Drivers of change in crop–livestock systems and their potential impacts on agro-ecosystems services and human wellbeing to 2030

A study commissioned by the CGIAR Systemwide Livestock Programme

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Drivers of change in crop–livestock systems and their potential impacts on agro-ecosystems services and human wellbeing to 2030

A study commissioned by the CGIAR Systemwide Livestock Programme

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Introduction

The CGIAR Systemwide Livestock Programme (SLP) commissioned a desk study titled 'Drivers of change in mixed crop–livestock systems'. The study was to be developed by a multi-disciplinary task force from across the CGIAR centres. The objective of the study was to identify places and production systems in the developing world which, due to global changes, may not be able to supply food for the growing population or, in doing so, the sustainability and maintenance of key ecosystem functions would be compromised. The project works are the cross roads of agriculture and livestock, poverty and the environment.

This report 1) develops a conceptual framework for studying the effects of drivers of change in mixed crop–livestock systems; 2) analyses the past trends of key indicators of change in mixed crop–livestock systems; and 3) uses these trends, along with modelling approaches and other tools, to develop a series of scenarios of how mixed systems in different regions might evolve, and what their constraints and opportunities could be. This information can be used to guide some basic priority setting for the SLP and for the CGIAR in more general terms.

What is the problem?

The world's population is predicted to increase by 50% over the next quarter of a century to reach 9 billion by 2030. During this period, and if the livestock revolution fully materializes (Delgado et al. 1999), in developing countries there is likely to be a rapid increase in demand for livestock products driven by increasing urbanization and rising incomes. On top of this, the impacts of a range of driving forces, such as water availability, climate change and technological innovations, on smallholder crop–livestock production may be substantial. Variations in these drivers will inevitably affect smallholder farms. The challenge is to ensure that the resource-poor, i.e. the mixed crop–livestock smallholder sector, which currently provides the majority of milk and meat in the tropics, is able to meet the increased demand for these products. To do so the sector will need to intensify but at the same time ensure that household food security, sustainable natural resource management and rural livelihoods are not compromised.

The framework for the study was based on that of the Millennium Ecosystem Assessment, which was subsequently used for other major assessments such as the Global Environment Outlook 4 (UNEP 2007) and the International Assessment of Agricultural Knowledge, Science and Technology for Development (2008). It shares common features with the frameworks of the Intergovernmental Panel on Climate Change (2007) and the Comprehensive Assessment of Water Management in Agriculture (2007). It is based on the notion that a set of drivers, both direct and indirect, can make systems change over time. The local development context determines how, where and which drivers play the most important role in which system. Different drivers exert different kinds of 'pressures' on key aspects of agro-ecosystems. These pressures include changes in land use, changes in resource and input use, and increased competition for biomass (food, feed and energy). In turn, these pressures have impacts on different agro-ecosystem services, such as climate regulation, watershed protection, and crop pollination. Depending on the magnitude of the pressures and the impacts on agro-ecosystems services, human wellbeing (measured, for example, by income, health, food security, and vulnerability) can be affected in different ways. Positive interventions can be made either by trying to regulate the effects of the drivers and pressures or by generating options for adapting the agro-ecosystems services to the impacts of the changes.

We used the IMPACT-Water model coupled with a farming systems classification and a range of spatial disaggregation methods for looking at alternative scenarios of change in mixed crop–livestock systems to 2030. We built upon the results of the IAASTD. The scenarios we used were 1) the reference scenario, which tries to mimic business-as-usual conditions of growth in agriculture, incomes and population. Additionally we investigated the consequences of an increased demand for biofuels, an increased expansion of irrigation to produce more food and feed, and a decreased demand for livestock products.

The following are the main messages from the study.

Mixed crop–livestock systems are and will continue to be the backbone of sustainable pro-poor agricultural growth in the developing world to 2030. Two-thirds of the global population live in these systems. They not only produce most of the milk and meat globally but also produce a significant proportion of the key staples of the world. Rates of growth in demand, production and consumption of agricultural products are significantly higher in these systems than in others. These systems will surpass the developed world in the production of cereals and some livestock products by 2030.

1. **Mixed intensive systems in the developing world face significant pressures**. These pressures are larger in some systems than in others but are all caused by the rising demands of the human population: its income shifts and rates of urbanization. For example, mixed intensive systems in South Asia are reaching a point where production factors are seriously limiting production as land per capita decreases. Significant trade-offs in the use of resources (land, water, nutrients) exist in mixed crop–livestock systems, especially as the demands for biomass for food, feed and energy increase.

2. **Prices of food–feed crops are likely to increase at faster rates than the prices of livestock products**. Due to the multiple competing demands for food, feed and energy, increases in the prices of commodities will be more marked for food–feed crops than for any other products, including livestock.

3. **Rates of change in crop, and therefore stover, production are likely to vary widely from region to region to 2030**. Large increases in stover production are likely to occur in Africa as a result of area and productivity increases mainly in maize, sorghum and millet. Other large increases will occur across systems in Central and South America but less so in the mixed extensive systems of East Asia. Stover production will stagnate in some areas, notably in the mixed extensive and intensive systems of South Asia, which together have the largest numbers of ruminants in any system in the world.

4. **Increase in ruminant numbers has outpaced the rate of growth of availability of stover per animal in many places.** This means that either stover will become less important as a feed in these systems or it will be substituted by other feeds in the diet, or that there will be significant feed deficits in some places.

5. **Land availability and water will be key constraints to the production of alternative feeds for ruminants in the most intensive systems.** Mixed intensive systems in South Asia, which depend on irrigation to a great extent, and which are supposed to produce 113 million tonnes of milk and 4.5 million tonnes of beef to feed increasing human populations, will have to support all their production from feed sources other than stover, as stover production only meets the maintenance requirements of the animals. If this production levels were to materialize, water demands from livestock would rise several fold (billions of litres) to produce fodders for animals and would compete directly with irrigation for the production of crops for multiple uses.

6. **Fodder markets are likely to expand in areas of feed deficits as demand for animal products increases.** Substantial local heterogeneity exists in supply and demand of feeds for ruminants. Areas of surplus are likely to trade with areas of feed deficits as prices of stovers and green feeds increase. Public investments will be required to create incentives and reduce transaction costs of moving feeds over long distances.

7. **The livestock revolution—at least for ruminants—could potentially exclude the poor in terms of the benefits of consumption of meat.** If green fodders became scarce due to land and water shortages and more grains are fed to ruminants to match production prices of animal products may further increase, bypassing the abilities of the poor to consume more milk and meat. This would present significant challenges in mixed systems, particularly in Asia.

8. **Rates of malnutrition relative to population increases are highest in agropastoral systems followed by the mixed intensive systems**. In agropastoral systems, malnutrition may be caused by increased vulnerability, lack of primary productivity, poor market access and lack of economic growth but with large land holdings (Thornton et al. 2006). In mixed intensive systems, too many people, especially poor, relative to the resources available may be the principle cause of malnutrition. South Asia and sub-Saharan Africa (SSA) exhibit particularly large rates of malnutrition across these systems.

9. **Expansion of biofuels is likely to reduce household food consumption in most systems**. Increased production of biofuels may raise the price of staple commodities, which will particularly affect the poor due to their low purchasing power. This effect may be stronger in rural and poor urban households that are net buyers of food.

10. **Highly intensive systems will require solutions that give high efficiency gains without using any more land and water.** More intensive crop management practices, such as efficiency gains in pig and poultry production may reduce pressure on land resources.

11. **Some systems may need to de-intensify or stop growing to ensure the sustainability of agro-ecosystems.** Developing sound, simple and equitable schemes for payments for ecosystems services could be part of the solution. Understanding the limits of land intensification is necessary along with developing a set of intensification thresholds to prevent irreparable environmental damage.

12. **Important productivity gains could be made in the more extensive mixed rainfed systems.** Resource constraints in some mixed intensive systems are reaching a point where livestock production could decrease and where environmental degradation may have deleterious impacts on humans. In more extensive systems, with less pressure on the land, yield gaps of crops and livestock in different regions are still large. Pro-poor policies and public investments in infrastructure will be essential to create systems of incentives, reduce transaction costs and improve risk management in these systems. Integration of production in these systems to supply agro-ecosystems services such as feeds and food to the more intensive systems should be promoted.

13. **Crop improvement programs could play a key role in helping meet the multiple demands for biomass**. Developing multi-purpose or more specialized crop varieties for the production of food, feed and energy may significantly decrease competition for these resources if they become limited.

14. **The dynamics of agriculture and other sectors are changing at unprecedented rates and are becoming more difficult to project.** Integrated assessments are becoming a key step towards understanding change but these studies are increasing in complexity and are difficult to put together comprehensively across sectors.

15. **Better targeting of studies and refining the methods used in this study are essential steps for better understanding change in farming systems.** A more comprehensive understanding of the interactions between drivers, ecosystem services and agricultural systems will enable better prioritization of sustainable options to meet the simultaneous demands of different sectors, but especially to meet the needs of the poor and the environment.

1 Introduction

This desk study was prepared by a multi-disciplinary team from across CGIAR to identify places and production systems in the developing world which, due to global changes, may not be able to supply food for the growing population or, in doing so, the sustainability and maintenance of key ecosystem functions would be compromised. The team worked at the cross roads of agriculture and livestock, poverty and the environment.

The report 1) develops a conceptual framework to study the effects of drivers of change in mixed crop–livestock systems; 2) analyses past trends of key indicators of change in mixed crop–livestock systems; and 3) uses these trends, along with modelling approaches and other tools, to develop a series of scenarios of how mixed systems in different regions might evolve, and what their constraints and opportunities could be.

The guiding principles for the study were the following:

• The study should be built around a conceptual framework on how farming systems are likely to evolve.

• It must describe the impacts of drivers of change and their effects at different scales and on different systems, but with special emphasis on crop–livestock systems.

• It should build on historical information as well as on scenarios of future changes.

• It should seek to introduce systems change concepts in the CGIAR centres' research and development agendas by providing information on what drives systems to change in different parts of the developing world, and how this occurs.

• It needs to be able to identify priority intervention points for coping with change in different systems.

• It should seek to find where synergistic activities between CGIAR centres will be of primary importance to deliver products for adapting to change in crop–livestock systems.

• It should build on the recent major assessments of global change such as the Intergovernmental Panel on Climate Change (IPCC), the International Assessment of Agricultural Knowledge, Science and Technology for Development (IAASTD), the Millennium Ecosystem Assessment (MEA), and the Comprehensive Assessment of Water Management in Agriculture (CA).

2 Framework for studying the dynamics and impacts of change in crop–livestock systems

A range of forward-looking international global assessments covering different aspects of the global use of resources and its significance to humanity have been conducted recently. Aspects covered have included agriculture and development (World Development Report 2008), agriculture, science and technology (IAASTD), ecosystem services (Millennium Ecosystem Assessment, MEA), environmental outlooks (Global Environmental Outlook [GEO-4], UNEP 2007), water management, and climate change (IPCC 2007).

The IAASTD and GEO-4 are based around the conceptual framework developed for the MEA and some similarities exist with the IPCC (2007). The present study uses a similar framework, but with the specific objective of looking in more depth at the effects of drivers of systems change on crop–livestock systems. It is useful to explicitly link the framework used in this study to those of other major assessments. This will enable us to have some coherence when comparing and integrating results from these other studies. To our knowledge, this is the only assessment that attempts to identify changes at the production systems level for the whole of developing world. This is a key difference to most other assessments, which provide aggregated data at the country or regional level.

The basic conceptual framework is presented in Figure 1. The key aspects of the framework are:

- Mixed crop–livestock systems (and other systems) are diverse, and their structure, function and potential are shaped by their development context.

- There is a set of drivers, both direct and indirect, that can make systems change over time. Direct drivers are those that have a direct measurable effect on different aspects of agro-ecosystems and humans. Indirect drivers act as key influences on one or many other drivers. For example, increased demand for livestock products (a direct driver) is the product of increases in human population and their income increases (indirect drivers).

- The local development context determines which direct and indirect drivers play a more important role in which system, in which location and in which ways.

- Different drivers of change exert different kinds of 'pressures' on key dimensions of agro-ecosystems. These can range from land use change, resource and input use to competition for biomass (food, feed and energy). For example, as global demands for food increase along with competition for biomass and resources and for use of inputs, greenhouse gas emissions are affected positively or negatively, or not changed, depending on location.

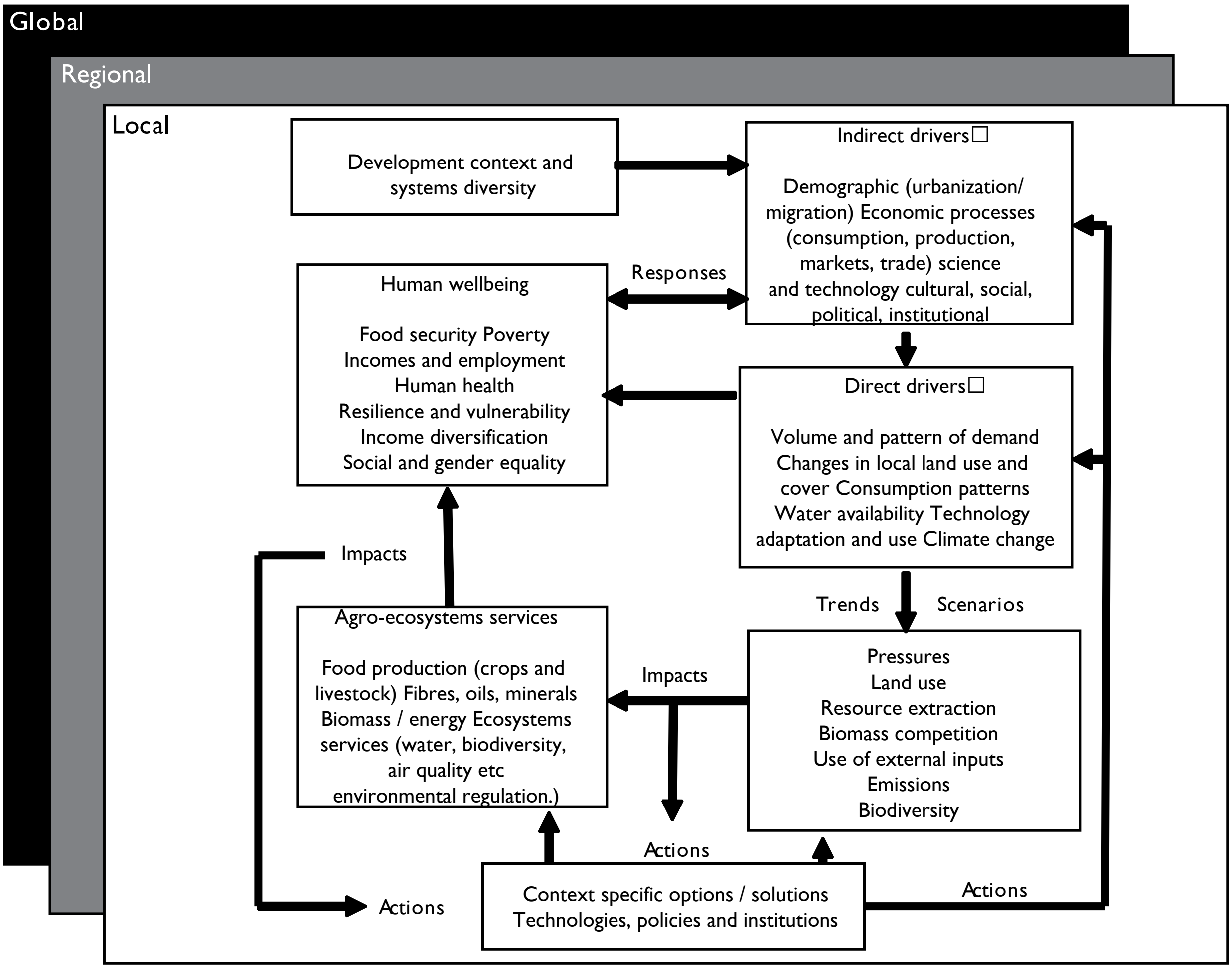
- These pressures have impacts on different agro-ecosystems services. These services can be divided into four categories: provisioning (e.g. of food/feed, water, or fuel); regulating (e.g. of the climate); cultural (e.g. spiritual, aesthetic, and recreation values); and supporting services (e.g. primary production and soil formation).

