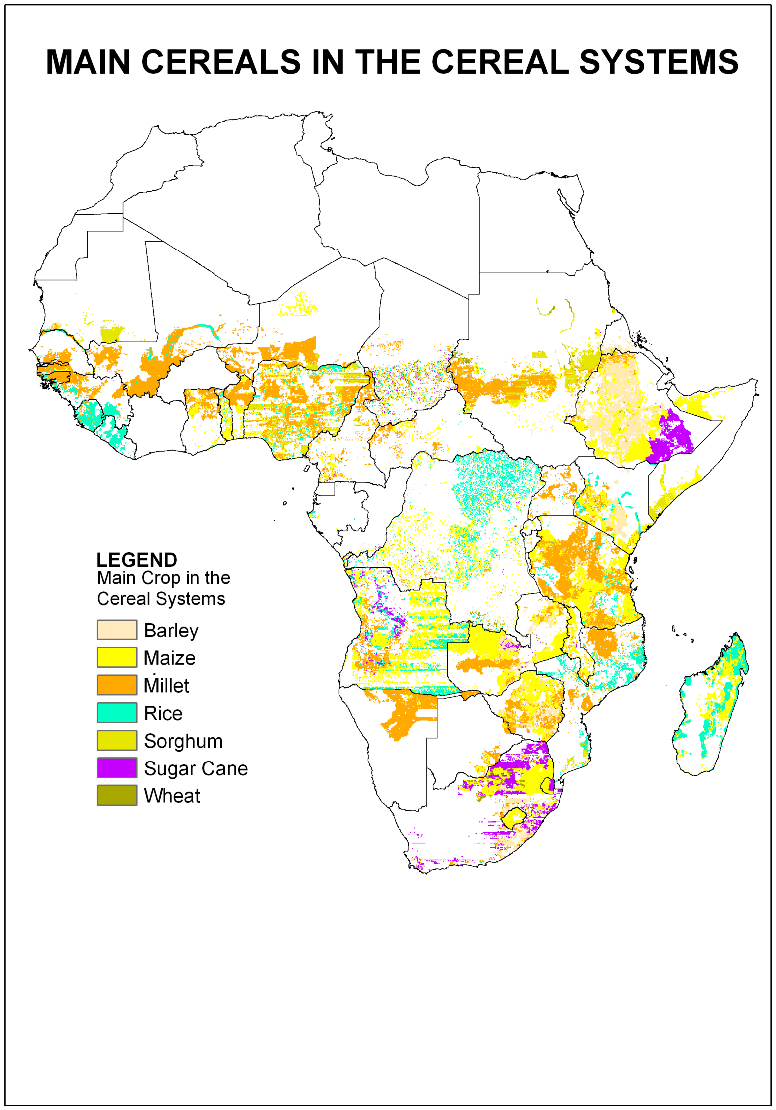


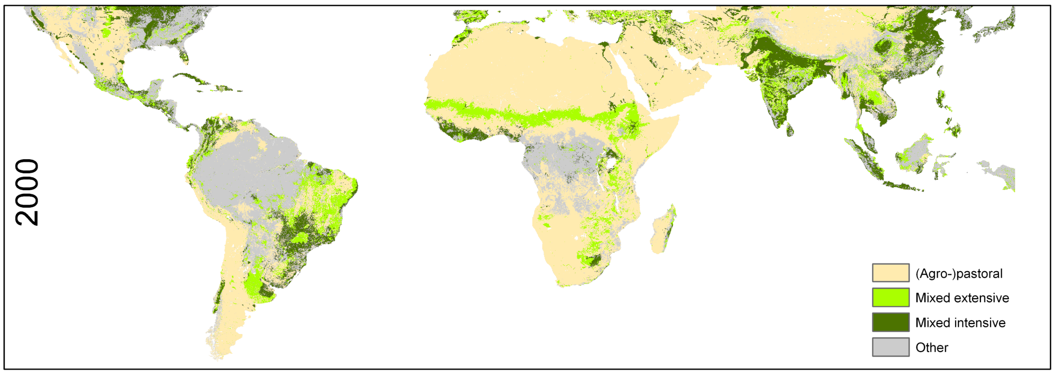
Fig. 4: The details within the cereal-based systems



2. Inclusion of intensification

To come up with the mixed "intensifying" systems, we added in two indicators, one to do with relatively high agricultural potential, and another related to market access, on the basis that mixed systems that are in high-potential areas that are close to large population centres and markets, will have a high potential of 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 (according to the LGP layers of Jones and Thornton). Good market access was defined using the time required to travel to the nearest city with a population of 250,000 or more. We applied a threshold of 8 hours. We used the travel time to Urban Centres with a population of more than 250,000 inhabitants (JRC, 2006). The distinction between extensive and intensive systems presented here is looking at potential intensification. This definition is used for the exploration of impacts of drivers of change on agro-ecosystems services and human wellbeing to 2030 funded by the CGIAR Systemwide Livestock Programme (Herrero et al 2009).

Fig. 5: differentiation extensive-intensive



Discussion

The system classification schemes presented in this paper 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. 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., 2008). 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 (Fernandez et al. 2004). Estimations of feed surplus and deficit areas and links with 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. In summary, we think that the classification schemes presented here provide adequate detail while at the same time being sufficiently generic to be useful to spatially frame the different research and development challenges encountered in the BFP Nile Basin Project.

Acceleration of economic, technological, social, and environmental change challenges decision-makers of various kinds 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 the likely evolution of agricultural systems (Nicholson, 2007). One of the interesting aspects of the ILRI S&S work is that the systems are defined in terms of population density and length of growing period (LGP), two variables for which future projections exist. This means that we can re-derive 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. In the longer term it will be important to also incorporate the output of landuse models, projections of crop and market accessibility. 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.

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

Finally, all that is presented in this document is work in progress. It is the result of many years of working on livestock production system classification. It will however be necessary to discuss in detail how to improve the usefulness for non-livestock focused users. Agreement of one standard classification ensuring compatibility across the project, decision on how to include available information on water availability and accessibility, while at the same maintaining clarity and securing the dynamic nature of the classification, are all challenging tasks ahead of the project team. The complementary expertise of the different centres, however, presents a unique opportunity for us to exploit.

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