- Depending on the magnitude of the pressures and the impacts on agro-ecosystem services, human wellbeing can be affected in different ways (e.g. incomes, health, food security, vulnerability etc.) and this in turn can have important feedbacks, especially on the indirect drivers of change.

- There are several pathways to generate solutions to respond locally and globally to the effects of the drivers of change. These are through technologies, policies, and institutional arrangements that promote intensification, diversification, expansion, regulation and exit from agriculture (Dixon et al. 2001).

- These key entry points operate through regulating the effects of the drivers and the pressures or through generating options for adapting the agro-ecosystems services to the impacts of the changes. For example, price policies may help regulate water demands, or mitigation strategies can be developed to prevent increases in greenhouse gas emissions from crop–livestock systems. We may want to promote alternative crop varieties to increase the production of grain and fodder for humans and animals. These three different alternatives present different instruments to provide a solution and consist of a different entry point (drivers, pressures and agro-ecosystems responses). These can be solutions that transcend scale in some cases (from global to local), though the impacts on people and systems will be felt differentially depending on location and context.

Figure 1. Conceptual framework for studying the impacts of drivers of change in crop–livestock systems



Adapted from GEO-4 (UNEP 2007) and the IAASTD (2007).

Figure 2 gives a very simple example of the framework and how it relates to a specific crop–livestock system. Consider just the local level, and a group of mixed systems in a region that is experiencing high population growth (the indirect driver). This affects two direct drivers. One is increasing local demand for livestock products. But at the same time, the average size of land holdings is decreasing, and the fallow period is being reduced further and further. The effects of the drivers are (1) capacity in the local market so that extra production could easily be absorbed; and

(2) real pressure on soil fertility that is tending to decline. The impact of declining soil fertility is that food and feed production is declining, and as a result, food security of these smallholders is being compromised and their income is declining.

Figure 2. Overview of a framework and how it relates to a specific crop–livestock system

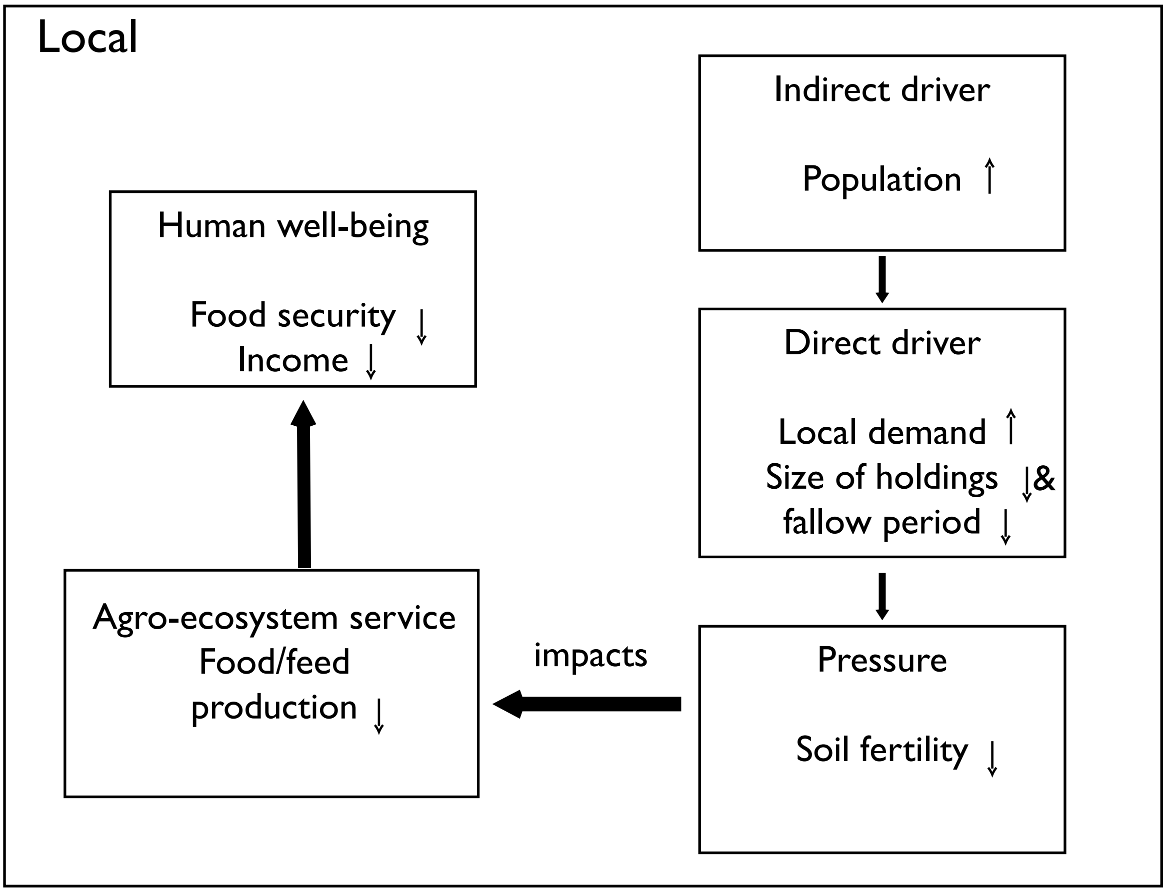


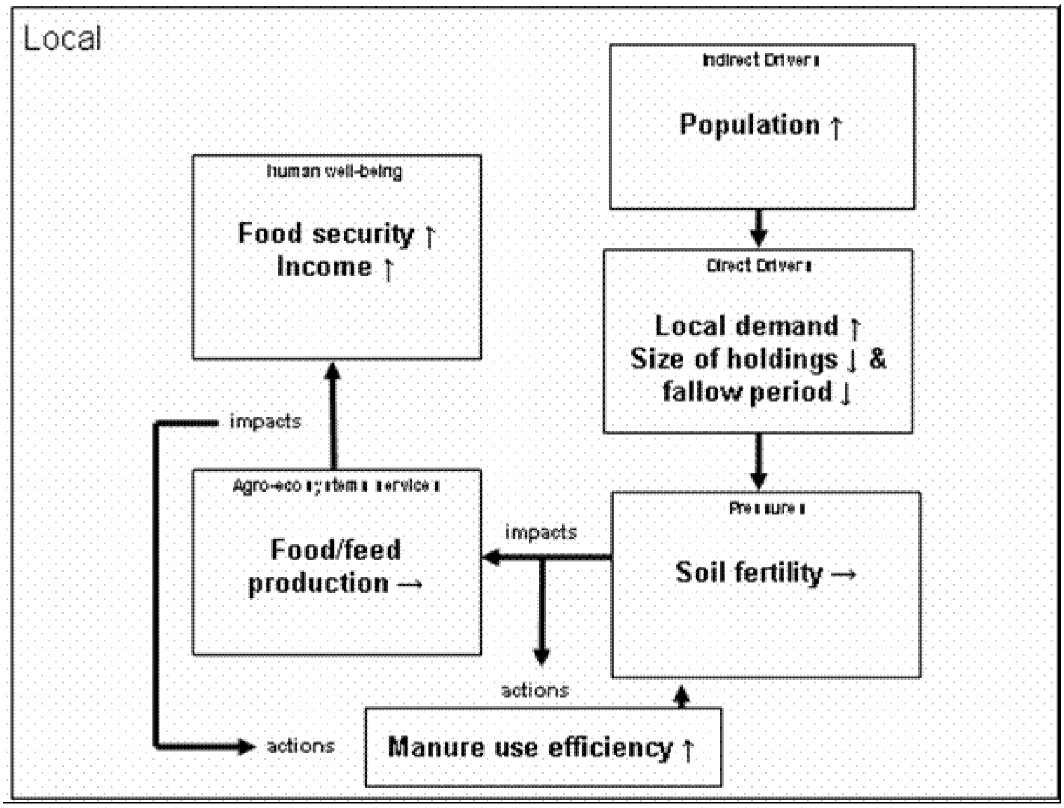
Figure 3 represents the situation after a specific action: here, assume that there is some technology that is taken up that increases the efficiency of on-farm use of manure (this could be something related to manure storage technology that reduces nutrient losses between collection of the manure and its application on plots, for example). This has a direct effect on soil fertility, and allows soil fertility to be maintained. This in turn implies that food and feed production can be maintained, and this has positive impacts on food security and household incomes. Note that here, there is an additional positive feedback from increased food/feed production on manure quality, and this feeds back to soil fertility maintenance via the manure efficiency box (hence the feedback loop on the left of the figure). Note also that in this example, there are really no effects of the 'action' on either the direct or the indirect drivers, so there are no feedback arrows on the right-hand side of the figure. Further, there are no direct connections between the drivers and human wellbeing in this example (in either figure), as all the effects are mediated through the agro-ecosystem services box (i.e. these are direct agricultural effects).

2.1 Key drivers of change in crop–livestock systems

The challenges facing economic development in general and livestock-based systems in particular, seem to be increasingly complex. There are many drivers of change operating at a variety of levels (see Hazell and Wood 2008). Some of these are highlighted below.

Population and demographics: The world's population will reach 7 billion by 2012, and in Africa alone, human population is projected to double to nearly 2 billion by 2050. This is being accompanied by rapid urbanization, which is expected to continue in many developing countries. The year 2008 is a watershed—for the first time, more than half the global human population (3.3 billion) is now living in urban areas. By 2030, this number will have increased to almost 5 billion: the next few decades will see unprecedented urban growth, particularly in Africa and Asia.

Figure 3. Overview of a framework and how it relates to a specific crop–livestock system under a technology intervention



Livestock product demand: The demand for livestock products is rising globally and will increase significantly in the coming decades because of income shifts, population growth, urbanization and changes in dietary preferences; this increased demand will largely be based in developing countries (Delgado 2005). The trends in demand will be for both increased quantity, especially as incomes rise, and for increasing quality, particularly among urban consumers who purchase livestock products from supermarkets. Such factors have enormous consequences for both the volume of global food demand and its composition: these increases in cereals and meat will need to be produced from the same land and water resources as currently exist. While the increased demand will probably be met mostly by increases in chicken and pig production, ruminant populations are also likely to increase substantially.

Changes in food prices: The general trend in relative food prices has been a downward one since the early 1970s (Hazell and Wood 2008), but the period from mid-2007 to today has seen quite remarkable increases in grain prices, largely a reflection of changes in demand. The price of rice has risen in dollar terms from a relative level of 100 in January 2007 to nearly 290 in April 2008 (The Economist, 19 April 2008, p 30), attributed largely to population and income increases and the 'voracious' appetites of western biofuels programs. The increases have been so rapid that the impacts on the poor and on farming in general are hard to gauge. The relationship between food prices and high energy prices are complex and difficult to foresee, but high energy prices are very likely to be a continuing feature of the global economy from now on.

Climate change: The world's climate is continuing to change at rates that are projected to be unprecedented in recent human history. Model projections of the Fourth Assessment Report of the IPCC (2007) suggest an increase in global average surface temperature of between 1.8 and 4.0°C from the present to 2100, the range depending largely on the scale of fossil fuel burning between now and then and on the models used. Moreover, the impacts of climate change are likely to be highly spatially variable. At mid to high latitudes, for example, crop productivity may increase slightly for local mean temperature increases of 1–3°C, while at lower latitudes, crop productivity is projected to decrease for even relatively small local temperature increases (1–2°C) (IPCC 2007). In the tropics and subtropics in general, crop yields may fall by 10 to 20% to 2050 because of warming and drying, but there are places where yield losses may be much more severe (Jones and Thornton 2003). Changes in climate variability are also projected; although there is considerable uncertainty about these changes, the total area affected by droughts is likely to increase, as are the frequency of heavy precipitation events. Increased frequencies of heat stress, drought and flooding will have adverse effects on crop–livestock productivity over and above the impacts due to changes in mean variables alone (IPCC 2007). Climate change is likely to have major impacts on poor croppers and livestock keepers and on the ecosystems goods and services on which they depend. These impacts will include changes in the productivity of rain-fed crops and forage, reduced water availability and more widespread water shortages, and changing severity and distribution of important human, livestock and crop diseases. Major changes can thus be anticipated in agricultural systems related, for example, to livestock species mixes, crops grown, and feed resources and strategies.

Changes in technology: Historically, new and improved technology has been a key driver of agricultural productivity growth (Hazell and Wood 2008). Many publicly funded international and national agricultural research centres have taken important steps in recent years to better address issues of sustainability related to technology design and development. There have been also considerable developments in the field of natural resource management in recent years. The trend is, however, for the continuing globalization and privatization of agricultural science; the private sector has much less incentive to undertake this kind of NRM or 'public goods' research. Scenario analysis in the IAASTD shows quite clearly that declining investments in agricultural science and technology may have serious implications: agricultural supporting services tend to degrade rapidly, and absolute childhood malnutrition levels may increase, possibly surpassing the malnutrition levels at the end of the twentieth century. In general, much better outcomes in developing country food security can be achieved for relatively modest investment levels (in global terms), trading off improved crop productivity with slightly lower investment levels in irrigation. The issue is how to achieve and make best use of the levels of investment that are required, given the need for an increased role of the private sector in such research and possible intellectual property concerns vs. international public goods.

Changes in sociocultural conditions: The impacts of changes in sociocultural conditions may be profound, but such changes are almost impossible to predict, and their implications may be so far-reaching as to make a mockery of careful assessments based on quantitative models and long-cherished (but erroneous) assumptions and analytical frameworks. These changes can occur at various levels. For example, recent changes in life-style expectations are inducing the Maasai of southern Kenya and northern Tanzania to become croppers and businessmen for example, so as to be much better linked to the market economy and the possibility of generating cash for themselves (BurnSilver 2007). In developed countries, the last 30 years have seen astonishing decreases in the importance that society in general attaches to agriculture and agricultural research. The average age of farmers in North America is about 60. At the same time, the resource base for agricultural research in the North has been undergoing long-term erosion—the plant pathologists, crop breeders, animal scientists, and agronomists of tomorrow simply are not to be found in anything like sufficient numbers. An aging farming population is also the case for many places in the tropics and subtropics, with massive movements off the land to the cities in search of more lucrative income-generating opportunities. The drivers of such changes are partly economic, but they are also partly brought about by complex changes in the sociocultural values of populations.

In summary, agricultural systems are being pulled this way and that in a highly dynamic and complex world. There are difficult trade-offs that have to be weighed up and decided upon if goals related to poverty reduction, social equity, economic growth, and environmental sustainability are to be achieved. There is a need for evidence-based inputs into decision-making at all levels in the hierarchy—from local scales up to the global negotiations required if equitable sustainable development is to be more than a pipedream. There is a considerable amount of work to be done to provide these inputs, including targeting work and scenario modelling, particularly in relation to assessing the impacts of interventions in the future and in evaluating the trade-offs that will inevitably arise between different groups of stakeholders with vastly different objectives and access to resources.

Table 1. Key drivers of change in crop–livestock systems

Table 2. Summary of global, country and local scale drivers of agricultural change. Source: authors (Importance: 0, very low; +, low–medium; ++, high. Trend: −−, strongly declining/negative; −, declining/negative; 0, stable; +, increasing/positive; ++, strongly increasing/positive; '/' indicates a range (reflecting both an observed range but also uncertainty). S&T, science and technology; LDC, less-developed country; R&D, research and development.)

drivers	importance	trend	remarks
global-scale drivers			
international trade and globalization of markets	+	+/++	greater role of trade; vertical integration and market power; higher quality foods
world prices for agricultural products	++	−−/0	long-term decline in prices; benefits consumers; squeezes small farmers
OECD agricultural support	++	0/−	over supply, further reduces prices; limits markets for LDC farmers
climate change: variability/extremes and trends	+/++	−/+	increasing variability/unpredictability; greater negative impacts in tropics
high energy prices	+	+/++	increase food costs, promote bio-fuel crops (perhaps increasing food price further)
globalization and privatization of agricultural science	+/++	+/++	increasing private sector role and IP for new science (e.g. biotechnology)
country-scale drivers			
per capita income growth	++	−/++	driver of expansion of food demand, investment assets (including human capital)
urbanization	+	+/++	alters food demand (more processed, fast food, oils, sugars and less home cooking)
commercializing/shortening market chains	+	+/++	greater consolidation; supermarkets; stricter price, volume, quality and timing norms
shifts in public policy: (i) agricultural support	+/++	+	LDC removal of state support (liberalization); hurt marginal/remote farmers
(ii) investments in agricultural S&T, extension, credit	++	−/+	public retreat from funding R&D, extension and other service provision
security: financial/business and conflict/crisis	+/++	−/+	climate for business and household investment; migration/re-settlement pressures
increasing water scarcities	++	++	water shortages within river basins and depleted ground-water and aquifers will curtail irrigated agriculture in many countries if not addressed soon
local-scale drivers			
poverty	++	−/+	aggregate declining; but growing in some LDC's; forces short-term perspectives
population pressure and demographic structure	+/++	−/++	growth negative/declining in many rich countries; positive/declining many LDCs
health (food production and consumption related)	++	−/+	malnourishment, obesity, HIV/AIDS, malaria; zoonoses; pesticide exposure, etc.
technology design	+/++	−/+	fitness for purpose (productivity, sustainability, profit-ability) often poor
property rights	+/++	−/+	absent/adverse property rights promote resource exploi-tation and underinvestment
condition and capacity of natural resources (on-site)	++	−−/+	on-site/off-site impact of residues greater in high-input systems
(externalities)	++	−−/0	externalities from resource degradation and agricultural expansion in low-input systems
infrastructure and market access	+	+/++	improves access to services, inputs, technologies as well as to output markets
non-farm opportunities	++	0/+	investment source; enable part-time farming and exit from agriculture

Source: Hazell and Wood (2008), originally modified from Wood et al. (2005).

3 Global trends in agriculture, agro-ecosystems services and human wellbeing

3.1 Trends in human demography, livelihoods and economic parameters

Human population

Today's global population is three times larger than it was at the beginning of the 20th century but most of that growth has been in the past 50 years. From 1900 to 1960 the population increased by little more than a billion (from 1.75 to 3 billion) whereas from 1960 to 2010 it grew by three times as much from 3 billion to 6.8 billion people (US Census Bureau 2010). Although the rate of growth has declined from a peak in the 1960s of more than 2% to the current 1.1%, absolute growth is such that by 2030 the global human population is predicted to reach 9 billion (UNEP 2008).

Table 2 shows that between 1950 and 2000 the world population increased from 2.5 billion to more than 6 billion. However, the rate of increase in population has not been commensurate across all regions: the population of industrialized countries increased by less than half in those 50 years whereas that of developing countries nearly tripled. Although Africa shows the highest rate of population growth for that period, increasing by 360% to nearly 800 million in 2000, in terms of absolute numbers of people, Asia is the forerunner: in 2000 it contained 3.5 billion people, three-quarters of the developing world's population and 60% of the world's population.

Increases in life expectancy contribute significantly to the growth in population in some places. Globally, life expectancy increased from 46 to 65 years in the second half of the 20th century. Again a large disparity exists between industrialized and developing countries. In 1950, people in industrialized countries lived, on average, to be 66 years old and by 2000 this had increased by only nine years to 75. In developing countries, the population started from a much lower level, with a life expectancy in 1950 of 41; by 2000, this had increased by 22 years to 62, a much greater increase than in industrialized countries.

The high increase in life expectancy in developing countries has for the most part been led by Asia: citizens of Asia can expect to live 24 years longer than they did in 1950 whereas Africans can only expect to live another 12 years, to 50.

Table 2. Population size and life expectancy between 1950 and 2000 for different world regions

Population size

	1950	1975	2000
		(million)	
Industrial countries	813	1,047	1,194
Developing countries	1,706	3,021	4,877
Africa	221	408	796
Asia	1,398	2,398	3,680
Europe	547	676	728
Latin America and Caribbean	167	322	520
North America	172	243	316
Oceania	13	22	31
World	**2,519**	**4,068**	**6,071**

Life expectancy, both sexes combined

	1950–55	1970–75	1995–2000
		(years)	
Industrial countries	66.1	71.4	74.8
Developing countries	41.0	54.7	62.5
Africa	37.8	46.2	50.0
Asia	41.4	56.3	65.7
Europe	65.6	71.0	73.2
Latin America and Caribbean	51.4	60.9	69.4
North America	68.8	71.6	76.4
Oceania	60.3	65.8	73.2
World	**46.5**	**58.0**	**64.6**

In demographic terms, Asia shows the most noticeable changes in the past half century as, from an already dominant position in terms of population size, it has experienced the largest increase in absolute numbers of people and the largest increase in life expectancy.

In developing countries, most farming systems can be classified into one of the following three categories: livestock only, i.e. agropastoral; mixed rainfed, i.e. where livestock are raised together with crops and where only rainfall is used for irrigation; and mixed irrigated, i.e. where livestock and crops are produced together and artificial irrigation is used (Table 3). Of these three systems, the vast majority of people, over 95%, live in mixed systems and, with the exception of East and South Asia, more people live in rainfed than irrigated systems. However, large regional variations exist. In SSA, only 6.4 million people live in irrigated systems compared to more than 400 million in rainfed farms. This is markedly different from West and North Africa, where roughly similar numbers, around 100 million people, live in each type of system.

Table 3. Population numbers in different farming systems in developing countries

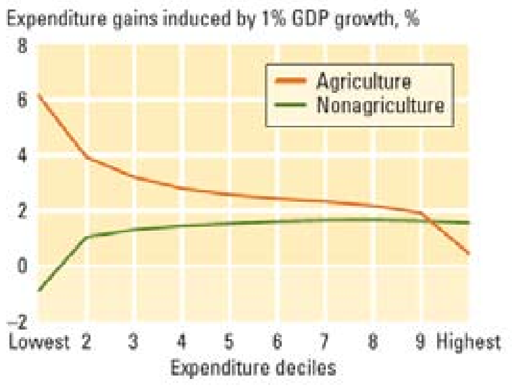
Total population				
	Livestock only	Mixed, rainfed	Mixed, irrigated	Other
SSA	59,582,725	412,487,392	6,429,093	666,579,184
WANA	31,451,502	102,100,670	99,394,564	385,158,052
LA	32,199,320	255,244,574	41,367,043	681,398,581
EECA	8,916,684	71,174,430	39,002,933	155,911,539
EA	22,974,011	592,985,668	952,991,633	2,002,014,904
SA	23,635,700	509,163,599	745,854,592	1,441,431,055
Total	178,759,942	1,943,156,333	1,885,039,858	5,332,493,315
Nr of poor (poor defined according to WB definition)				
SSA	28,563,410	182,677,816	2,893,091	299,938,730
WANA	7,405,597	26,735,721	23,820,409	96,664,059
LA	13,718,552	104,264,614	17,219,196	282,671,233
EECA	2,883,979	19,006,105	9,580,626	40,651,398
EA	1,924,890	82,316,995	100,202,575	265,687,436
SA	8,212,872	188,746,190	275,397,792	532,777,397
Total	62,699,300	603,746,441	429,113,689	1,508,390,253
Nr of poor livestock keepers				
SSA	20,977,629	121,773,739	735,488	165,534,044
WANA	4,926,333	14,284,693	5,523,800	33,422,177
LA	6,065,863	38,292,394	2,020,449	67,290,569
EECA	1,951,375	12,125,205	2,675,194	19,041,099
EA	1,407,513	49,575,663	24,087,636	91,571,722
SA	5,715,219	120,912,280	67,560,252	208,952,603
Total	40,123,932	356,964,054	102,602,819	585,812,204

Source: Thornton et al. (2002).

Table 3 also shows the number of poor living within each of these agricultural systems. In agropastoral systems, 63 million people, more than a third of the total, are classified as poor. In mixed systems, the numbers are much larger but the percentages are slightly lower: 31% of people are poor in rainfed systems and 23% in farms that use irrigation. Again, substantial regional variations exist: in SSA and Latin America, regardless of the type of farming, almost half of the farming population is poor, whereas in East Asia, the poor only comprise between 8 and 14% of farmers.

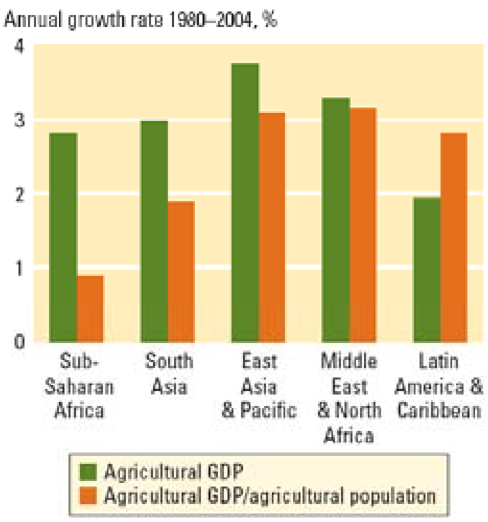
Progress in agricultural growth has been dominated by the significant increases in growth in Asia, especially in mixed crop–livestock systems in China. Figure 5 shows that growth in agricultural GDP per capita is lowest in SSA. In most cases, countries with high rates of agricultural value added per capita of agricultural production, such as China, were also good performers in rural poverty reduction.

Figure 4. Expenditure gains in 42 developing countries for a 1% increase in GDP growth



Source: Ligon and Sadoulet 2007.
Note: Based on data from 42 countries during the period 1981–2003. Gains are significantly different for the lower half of expenditure deciles.

Figure 5 Growth in agricultural GDP in developing countries



Sources: FAO 2006a; World Bank 2006y.

GDP per capita

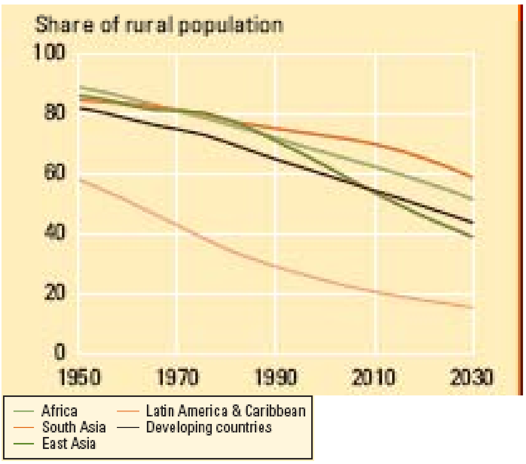
The graph shows that between 1981 and 2003 for 42 developing countries, a 1% growth in GDP originating in agriculture increased the countries' expenditures within the lowest third of the expenditure declines at least two and a half times more than growth originating in the rest of the economy, i.e. GDP growth originating in agriculture benefits the poorest half of the population substantially more than the wealthiest (World Bank 2007). This stresses the importance of agriculture (and livestock production) for the poor and raises evidence of why investments in pro-poor development interventions need to be related to revitalizing their agricultural sectors (World Bank 2007).

Growth of agricultural GDP in SSA is highly variable among countries and over time. Over the past 25 years, only Nigeria, Mozambique, Sudan and South Africa have maintained agricultural growth rates per capita of agricultural population above two per cent per year; many other countries have had significant periods of negative growth associated with conflicts or economic crises (World Bank 2007).

Rural and urban migrations

For the first time in history more people live in cities than in rural areas. Figure 6 shows that although populations in developing countries are still predominantly rural, rates of immigration to urban areas have been very high since the 1950s. In Latin America and the Caribbean, rural populations now only stand at about 20% of the total population and in developing countries as a whole, at just over 50%. Within the next 20 years this number is predicted to further decrease to the extent that more people will be living in urban areas than rural.

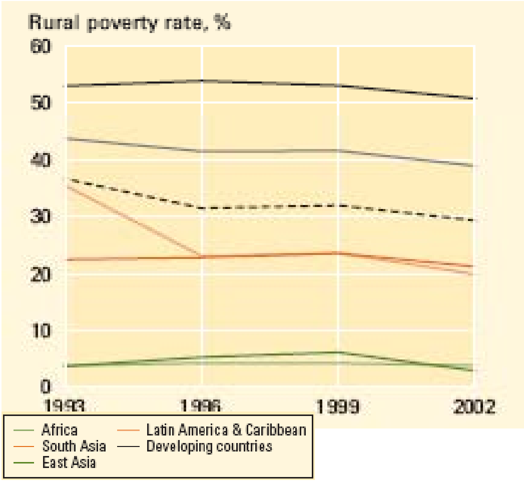
Figure 6. Proportion of total population in developing countries that is rural



Of the 3 billion rural inhabitants in developing countries, an estimated 2.5 billion are involved in agriculture: 1.5 billion living in smallholder households and 800 million working in smallholder households (World Bank 2007).

Poverty rates in rural areas have declined over the past decade, mostly because of impressive gains in economic growth in China. However, 75% of the world's poor still live in rural areas and rural poverty rates remain high in South Asia and SSA. Rural poverty reduction contributed more than 45% to overall poverty reduction in 1993–2002, with only a small share of that resulting from rural–urban migration. Rural–urban income gaps have narrowed in most regions, except Asia (World Bank 2007).

Figure 7. Rural poverty rates from 1993 to 2002

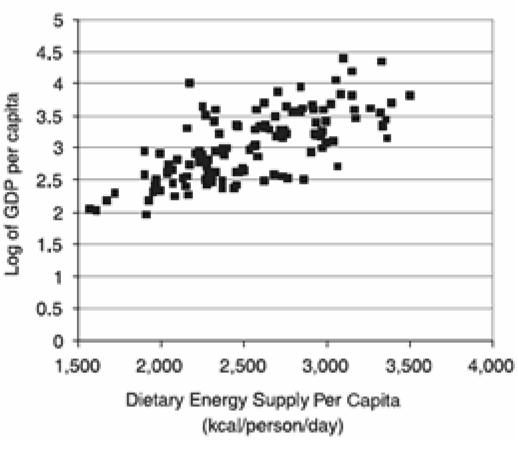


Food consumption

Supply of food

As shown in Figure 8, Arcand highlighted that a strong correlation exists between income and nutrition: as the amount of food supplied per person increases so does per capita income. Thus increasing average daily energy supplies (DES) can act as a driver of economic growth. In particular, Arcand calculated that increasing the DES to 2700 k cal per person per day in countries that were below that level, could increase the rate of economic growth by up to 1.13% per year.

Figure 8. Association between National Average Dietary Energy Supply and GDP, per capita



Demand for food

Increasing population sizes result in a direct increase in demand for food. At the same time increasing incomes change diets and alter the demand for different foods. In particular, demand for the consumption of high value products increases as incomes rise (Delgado et al. 1999).

For example, the growth rate of per capita consumption of animal food products is determined by economic factors such as incomes and prices and lifestyle changes. Figure 9 shows that in developing countries, per capita consumption of meat and horticulture increased rapidly between 1980 and 1995 (Delgado et al. 1999).

Figure 9. Domestic consumption of meat and cereals in developing countries between 1980 and 2005

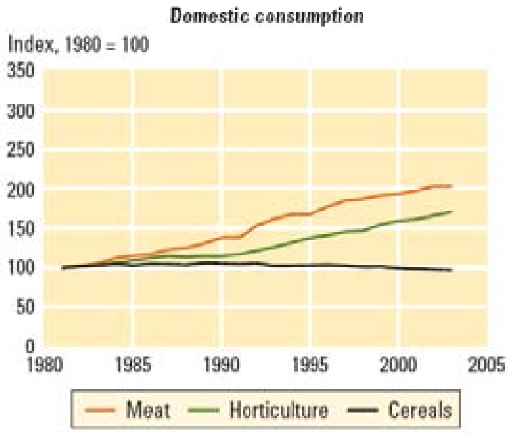


Table 4 shows that between 1962 and 2000 in developing countries the per capita consumption of cereals, milk and meat increased but with a heavy skew towards milk and meat products. Root and tuber consumption decreased. Being animal products, an increase in demand for milk and meat requires an increase in the supply of animal fodder. In developing countries, all the crop products required to feed animals to meet this increasing demand come from mixed crop–livestock systems.

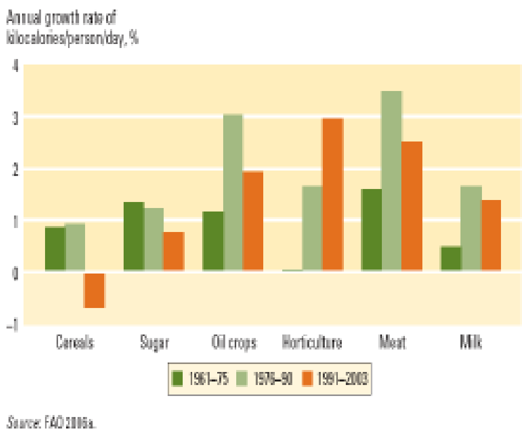
Table 4 Changes in food consumption in developing countries

	1962	1970	1980	1990	2000
Consumption kg/person/year					
Cereals	132	145	159	170	161
Roots and tubers	18	19	17	14	15
Starchy roots	70	73	63	53	61
Meat	10	11	14	19	27
Milk	28	29	34	38	45

Source: Steinfeld et al. (2006).

Figure 10 shows how per capita food consumption in developing countries is shifting to fruits and vegetables, meat, and oils. Although the rate of growth of consumption of oils and meats dropped between 1976–1990 and 1991–2003, it was still more than 1% per year; that of fruit and vegetables continued to increase to reach a high of 3% in the period 1991–2003.

Figure 10. Per capita food consumption in developing countries between 1961 and 2003

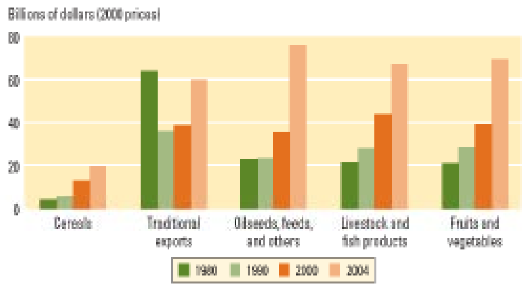


Increasing consumption implies increasing demand for food. About 60% of the rural population in developing counties consists of farmers living in areas of good agricultural potential and with access to markets. In these areas, good opportunities exist for farmers to diversify to higher value products such as milk, meat, fruit and vegetables, and oils. By doing so they can offset a decline which has been seen in prices for cereals and traditional exports such as tea, coffee, rubber and tobacco (World Bank 2007).

Livestock are closely interwoven with the socio-economic status of rural people in developing countries. Livestock contribute to the livelihoods of at least 70% of the world's rural poor and their livelihoods are enhanced by strengthening their capacity to cope with income shocks. Most people as well as most poor live in mixed systems. In terms of area, rangeland systems are the largest land use system on Earth, most milk and meat, however, comes and will continue to come from, mixed systems (Seré and Steinfeld 1996; Delgado et al. 1999).

Figure 11 shows how high value exports are expanding rapidly in developing countries (World Bank 2007). Diversification into higher value commodities and off-farm activities is increasingly becoming a key option in mixed farming systems, and, to a lesser extent, in marginal pastoral systems.

Figure 11. Changes in the value of exports of crops in developing countries between 1960 and 2004



Source: United Nations Commodity Trade Statistics Database (COMTRADE).
Notes: Traditional exports include cocoa, tea, coffee, rubber, tobacco, sugar, cotton, and spices.

Due to high population densities in the mixed systems, higher demands and trade-offs arise in terms of biomass use (food, feed and energy) and ecosystems services.

Table 5. Area, people, poverty and livestock within agricultural production systems

	Sub-Saharan Africa	Central and South America	West Asia and North Africa	East Asia	South-east Asia	South Asia	Newly independent states of Central Asia	Total
Animal production system area (million square kilometers)								
Rangeland	8.97	8.47	1.61	4.33	0.21	0.36	2.06	23.19
Mixed irrigated	0.12	0.40	0.83	1.37	0.48	1.62	0.41	5.13
Mixed rainfed	6.53	5.23	1.56	2.47	1.41	1.72	1.05	19.93
Other lands with some livestock	8.45	9.24	8.09	2.80	2.66	0.80	0.37	32.60
Total	24.2	20.3	12.3	11.0	4.8	4.4	4.0	80.8
People and poverty in production systems								
Number of people (millions)	606	329	310	1,187	401	1,256	64	4,063
Number of people below national poverty lines (millions)	268	132	85	111	127	530	17	1,273
Number of poor livestock keepers[a] (millions)	152	46	34	24	52	192	10	509
Share of total who are poor (percent)	43	40	27	9	32	42	27	44
Share of total who are poor livestock keepers (percent)	30	14	11	2	13	15	16	13
Cattle, sheep, and goats (tropical livestock units[b])								
Number (millions)	246	391	57	111	80	276	24	1,180
Density (number per square kilometer)	10.2	19.3	4.6	10.1	17.7	62.7	6.0	14.7
Estimated water needs for maintenance of livestock[c] (billion cubic meters a year)								
Drinking	2.2	3.7	0.5	1.0	0.8	2.8	0.2	0.9
Feed production	111	176	28	50	38	124	11	538

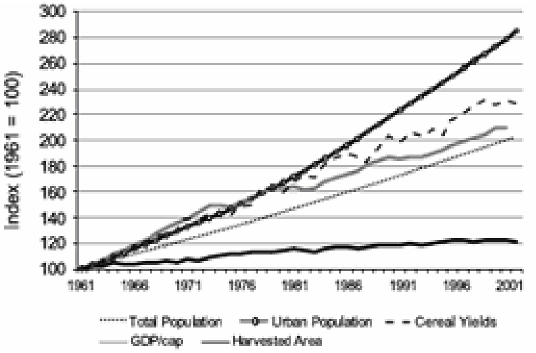
a. Refer to map 13.1 for geographic distribution.
b. One tropical livestock unit = 250 kg of live animal weight.
c. Maintenance refers to minimum amount of water needed to keep animals alive without weight loss but excludes extra feed needed for growth, lactation, and work; see text for explanation.
Source: Adapted from Thornton and others 2002.

3.2 Trends in agriculture

Crop production

The increase in human population creates substantial pressure on food and ecological systems, especially in mixed crop–livestock systems. The pressures can differ depending on factors such as the level of development, environmental conditions, resource endowments, and the parallel effects of other drivers such as climate change. Globally, ecosystems have met the rising demand for food over the last 50 years. Figure 12 shows that the availability of basic food items such as cereals has increased at a faster rate than population growth and that yields have increased whilst the area of land being harvested has remained more or less constant (i.e. that production is been successfully intensified). GDP has increased and the price of staple food items for many people is lower than ever.

Figure 12. Trends in selected drivers of food provision worldwide, 1961–2001



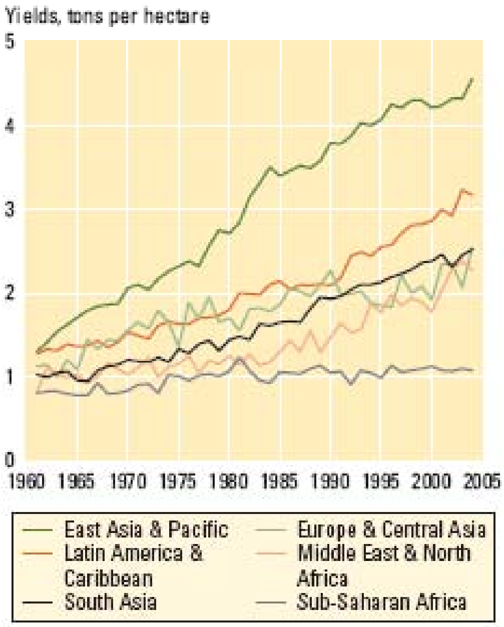
Globally, cereal production and yields have been consistently and significantly increasing in the past 50 years. The exception to this is in SSA where production, already lower than elsewhere, has only increased marginally. This has led to a widening of the yield gap between SSA and the rest of the world (World Bank 2007). In most cases increasing yields have been through intensification (increased input use, access to irrigation and crop varietal changes). In SSA, the increases in production have generally been through increases in area planted. These differences are a result of differences in production systems in terms of their agricultural potential, their market access, infrastructure, and population density.

Driven by population growth and expanding markets, traditional agricultural production grew by bringing more land under cultivation. However, in SSA and South Asia, the expansion of agricultural land relative to population density is now decreasing (Figure 14). Therefore, the increasing demand for crop production can only be met by intensification of the current mixed systems.

At the same time, land now used for agriculture is threatened by pollution, salinization and soil degradation from poorly managed intensification. These factors all affect productivity and reduce potential yields. Soil degradation through nutrient mining is a major problem in SSA, though much of it is reversible through better soil management and fertilizer use.

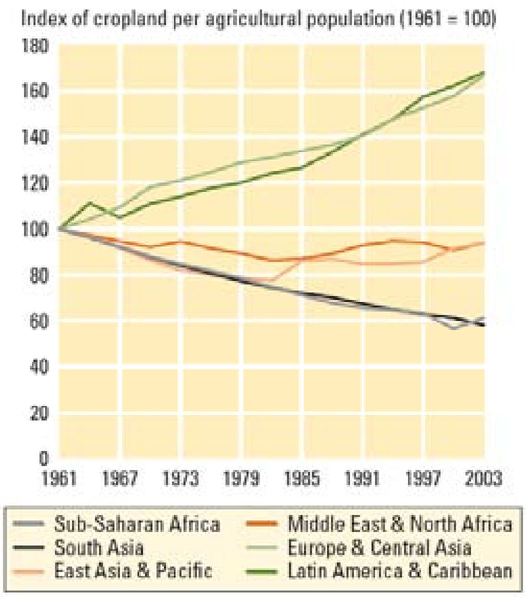
Figure 14 also shows how the area in land under cultivation has increased relative to population size in Latin America, Europe and Central America. However, in some places, notably in Asia's mixed rainfed systems, population densities are so high that increases in production through area expansion are not possible.

Figure 13. Regional cereal yields between 1960 and 2005



Source: World Bank (2007).

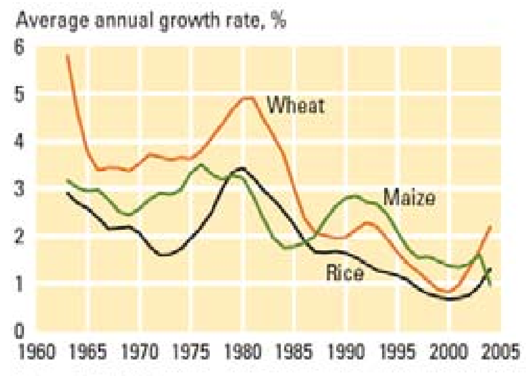
Figure 14. Arable and permanent cropland per capita of the agricultural population



Source: FAO 2006a.
Notes: Cropland represents both arable and permanent cropland.

With growing resource scarcity, future food production depends more than ever on increasing crop yields and livestock productivity, especially in mixed systems. However, although absolute yields of cereals have been increasing in developing countries, the rate of increase of these yields has been slowing significantly since 1980 (Figure 15). Whether future technological options will be available to increase crop yields without significant expansion in cropping area still remains to be seen.

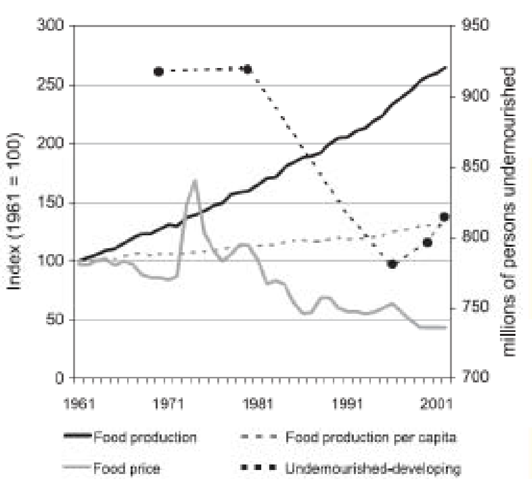
Figure 15. Growth rates of yields for major cereals in developing countries



Source: FAO 2006a.
Note: Data smoothed by locally weighted regressions.

Increasing global food production relative to population size has kept food prices down since the early 1970s. Moreover, as Figure 16 shows, between 1980 and the mid-1990s there was a positive correlation, albeit with some lag, between the global number of undernourished people and food price per capita. This trend was less obvious in SSA.

Figure 16. Global trends in food production and price in relation to undernourishment



From the mid-1990s onwards, the figure for undernourished people began to rise again, and currently even though food prices, which have fluctuated significantly, are now low, the poorer sectors of society are still not in a position to buy the basic staples. Unequal income distribution remains a problem and is increasing.

Livestock production

Crop and livestock production tends to be heavily interlinked in most developing countries. As can be seen in Table 6, at a global level, mixed crop–livestock systems account for the bulk of meat and milk production, and in Asia in particular, the use of mixed systems is especially dominant. Grazing-only systems are prevalent in SSA providing nearly two-thirds of cattle meat and three-quarters of milk production.

Table 6. Share of milk and meat outputs by production systems in selected regions

System/ Production	Milk	Cattle meat	Buffalo meat	Sheep and goat meat	Poultry meat
	(percent)				
World					
Grazing	8	23	0	30	2
Mixed	92	65	100	69	24
Landless	0	12	0	1	74
SSA					
Grazing	74	62	0	42	25
Mixed	26	38	0	58	46
Landless	0	0	0	0	29
Asia					
Grazing	0	16	0	22	0
Mixed	100	84	100	78	50
Landless	0	0	0	0	50
Central and South America					
Grazing	31	56	0	55	5
Mixed	69	44	0	45	20
Landless	0	0	0	0	75

Source: Sere and Steinfield 1996

Source: ParthasarathyRao et al. (2005).

Evidence suggests that grazing systems are gradually evolving into mixed systems partly as a consequence of population increases and land fragmentation (ParthasarathyRao et al. 2005).

In farming systems in developing countries the level of intensity of the system is related to the end livestock product. Table 7 shows that beef tends to come from the more extensive systems (though both mixed and livestock only) whereas more than half of all milk production comes from irrigated systems. Chicken and pork are largely produced in industrial systems. These differences reflect the availability of markets as well as the agricultural suitability of the land.

Table 7. Livestock population and production in different production systems in developing countries

Parameter	Livestock production systems			
	Grazing	Rain fed mixed	Irrigated mixed	Landless/ industrial
Population (million head)				
Cattle and buffaloes	342.0	444.0	416.0	1.0
Sheep and goat	405.0	500.0	474.0	9.0
Production (million tonnes)				
Beef	9.8	11.5	9.4	0.2
Mutton	2.3	2.7	3.4	0.1
Pork	0.6	3.2	26.6	26.6
Poultry meat	0.8	3.6	9.7	25.2
Milk	43.8	69.2	130.8	0.0
Eggs	0.4	2.4	15.6	21.6

In developing countries, the majority of ruminants are found outside temperate regions. This implies they tend to be in arid or semi-arid regions which have very low primary productivity and low yields per animal. Table 8 shows that beef production in the temperate zones is equal to that of the arid and humid zones together, although cattle numbers are three times higher in the latter regions. Thus the large numbers of cattle in extensive, livestock-only systems do not necessarily confer high productivity.

Table 8. Livestock population and production in different agro-ecological zones

Parameter	agro ecological zones		
	Arid ans semi arid tropics and sub tropics	Humid ans sub humid tropics ans sub tropics	Temperature and tropical highlands
Population (million head)			
Cattle and buffaloes	515.0	603.0	381.0
Sheep and goat	810.0	405.0	552.0
Production (million tonnes)			
Beef	11.7	18.1	27.1
Mutton	4.5	2.3	5.1
Pork	4.7	19.4	18.4
Poultry meat	4.2	8.1	8.6
Milk	117.2	73.6	343.5
Eggs	4.7	10.2	8.3

The landless and industrial systems of pork and poultry meat are mostly found in humid zones or in the temperate regions and highlands.

Globally, livestock numbers are increasing and at the same time, a larger share of the world's cereal production is being used for animal feed. This reflects the large increases in (relatively intensive) pig and poultry production to meet human demand. This will create important changes in mixed systems especially, as they produce the bulk of cereals in developing countries.

Past and projected figures for cereal demand for feed can be seen in Table 9. China has been the forerunner in this area, using more cereal for feed than all of Latin America, i.e. about half of the total for the developing world. That dominance is projected to continue to 2020 but by that time consumption of cereals for feed is projected to have doubled from its 1997 levels.

Table 9. Global trends and projections in the use of cereal as feed

Trends and Projections in the Use of Cereal as Feed. Figures are three-year moving averages centered on year shown. The 2020 projections are from the July 2002 version of the IMPACT model. (Delgado et al. 2003, calculated from data in FAOSTAT 2004)

Region	Total Cereal Use as Feed			
	1983	1993	1997	2020
	(million tons)			
China[a]	40–49	78–84	91–111	226
India	2	3	2	4
Other East Asia	3	7	8	12
Other South Asia	1	1	1	3
Southeast Asia	6	12	15	28
Latin America	40	55	58	101
Western Asia and North Africa	24	29	36	61
Sub-Saharan Africa	2	3	4	8
Developing world	128	194	235	444
Industrial world	465	442	425	511
World	**592**	**636**	**660**	**954**

[a] Ranges show high and low estimates based on data from various sources.

Some marginal systems might also benefit from this increased demand, as more land might be converted to produce more crops.

Although large increases in pig and poultry numbers are creating a demand for more feed, significant improvements have been made in the productivity per kilo of feed consumed for these animals. Table 10 shows increases in productivity parameters for pigs and poultry in different world regions. Gains in production efficiency between 1980 and 2005 were made across all regions, but in Latin America and South Asia in particular, these gains were especially large. These increased efficiencies should help to defray the increased demand for grains as feed for pigs and poultry.

Table 10. Key productivity parameters for pigs and poultry in different world regions

Region	Chicken meat (kg output/biomass/year)		Egg yield (kg/layer/year)		Pig meat(kg output/kg biomass/year)	
	1980	2005	1980	2005	1980	2005
World	1.83	2.47	8.9	10.3	0.31	0.45
Developing Countries	1.29	1.98	5.5	8.8	0.14	0.33
Developed Countries	2.26	3.55	12.2	15	0.82	1.2
Sub-Saharan Africa	1.46	1.63	3.4	3.6	0.53	0.57
West Asia and North Africa	1.73	2.02	7	9.4	1.04	1.03
Latin America and the Caribbean	1.67	3.41	8.6	9.8	0.41	0.79
South Asia	0.61	2.69	5.8	8.1	0.72	0.71
East and South East Asia	1.03	1.41	4.7	9.5	0.12	0.31
Industrialized countries	2.45	3.72	14.1	16	1.03	1.34
Transition countries	1.81	2.75	9.6	13	0.57	0.75

3.3 Environmental trends and crop–livestock systems

Climate change

Table 11 summarizes the findings of the IPCC's Fourth Assessment (Christensen et al. 2007) in terms of the potential changes in weather as a result of climate change on Africa, Asia and Central and South America.

Even though the magnitude of the economic losses may be higher in rich countries than poor, natural disasters tend to have, and are predicted to do so in the future, a greater effect on poorer nations. Poorer countries generally have a worse infrastructure, less advanced technology, and fewer resources with which to finance recovery than rich ones. Figure 17 shows that although between 1985 and 1999 the world's 10 richest nations lost almost two and a half times more money than the 10 poorest nations, in terms of per cent of GDP, the richest nations lost only a sixth of that of the poorest.

Figure 17. Disaster losses, total and as a share of GDP between 1985 and 1999 in the world's ten richest and poorest nations

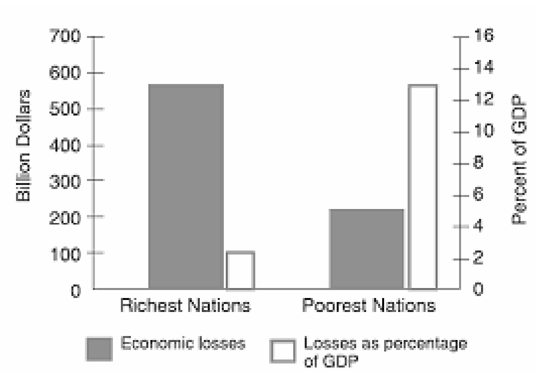
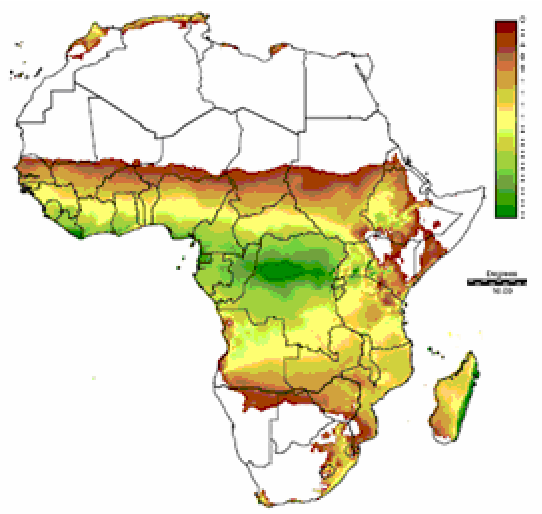


Table 11. Regional climate change projections from the IPCC's Fourth Assessment

	Africa	Asia	Central and South America
Temperature	Warming **very likely** to be larger than the global annual mean warming throughout the continent and in all seasons, with drier subtropical regions warming more than the moister tropics.	Warming **likely** to be well above the global mean in central Asia, the Tibetan Plateau and northern Asia, above the global mean in eastern Asia and South Asia, and similar to the global mean in Southeast Asia.	Annual mean warming **likely** to be similar to the global mean warming in southern South America but larger than the global mean warming in the rest of the area.
Rainfall	Annual rainfall **likely** to decrease in Mediterranean Africa and northern Sahara. Rainfall in southern Africa **likely** to decrease in much of the winter rainfall region and western margins. **Likely** increase in annual mean rainfall in East Africa. Unclear how rainfall in the Sahel, the Guinean Coast and the southern Sahara will evolve.	Precipitation in boreal winter is **very likely** to increase in northern Asia and the Tibetan Plateau, and **likely** to increase in eastern Asia and southern parts of Southeast Asia. Precipitation in summer is **likely** to increase in northern Asia, East Asia, South Asia and most of Southeast Asia, but is **likely** to decrease in central Asia.	Annual precipitation **likely** to decrease in Central America and southern Andes (large local variability in mountains). Winter precipitation in Tierra del Fuego, summer precipitation in south-eastern South America, **likely** to increase. Uncertain how mean rainfall will change over northern South America, including the Amazon forest. Some qualitative consistency in some areas: rainfall increasing in Ecuador and northern Peru; decreasing in southern NE Brazil.
Extreme events	Increase in dry spells **likely** in most subtropical areas.	**Very likely** that hot spells in summer will be longer, more intense and more frequent in East Asia. Fewer very cold days are **very likely** in East Asia and South Asia. **Very likely** an increase in frequency of intense precipitation events in South and East Asia. Extreme rainfall and winds associated with tropical cyclones are **likely** to increase in East Asia, Southeast Asia and South Asia.	Increase in dry spells **likely** in most subtropical areas.

The climate is changing and the number of extreme events that result in an increase in natural disasters is predicted to increase.

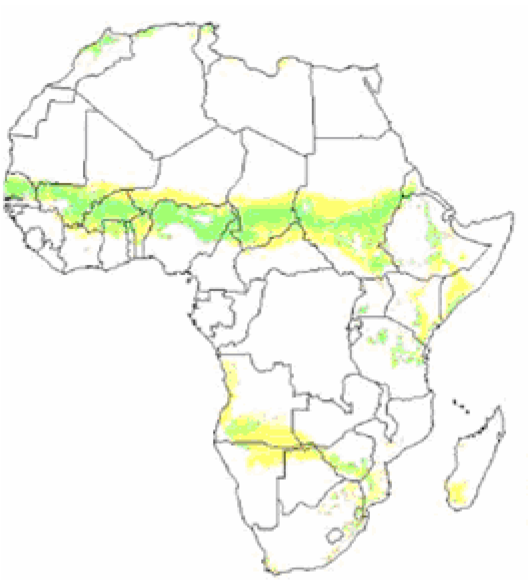
Figure 18. Length of growing period (days per year) for 2000



Source: Thornton et al. (2006).

Figure 19 shows the areas within pastoral and mixed rainfed production systems in arid and semi-arid regions of Africa that are projected to undergo more than a 20% reduction in length of growing period by 2050, under the HadCM3, A1 scenario.

Figure 19. Areas within the LGA (in yellow) and MRA (in green) systems projected to undergo more than 20% reduction in the length of growing period by 2050



These are mostly marginal areas of the Sahelean belt and southern Africa in which pastoral systems and marginal mixed-crop–livestock systems predominate.

Energy use

Economic and population growth, together with a high demand for transportation services and policies (e.g. subsidies) are the top three factors directly driving the growth in demand for bio-energy. Strong world economic growth has pushed up energy consumption, global economic development, especially in developing countries (notably China and India) has helped drive global renewable energy investment. The European Union and the United States are the heaviest investors in this sector followed by China and India.

From population growth alone aggregate energy demand will hit 14 billion tonne oil equivalents in 2030, a 32% increase from 2006. According to the World Energy Outlook 2007, the total 2030 world energy demand will be more than 17 billion tonne oil equivalents, led by China and OECD countries (Table 12).

Table 12. Global projections of energy demand in 2015 and 2030

Total Primary Energy Demand (Mtoe)		
	2015	2030
World	14361	17721
Africa	726	943
Middle East	734	1027
India	770	1299
OECD North America	3166	3573
China	2851	3819
Latin America and the Caribbean	646	873
European Union	1910	2006
Russia	766	871

* Mtoe is millions of tonne oil equivalents.

Source: International Energy Agency's 2007 World Energy Outlook.

Oil price volatility arising from social and political instability in some oil producing countries has also pushed interest towards bio-energies.

The largest projected increase in energy demand occurs in the transportation sector. Security of fuel for transport has attracted much attention in developing countries. China and India, which together with United States comprise the top three energy consuming countries (International Energy Agency) will consume about 70% of the projected energy demanded by the transport sector from 2005 to 2025. Growth rates of energy demand are expected to be 5% and 4.4% per year for this period for China and India, respectively. So, under mounting pressure to improve domestic energy security and combat global climate change, countries are now turning to ethanol and biodiesel as alternative fuel sources.

Table 13. Global biofuel production and crops

country	Million litres	Share of the world production (%)	Feed stocks
Ethanol (2006)			
United States	18,378	36	Maize
Brazil	17,000	33.3	Sugarcane
China	3,850	7.5	Maize, wheat and cassava
India	1,900	3.7	Sugarcane, sweet sorghum
France	950	2	Sugar beets, wheat
Other Countries	8,982	17	
World	51,060		
Bio-diesel (2005)			
Germany	507	51	Rapeseed, sunflower seed
France	147	15	Rapeseed
United States	75	8	soybean
Italy	60	6	sunflower seed, rapeseed
Other Countries	168	21	
World	994		

Source: Licht (2006).

In 2006, the United States passed Brazil to become the world's number one producer of bio-ethanol.

The principal crops used to produce biofuels are maize, wheat, sugarcane, cassava and sweet sorghum (for bio-ethanol) and rapeseed, soybean, and sunflower seed for biodiesel. Since a number of these crops, such as maize, wheat, and cassava, are also major animal feeds, competition for crops for feed and for biofuel production now exists. This has had the effect of pushing up the price of livestock feed and, consequently, of livestock products.

Cellulose conversion is becoming an economically feasible technology for biofuel production, and may in turn result in competition for fodder and pasture.

Controversy regarding biofuels comes from the food security for food deficit area, increasing food prices, greenhouse gas emissions and biofuel cost-efficiency (IFPRI 2006; Rosegrant et al. 2006; ODI 2007; Peskett et al. 2007; Tokgoz et al. 2007; Dixon et al. 2008). Impact on crop–livestock production is a key point for the human food consumption and livestock industry sustainable development. Specific impacts need to be investigated at country- and farming system-level based on local energy and resource availability. Table 14 gives examples of the most important regions of the developing world that have significant potential for further biofuel development.

Table 14. Human, livestock and total energy consumption in selected farming systems

Region	Farming system	Example countries	Energy consumption	Fossil fuels	Total human calorie consumption	Cereal food consumption	Animal food consumption
			Toe per GDP[a]	% to total energy use	Kilocalories/ person/day	% to total calories	% to total calories
EAP	Tree crop mixed	Indonesia	239	68	2912	62	4
EAP	Lowland rice	China	231	82	2958	49	20
EECA	Small scale cereal-livestock	Turkey	167	87	3358	50	10
LAC	intensive mixed system	Brazil	146	58	3010	31	22
LAC	Cereal-livestock	Brazil	146	58	3010	31	22
LAC	Temperate mixed (Pampas)	Argentina	139	86	3075	33	31
SA	Dry rainfed	India	190	59	2420	59	8
SA	Rice	East India	190	59	2420	59	8
SSA	Maize mixed	Kenya	468	16	2107	48	12
SSA	Forest based	Nigeria	777	20	2705	45	3

Water use

Over the last 40 years the world food supply has increased by about 25% in relation to population growth, from 2250 calories per person per day to approximately 2800 calories per person per day. Although this increase has occurred uniformly across much of the world, Figure 20 shows that whilst the global food supply is only just reaching the threshold for national security, distribution inequalities mean that in many countries in Asia and SSA food supply is still below that needed for food security.

Today, each calorie of food takes approximately 1 litre of water to produce, indicating that the annual amount of water used to produce the world's food is approximately 7,000 cubic kilometres. Approximately 20% of this is used in irrigated agricultural systems.

Much of the last decades' increased production of food has come from the expansion of irrigated agriculture. Over the last 50 years there have been enormous developments in water technology for agricultural production. Even after the World Bank dramatically slowed its lending for irrigation infrastructure in the mid-1980s, the global area under irrigation continued to grow. And while the world's population has more than doubled since 1950, food production outstripped population growth, resulting in a marked decline in food prices. This decline is only just beginning to reverse. Loss of water from natural reserves because of large-scale irrigation and cumulative agricultural activities are now being seen to impact on aquatic ecosystems. One index of aquatic ecosystem health, the Living Planet Index of Freshwater Species has declined dramatically.

Figure 20. Global changes in food consumption from 1961 to 2003

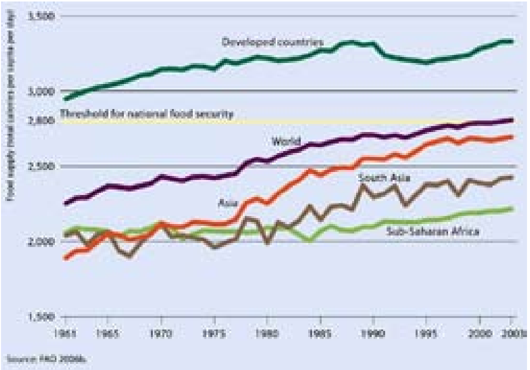
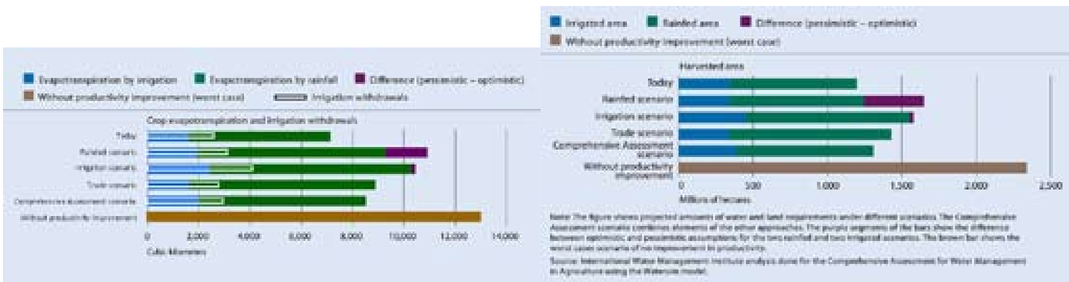


Figure 21. Investing in irrigation based on FAO and World Bank data

In the Comprehensive Assessment of Water Management in Agriculture (2007), scenarios were presented that define the land and water required at a global level to produce enough food to feed the population in 2050. In an optimistic rainfed scenario reaching 80% maximum obtainable yields while relying on minimal increases in irrigated production, the total cropped area would have to increase by only 7%, and the total increase in water use would be 30%, with direct water withdrawals increasing by only 19%. In contrast, focusing on irrigation first could contribute 55% of the total value of food supply by 2050. But that expansion of irrigation would require 40% more withdrawals of water for agriculture, surely a threat to aquatic ecosystems and capture fisheries in many areas. The factors that contribute to optimistic and pessimistic estimates of total water needs are primarily differences in water productivity. Without gains in water productivity, water resources devoted to agricultural production will likely increase by 70 to 90%. On top of this is the amount of water needed to produce fibre and biomass for energy.

Figure 22. Some examples of scenario options



Source: Comprehensive Assessment of Water Management in Agriculture (2007).

Land use and soil nutrients

Over the last 20 years, increasing human population, economic development and emerging global markets have driven unprecedented land-use change (UNEP 2007). Continuous cropping without adequate restorative practices may endanger the sustainability of agriculture. Nutrient depletion is a major form of soil degradation in mixed crop–livestock systems. A soil nutrient balance is a commonly used indicator to assess changes in soil fertility. Constructed N, P and K balances for 37 SSA countries revealed that soil fertility is generally following a downward trend on the African continent. Table 15 indicates average nutrient balances of some SSA countries.

Table 15. Average nutrient balances of some SSA countries

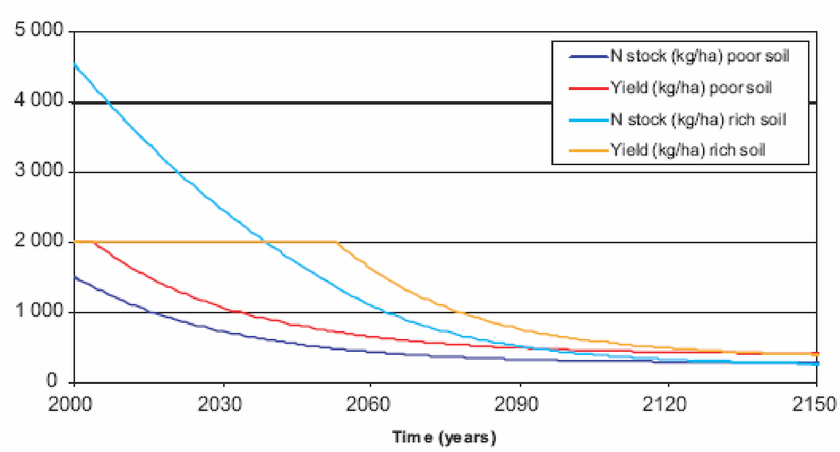
Average nutrient balances of some sub-Saharan African countries

Country	N		P		K	
	1982-84	2000	1982-84	2000	1982-84	2000
	(kg/ha/year)					
Benin	-14	-16	-1	-2	-9	-11
Botswana	0	-2	1	0	0	-2
Cameroon	-20	-21	-2	-2	-12	-13
Ethiopia	-41	-47	-6	-7	-26	-32
Ghana	-30	-35	-3	-4	-17	-20
Kenya	-42	-46	-3	-1	-29	-36
Malawi	-68	-67	-10	-10	-44	-48
Mali	-8	-11	-1	-2	-7	-10
Nigeria	-34	-37	-4	-4	-24	-31
Rwanda	-54	-60	-9	-11	-47	-61
Senegal	-12	-16	-2	-2	-10	-14
United Republic of Tanzania	-27	-32	-4	-5	-18	-21
Zimbabwe	-31	-27	-2	2	-22	-26

Source: FAO (2003).

Anticipated human population increases and continued economic growth are likely to further increase exploitation of land resources over the next 50 years (UNEP 2007). Figure 23 indicates the trends in yield and nutrient stocks for two soil types.

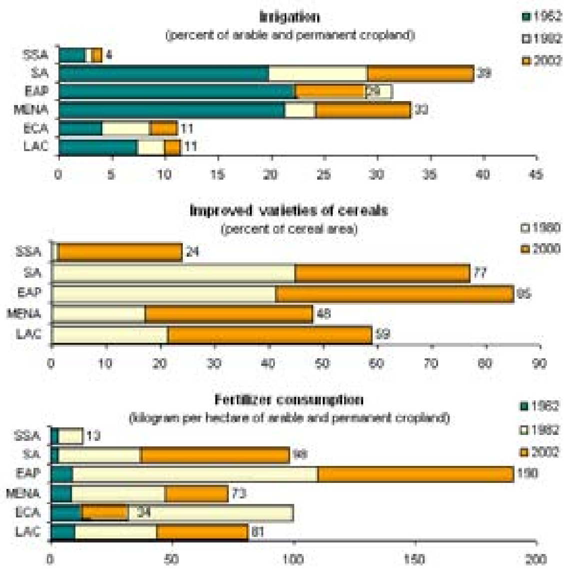
Figure 23 Trends in yield and nutrient stocks for two soil types



There is no remedy for soils that are deficient in nutrients other than adding the necessary inputs. Efforts to improve soil fertility have focused on the replenishment of nutrients by the use of inorganic fertilizers and organic manure. This has been very successful in many parts of the world, and is responsible for a large increase in agricultural production. Yields may double or triple on a sustained basis by even modest application of fertilizer (UNEP 2007). However, across most of the tropics, the use of inorganic fertilizers is limited by availability and costs, although inorganic fertilizers often have favourable value-to-cost ratios.

Low soil fertility is a major contributor to the low productivity of African production systems (IAC 2004). The yield gap for certain crops like cereals between SSA and other regions has widened. Globally, improved varieties have been widely adopted except in this region (World Bank 2007). Figure 24 shows that the use of agricultural inputs have also expanded rapidly, but lagged in SSA.

Figure 24. Modern inputs have expanded rapidly but have lagged in SSA



Research showed that major impediments to improved soil fertility management include low levels of farmers' human, physical and financial capitals, lack of investment in science and technology and poor uptake of products derived from them, low agricultural commodity prices relative to fertilizer and other input prices, lack of pro-agriculture policies, and the failure to view the maintenance of soil fertility as an important public good.

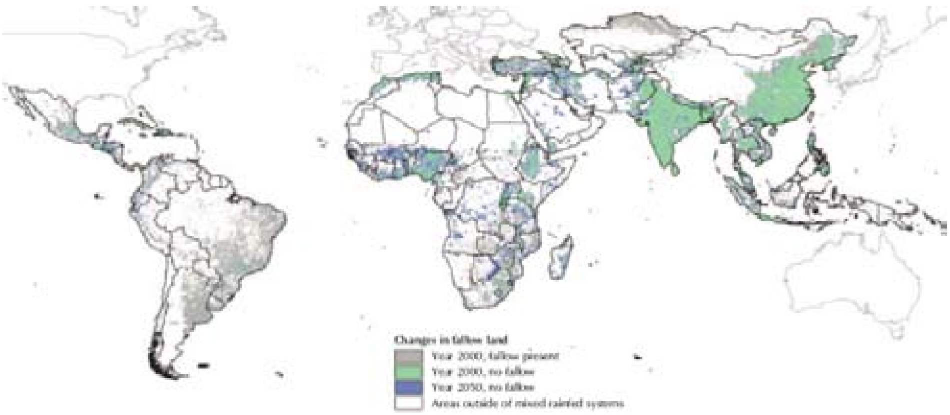
In certain production systems it is not nutrient depletion that is the cause of land degradation but eutrophication. Rivers, lakes and coastal waters receive large quantities of nutrients from the land as, for example, in East Asia, where pig and poultry operations produce overwhelmingly more nutrient discharge than other sources of pollution. Table 16 shows the estimated relative contribution of pig waste to nitrogen and phosphorus emissions in water systems.

Table 16 Estimated relative contribution of pig waste, domestic wastewater and non-phosphorus emissions in water systems

Country/Province	Nutrient	Potential load (tonnes)	Percentage contribution to nutrient emissions in water systems		
			Pig waste	Domestic wastewater	Non-point source
China-Guangdong	N	530 434	72	9	19
	P	219 824	94	1	5
Thailand	N	491 262	14	9	77
	P	52 795	61	16	23
Viet Nam	N	442 022	38	12	50
	P	212 120	92	5	3

Figure 25 shows changes in fallow land in mixed rainfed production systems between 2000 and 2050 (Thornton et al. 2002). Increases in population density have increased the pressure on land for cultivation, and farm sizes have diminished. The traditional practice of crop rotation has also decreased in large parts of the world (green areas on the map), and fertilizers and pesticides are used instead. However, to date there are still large areas (grey on map) that use a system of regularly changing the crops grown on a piece of land to utilize and add to the nutrients in the soil and to prevent the build-up of insect and fungal pests and diseases. Increased intensification will result in a reduction in the use of fallow land over time (blue areas). The increasing pressure on land in the future may lead to an excessive depletion of soil nutrients and loss of soil structure in the event that no proper crop rotation and/or use of fertilizers are applied. An additional risk is that feed resources may become more limited and it may therefore be more difficult to maintain cattle. Often, the traditional component of crop rotation is the replenishment of nitrogen through the use of green manure (legumes) and these legumes are used as fodder crops.

Figure 25. Changes in fallow land to 2030



Source: Thornton et al. (2002).

4 Methods and scenarios for evaluating changes in mixed crop–livestock systems and human wellbeing

4.1 Methods

For a number of socio-economic and production indicators the current situation is compared with future projections under different scenarios. These indicators are mapped and summaries per region and production system produced and discussed.

The production of the maps and regional summaries follows a two-step process.

In a first step, the IMPACT model is used to produce future projections of, amongst others, crop–livestock production, water use, world prices, income and malnutrition. The first sections (section 4.2 and 4.3) describe the IMPACT model, its input and output variables and the different scenarios used in this study.

A second step then applies GIS technology to spatially re-allocate the country and food production unit level outputs from IMPACT to different livestock production systems within countries and regions. Section 4.4 describes this process in more detail.

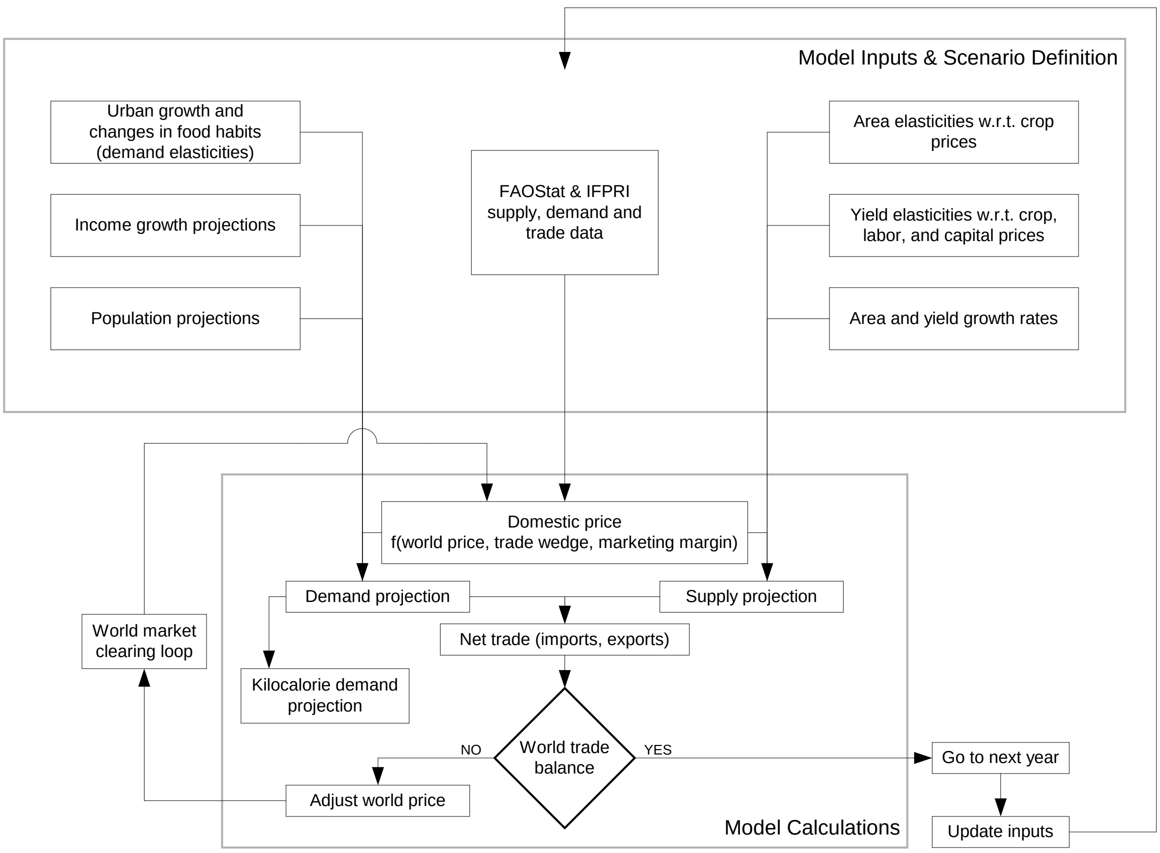
4.2 Brief IMPACT model description

The IMPACT model combines an extension of the original International Model for Policy Analysis of Agricultural Commodities and Trade (IMPACT) with a global water simulation model based on state-of-the-art global water databases (Rosegrant et al. 2002). The water module projects the evolution of availability and demand, with a base year of 2000 (average of 1999–2001), taking into account the availability and variability in water resources, the water supply infrastructure, and irrigation and non-agricultural water demands, as well as the impact of alternative water policies and investments. Water demands are simulated as functions of year-to-year hydrologic fluctuations, irrigation development, growth of industrial and domestic water uses, and environmental and other flow requirements (committed flow). Off-stream water supply for the domestic, industrial, livestock, and irrigation sectors is determined based on water allocation priorities, treating irrigation water as a residual; environmental flows are included as constraints.

The food module is specified as a set of 115 country or regional sub-models, within each of which supply, demand and prices for agricultural commodities are determined for 32 crop, livestock, and fish commodities, including all cereals, soybeans, roots and tubers, meats, milk, eggs, oils, oilcakes and meals, sugar and sweeteners, fruits and vegetables, and low- and high-value fish. These country and regional sub-models are intersected with 126 river basins—to allow for a better representation of water supply and demand—generating results for 281 Food Producing Units (FPUs). Crop harvested areas and yields are calculated based on crop-wise irrigated and rainfed area and yield functions. These functions include water availability as a variable and connect the food module with the global water simulation model.

The 'food' side of the IMPACT model uses a system of supply and demand elasticities incorporated into a series of linear and nonlinear equations to approximate the underlying production and demand functions. World agricultural commodity prices are determined annually at levels that clear international markets (Figure 26). Demand is a function of prices, income and population growth. Growth in crop production in each country is determined by crop prices and the rate of productivity growth. Future productivity growth is estimated by its component sources, including crop management research, conventional plant breeding, wide-crossing and hybridization breeding, and biotechnology and transgenic breeding. Other sources of growth considered include private sector agricultural research and development, agricultural extension and education, markets, infrastructure and irrigation.

Figure 26. Overview of the 'food' side of the IMPACT model



IMPACT projects the share and number of malnourished preschool children in developing countries as a function of average per capita calorie availability, the share of females with secondary schooling, the ratio of female to male life expectancy at birth, and the percentage of the population with access to safe water (see also Smith and Haddad 2000; Rosegrant et al. 2001).

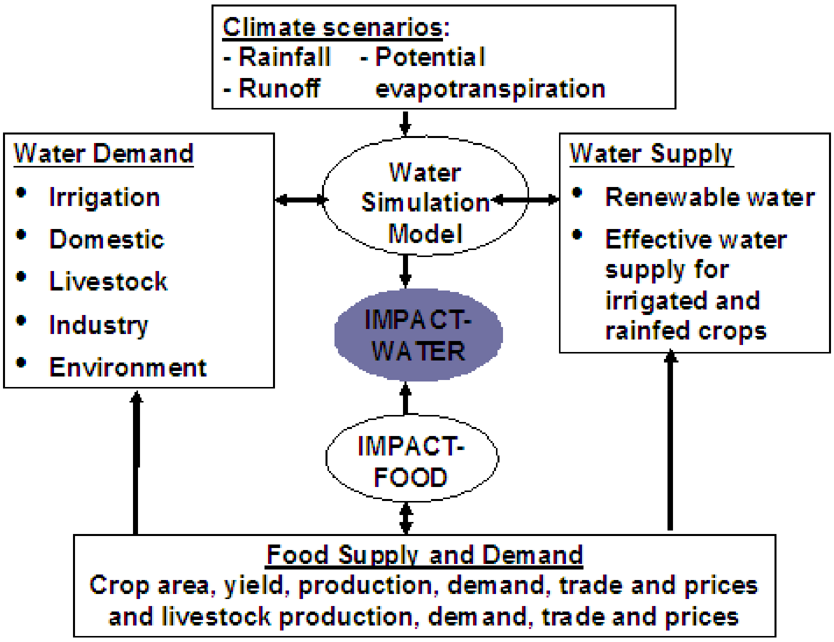
The 'water' side of the IMPACT model interacts with the 'food' module by simulating the reductions in area and yield that result from deficits in water supply given that the total water requirements for maximum potential yield may not be met and that other non-agricultural demands for water that must be satisfied within the given basin. Whereas the 'food' model simulates trade in a non-spatial way, the 'water' model allocates water in each spatial unit according to the crop irrigation, livestock, industrial and municipal demands that are projected. A simple schematic showing the linkage of the 'food' and 'water' modules of IMPACT is provided in Figure 26.

The model is written in the General Algebraic Modelling System (GAMS) programming language and makes use of the Gauss-Seidel algorithm. This procedure minimizes the sum of net trade at the international level and seeks a world market price for a commodity that satisfies market-clearing conditions.

IMPACT generates annual projections for irrigation, livestock, and non-agricultural water withdrawals and depletion as well as irrigated and rainfed crop area, yield, production, demand for food, feed and other uses, prices, and trade; and livestock numbers, yield, production, demand, prices, and trade.

The model incorporates data from FAOSTAT (FAO 2003), commodity, income, and population data and projections from the World Bank (World Bank 2000), the Millennium Ecosystem Assessment, and the UN (UN 2000) and USDA (USDA 2000), a system of supply and demand elasticities from literature reviews and expert estimates (see Rosegrant et al. 2001), and rates for malnutrition from ACC/SCN (1996) and WHO (1997) and calorie-child malnutrition relationships developed by Smith and Haddad (2000).

Figure 27. Schematic representation of the linkage of the food and water modules in the augmented IMPACT model (IMPACT-Water)



4.3 Descriptions of IMPACT scenarios used for drivers study

1. **Drastic biofuel expansion**. This scenario takes the actual national biofuel plans of those countries which have installed capacity and accelerates the growth of feedstock demand over different periods within the projections horizon. Feedstock demands for biofuel production are taken at their historical levels from 2000 to 2005, whereas the demand by 2010 is taken to be 50% higher than the gradual rate of 1% annual expansion that would otherwise be assumed. This rate of expansion is doubled between 2015 and 2020, and gives a fairly strong projection of feedstock demand from the key crops used in biofuel production, namely sugarcane, maize, cassava (for ethanol) and oil products (for biodiesel).

2. **Irrigation expansion**. This scenario is taken from one of the variants to the 'reference' (or baseline) case used in the International Assessment for Agricultural Science and Technology for Development (IAASTD). Whereas the reference case describes a trend of slowly declining rates of growth in agricultural research (and extension), the 'higher' variants for Agricultural Knowledge, Science and Technology (AKST) consider expanded investments in agriculture over the period 2000 to 2050. The variant that we use in this scenario corresponds to higher levels of crop–livestock yields as well as expanded investments in complementary sectors, such as irrigation. The improvements in irrigation infrastructure are represented by accelerated growth in irrigation area and increasing

efficiency of irrigation water use. Other improvements that are introduced under this scenario are accelerated growth in access to drinking water, and changes in the enrolment levels of secondary education for females, both of which are important determinants for human wellbeing outcomes, such as child malnutrition. The details of what is included in this scenario are shown in Table 17.

Table 17. Assumptions for reference case and the scenario variant with high agricultural investment combined with other AKST-related factors (used as IRRIGATION EXPANSION scenario)

Parameter changes for growth rates	2050 REFERENCE CASE	Drastic biofuel expansion	Low meat demand	2050 High AKST + other services (IRRIGATION EXPANSION)
GDP growth	3.06 % per year	3.06 % per year	3.06 % per year	3.31 % per year
Livestock numbers growth	Base model output numbers growth 2000–2050 Livestock: 0.74%/year Milk: 0.29%/year	Base model output numbers growth 2000–2050 Livestock: 0.74%/year Milk: 0.29%/year	Base model output numbers growth 2000–2050 Livestock: 0.74%/year Milk: 0.29%/year	Increase in numbers growth of animals slaughtered by 30% Increase in animal yield by 30%
Food crop yield growth	Base model output yield growth rates 2000–2050: Cereals: %/year: 1.02 R&T: %/year: 0.35 Soybean: %/year 0.36 Vegetables: %/year 0.80 Sub-tropical/tropical fruits: 0.82%/year	Base model output yield growth rates 2000–2050: Cereals: %/year: 1.02 R&T: %/year: 0.35 Soybean: %/year 0.36 Vegetables: %/year 0.80 Sub-tropical/tropical fruits: 0.82%/year	Base model output yield growth rates 2000–2050: Cereals: %/year: 1.02 R&T: %/year: 0.35 Soybean: %/year 0.36 Vegetables: %/year 0.80 Sub-tropical/tropical fruits: 0.82%/year	Increase yield growth by 60% for cereals, R&T, soybean, vegetables, ST fruits and sugarcane, dryland crops, cotton Increase production growth of oils, meals by 60%
Irrigated area growth (apply to all crops)	0.06	0.06	0.06	Increase by 25%
Rainfed area growth (apply to all crops)	0.18	0.18	0.18	Decrease by 15%
Basin efficiency				Increase by 0.15 by 2050, constant rate of improvement over time
Access to water				Increase annual rate of improvement by 50% relative to baseline level, (subject to 100 % maximum)
Female secondary education				Increase overall improvement by 50% relative to 2050 baseline level, constant rate of change over time unless baseline implies greater (subject to 100 % maximum)

Biofuel feedstock demand	2000–2005: Historical level 2005–2050: 1%/year expansion	2005–2015: 50% higher than reference case 2015–2050: 100% higher than reference case	2000–2005: Historical level 2005–2050: 1%/year expansion	2000–2005: Historical level 2005–2050: 1%/year expansion
Rate of decline of income elasticity of demand for meat			Developed regions: 150% of reference case Developing regions: 110% of reference case	
Rate of decline of income elasticity of demand for non-meat products			Developed regions: 50% of reference case Developing regions: 90% of reference regions	

3. **Low meat demand**. This scenario is also taken from the IAASTD and is an additional variant to the reference case. In this scenario, the rate at which the demand for livestock products increases with income is slowed, over time, whereas the rate at which dietary preferences for fruits and vegetables changes is accelerated. This acts to decrease the share of meat products in the diets of the population, and strengthen preferences for non-meat products. The global slowdown in the growth of meat demand is implemented through adjustments to the way in which income demand elasticities for meat and vegetarian foods change over time. Income demand elasticities for meat products (beef, pork, poultry, sheep and goat) decline at a faster rate than they do under the reference case. Simultaneously, income demand elasticities for vegetarian foods (fruits and vegetables, legumes, roots and tubers, and cereal grains) decline at a slower pace than under the reference case, whereas the elasticities for animal products such as dairy and eggs are left the same. This happens globally using a differentiated set of multipliers for developed vs. developing regions, and assumes that the slowdown in meat demand is stronger in the developed regions, compared to that in developing regions. Regional average income demand elasticities for meat and non-meat foods are shown in Table 18 for the aggregate regions used in the IAASTD study. The effect, in general, is that the meat income demand elasticities in developed regions decline at a rate that is 150% of the baseline case, whereas those for non-meat foods decline only half as fast. In developing regions, the rates of decline are taken to be 110% and 90% of the baseline rates for the meat and non-meat commodities respectively.

Table 18. Changes to average income demand elasticities for meat and vegetarian foods by IAASTD region under low growth in meat demand

			2000	2010	2030	2050
Meat	Baseline	Central West Asia and N. Africa (CWANA)	0.7223	0.6673	0.5576	0.4806
		East and South Asia and Pacific (ESAP)	0.5538	0.5145	0.4507	0.4169
		Latin America and Caribbean (LAC)	0.5679	0.5129	0.4023	0.2914
		N. America and Europe (NAE)	0.2761	0.2402	0.1732	0.1161
		Sub-Saharan Africa (SSA)	0.8121	0.7966	0.7634	0.7221
	Low meat demand	CWANA	0.7223	0.6554	0.5253	0.4375
		ESAP	0.5538	0.4953	0.4064	0.3844
		LAC	0.5679	0.5046	0.3781	0.2562
		NAE	0.2761	0.2178	0.1227	0.0533
		SSA	0.8121	0.7931	0.7529	0.7044
Vegetarian foods	Baseline	CWANA	0.2486	0.2299	0.2063	0.2025
		ESAP	0.2243	0.2003	0.1660	0.1222
		LAC	0.1579	0.1421	0.1322	0.1324
		NAE	0.2733	0.2547	0.2235	0.1930
		SSA	0.3359	0.2775	0.2027	0.1751
	Low meat demand	CWANA	0.2486	0.2337	0.2149	0.2134
		ESAP	0.2243	0.2138	0.2046	0.1848
		LAC	0.1579	0.1436	0.1345	0.1337
		NAE	0.2733	0.2687	0.2599	0.2477
		SSA	0.3359	0.2834	0.2164	0.1887

4.4 Allocation of the FPU-level impact outputs to regions and systems

In order to redistribute the FPU-level impact outputs, a two-step process was followed using geographical information system technology. Firstly, the FPU-level data was spread out to create a continuous raster layer. In a second step this raster data was overlaid with the system layers and country boundaries, and summary statistics per country/system combination were calculated.

Spatial reallocation of FPU-level indicators to continuous rasters

All the spatial reallocations are done using existing spatially disaggregated baseline layers for the year 2000 that are most related to the IMPACT variables. For example, IMPACT maize estimates by FPU would be 'spread out' within the FPU area weighted by the best known 'sub-national or sub-FPU' maize layers available for the current situation (year 2000). The reallocations take this form:

*[re-allocated layer] = [totals per cell of the disaggregated baseline layer] * [Impact prediction per FPU]/ [sum of baseline layer by FPU]*

Livestock

IMPACT runs delivered number of animals slaughtered, milk, and eggs etc. per FPU. These were converted to numbers of live animals according to the ratio of live animals to slaughtered animals as provided by IFPRI (this ratio was assumed to be invariant to 2030). The number of live animals in the year 2000 was re-allocated within the FPU according to the FAO gridded livestock of the world 'observed' database (FAO 2007).

Crops

We used the IMPACT area and production results for wheat, rice, maize, sorghum, millet, potato, sweetpotato, and cassava. Barley had to be estimated based on results for 'other grains' and the area and production fractions covered by barley within these.

You and Wood (2004) recently completed the spatial allocation of 20 main crops grown worldwide. The pixel-scale allocations were performed through the compilation and fusion of relevant spatially explicit data, including production statistics, land use data, satellite imagery, biophysical crop 'suitability' assessments, population density, and distance to urban centres, as well as any prior knowledge about the spatial distribution of individual crops (You et al. 2007). The resulting dataset consist of global estimates of area, production and yields of rice, wheat, maize, sorghum, millet, barley, groundnuts, cowpeas, soybeans, beans, cassava, potato, sweetpotato, coffee, sugarcane, cotton, bananas, cocoa, and oil palm at a resolution of five minutes. The FPU-level crop production and area estimates from IMPACT were spread out according to these layers.

Feed from cereals

In addition to the crop–livestock numbers, the local availability of feed resources from crop residues was compared with the ruminant density. This comparison gives us a first rough estimate about local feed deficits. In combination with feed transfers/trade and overall demand (in terms of human consumption), this is the first piece of information that can feed into trade-off analysis, impact assessment and comparison of strategic interventions. In other words, this is a first step to answer questions like:

- How much grain has to be imported to meet the demand from livestock, while keeping the crop productivity constant? And where could it come from?
- What is the impact of yield increase or introduction of dual purpose crops?
- What is the impact of a drought/climate change on yield of crops, pasture productivity and hence livestock productivity?

For this study we only considered cereals. We looked at stover, brans and cakes. For stover, not only the dry matter (DM), but also metabolizable energy (ME) was calculated. Based on reallocated layers of cereals the feed supply was estimated using the following formulae:

$$\text{Stover (DM)} = \sum \frac{\text{Prod}_i * \text{c-fact}_i * \text{util}_i}{100} * \text{Dm-fact}_i$$

$$\text{Stover (ME)} = \sum \frac{\text{Prod}_i * \text{c-fact}_i * \text{util}_i}{100} * \text{Dm-fact}_i * \text{enerval}$$

$$\text{Brans (DM)} = \sum \text{Prod}_i * \text{br-fact}_i * \text{Dm-fact}_i$$

$$\text{Cakes (DM)} = \sum \text{Prod}_i * \text{bp-fact}_i * \text{Dm-fact}_i$$

With *i* $\in$ *wheat, rice, maize, sorghum, millet, barley*

$Prod_i$: production of grain in MT

$c\text{-}fact_i$: conversion factor indicating how much straw is produced compared to crop yield (derived from harvest indices)

$util_i$: utilization factor—the fact that cereals are grown in a particular area does not mean that these are actually used as feed resources. Other competing uses are as soil amendments or as fuel for cooking

br-$fact_i$: proportion of the grain that is turned into agro-industrial by-products (brans)

bp-$fact_i$: proportion of the crop yield giving by-products, e.g. oilcakes

Dm-$fact_i$: dry matter content of fresh straw

Enerval: energy value of the stover expressed in MJ/MT dry matter

It is important to note that the analysis excludes cut and carry forages, small grazing areas found in mixed systems and purchased feeds (grain supplements and purchased fodder).

Table 19. Indices used

Crop	C-fact	Utilization factor	Br-fact	Bp-fact	dm_fact	enerval
Wheat	1.3	85	0.05	0.1	0.9	9
Rice	1.4	75	0.05	0.05	0.9	7.5
Maize	2	95	0.05	0	0.9	8.2
Sorghum	3	95	0.05	0	0.9	7.4
Millet	2	95	0.05	0	0.9	7.4
Barley	1.3	95	0	0	0.9	6.6

Malnutrition

IMPACT's malnutrition output, in terms of number of malnourished (underweight) children below age five was spatially disaggregated according to the Center for International Earth Science Information Network's (CIESIN) underweight data layer (CIESIN 2005).

Water

For domestic water use, human population totals (GRUMP 2005) were used for the disaggregation. Industrial use was re-allocated according to the population numbers within the GRUMP urban area extents (Balk et al. 2004). Livestock water was spread out according to the total number of animals (bovine, small ruminants, poultry and pigs expressed in LU's). For irrigation, finally, the GMIA version 4 'hectares irrigated per cell' was used for re-allocation (Siebert et al. 2007).

Zonal statistics

A production systems layer was created (see description below) and overlaid with country boundaries and the spatially re-allocated layers to come up with totals per system per country. These totals were then further summarized by region. The definition of the regions used is presented in Appendix A.

A dynamic systems classification

This section comes mostly from Herrero et al. (2008) but has been adapted for this study.

Seré and Steinfeld (1996) developed a global livestock production system classification scheme. A method was devised for mapping the classification based on agro-climatology, land cover, and human population density (Kruska et al. 2003). The classification system can be applied in response to different scenarios of climate and population change to give very broad-brush indications of possible changes in livestock system distribution in the future. This method was recently revised by Thornton et al. (2006) and this study uses those modifications. Below is a brief outline of the data sets and methods used.

The livestock production system proposed by Seré and Steinfeld (1996) is made up of the following types of systems: landless monogastric, landless ruminant, grassland-based, mixed rainfed, and mixed irrigated systems. The grassland-based and mixed systems are further categorized on the basis of climate: arid/semi-arid (with a length of growing period < 180 days), humid/sub-humid (LGP > 180 days), and tropical highlands-temperate regions. This gives 11 categories in all. This system has been mapped using the methods of Kruska et al. (2003).

This classification has been used previously in poverty and vulnerability analyses (Thornton et al. 2002, 2006), for prioritizing animal health interventions (Perry et al. 2003) and for studying systems changes in West Africa (Kristjanson et al. 2004). It is used in this study for disaggregating methane emissions by production systems, which have different land areas, population densities, number of livestock, diets for ruminants and may evolve at different rates.

The Seré and Steinfeld livestock system classification says little about the location of intensive and/or industrial agricultural systems. This breakout is, however, very important for several reasons: systems exist that may be expected to undergo rapid technological change, or exhibit rapid uptake of technology, or be particularly susceptible to the diseases of intensification and/or the emergence of new disease risks.

We therefore implemented a classification that includes a measure of intensification potential.

1. Agropastoral and pastoral systems, in which natural resources are constrained and people and their animals adopt adaptation strategies to meet these constraints.

2. Mixed crop–livestock systems, in which natural resources are most likely to be extensively managed.

3. Mixed crop–livestock systems, in which natural resources can be managed to intensify the productivity of the system.

4. Others, which includes an amalgamation of all the others, e.g. urban, forest-based and landless systems.

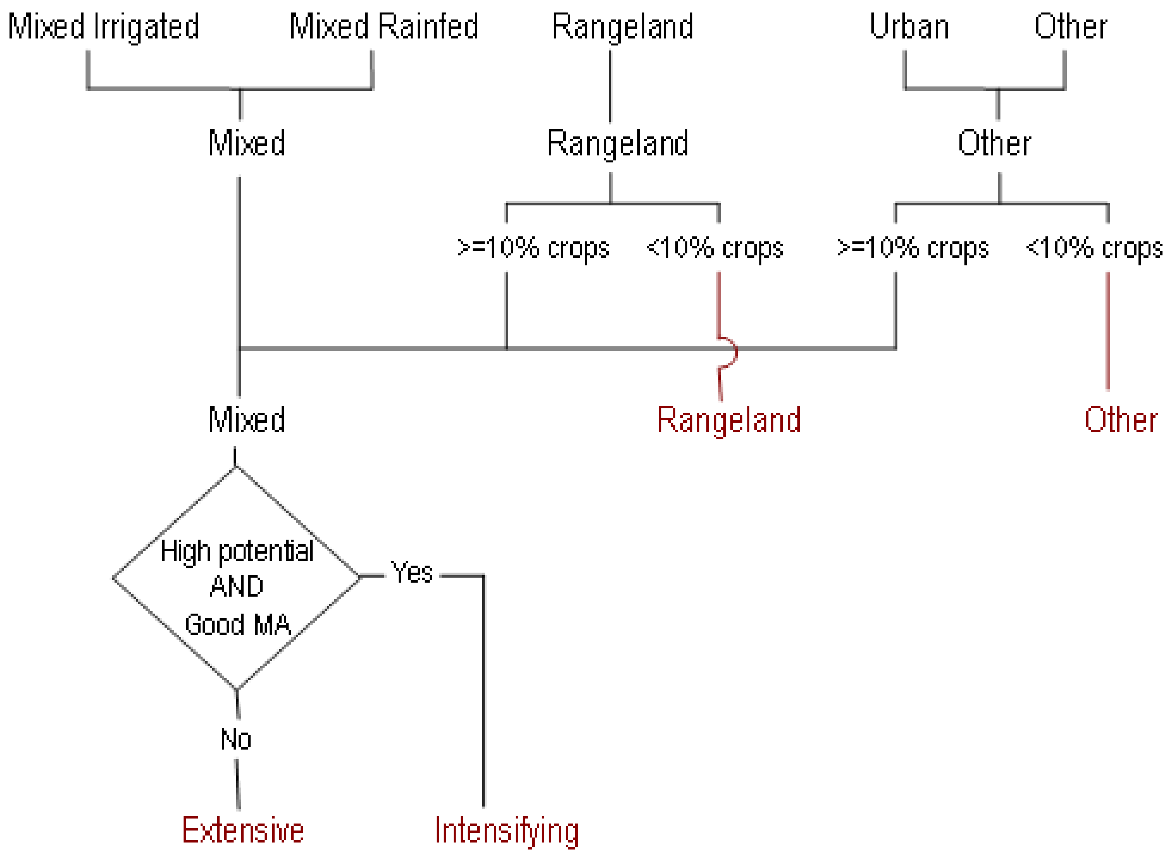
The agropastoral/pastoral systems correspond to the three rangeland-based categories (LGA, LGH, LGT) of Seré and Steinfeld where simultaneously less than 10% of the total land area is covered by crops (according to the crop layers from You and Wood 2004).

The crop–livestock systems correspond to the six mixed rainfed and mixed irrigated (MR and MI, both by arid/semi-arid, humid/sub-humid, and temperate/highland) categories of Seré and Steinfeld together with all the areas that have more than 10% of the area under crop (according to the crop layers from You and Wood 2004).

To derive the mixed 'intensifying' systems, we added two indicators, one to do with relatively high agricultural potential, and another one related to market access, on the basis that mixed systems that are in high-potential areas and 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 Seré and Steinfeld) 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 eight hours. We used the travel time to urban centres with a population of more than 250,000 inhabitants. The distinction between extensive and intensive systems presented here is looking at potential intensification.

The flow chart below (Figure 28) shows the process of deriving the different production system categories starting from Seré and Steinfield.

Figure 28. *Flow chart of the process used in establishment of the production systems*

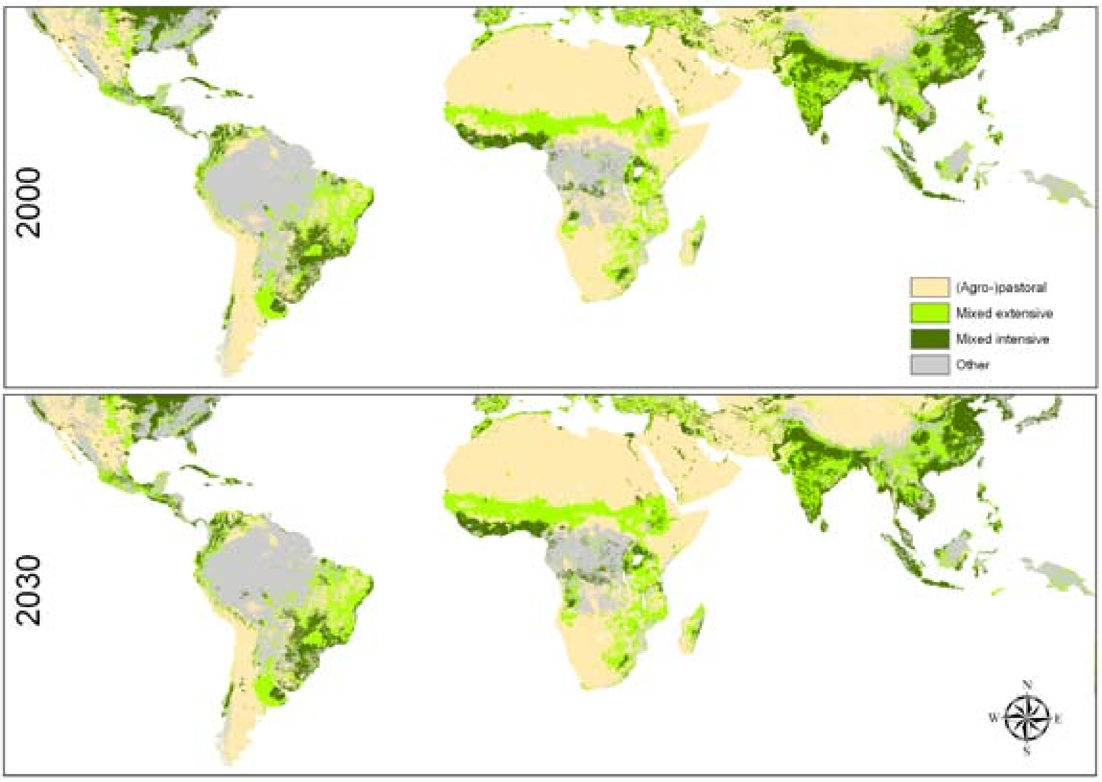


5 Results

5.1 Farming systems and the distribution of human population

The distribution of farming systems, as classified for this study, can be observed in Figure 29. Table 20 also shows the area and human population by system and region.

Figure 29. The distribution of farming systems, as classified for this study, for 2000 and 2030



Grazing systems occupy the largest area on earth. Relative to crop–livestock systems, they occupy more than double the land. SSA, West Asia and North Africa have the largest areas of pastoral and agropastoral 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.

Mixed intensive systems have the lowest land area but they contain more than half of the world's population (2.6 billion). This very high population will increase by almost a billion people by 2030 while remaining virtually with the same amount of land. Population growth elsewhere will also increase significantly to the point that people living in mixed systems (both intensive and extensive) will comprise roughly 80% of the global population. The large population densities in these systems place, and will keep on doing so, a very high pressure on agro-ecosystem services, notably on food production, water resources, and biodiversity. Although larger in area, agropastoral systems will also become more densely populated, possibly leading to increased land fragmentation and the subsequent loss of traditional livelihood strategies, especially in SSA. These aspects have been documented by Reid et al. (2008).

Table 20. Farming systems: area and human population for different regions of the world under alternative scenarios to 2030

Farming system	Region	Area 2000 (10^6 km^2)	Area 2030 (10^6 km^2)	Population 2000 (10^6 people)	Population 2030 (10^6 people)
(Agro-) pastoral	CSA	5.4	5.4	40.5	65.8
	EA	5.5	5.5	41.3	53.6
	SA	0.5	0.5	19.2	34.8
	SEA	0.2	0.2	2.2	3.0
	SSA	13.4	12.5	80.2	140.8
	WANA	10.2	10.1	111.7	199.3
Total		**35.2**	**34.3**	**295.1**	**497.3**
Mixed extensive	CSA	3.5	3.6	100.7	155.2
	EA	1.7	1.9	195.4	264.6
	SA	1.6	1.6	371.9	543.6
	SEA	1.2	1.0	85.3	92.0
	SSA	5.1	5.8	258.7	484.8
	WANA	0.9	0.9	87.2	129.9
Total		**14.0**	**14.9**	**1099.2**	**1670.0**
Mixed intensive	CSA	2.4	2.4	221.2	286.3
	EA	2.3	2.1	938.5	1020.5
	SA	1.8	1.8	844.6	1248.9
	SEA	1.1	1.3	347.2	499.1
	SSA	1.5	1.7	168.2	327.1
	WANA	0.6	0.6	154.4	257.6
Total		**9.8**	**9.8**	**2674.0**	**3639.5**
Other	CSA	8.8	8.8	125.8	174.0
	EA	1.5	1.5	104.2	111.7
	SA	0.4	0.4	69.5	103.4
	SEA	1.9	1.9	40.4	57.9
	SSA	4.1	4.1	109.2	190.3
	WANA	0.2	0.2	31.3	45.0
Total		**16.9**	**16.8**	**480.3**	**682.3**

Key: CSA: Central and South America; EA: East Africa; SA: South Asia; SEA: South East Asia; SSA: sub-Saharan Africa; WANA: West and North Africa.

There are large differences between regions and systems. These reflect the variability in agricultural potential, population densities and access to markets of 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 Central and South America, while in South and East Asia, land availability per capita is a constraint. SSA has suitable land for increased intensification but constraints like lack of investment, markets and service provision prevent better utilization of these 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.

Other systems, such as forests, occupy significant land areas, notably in Latin America and SSA. As demand for food, feed, and energy increase, these areas, usually with very high agricultural potential but somewhat poor market access, become under significant pressure to convert to agriculture and livestock to satisfy the needs of people living in other rural systems or in the increasingly populated urban areas.

5.2 World food prices

World food prices are presented in Table 21 and are taken directly from IAASTD.

With the exception of milk, the prices of crops and livestock products will increase significantly to 2030 as a result of competing demands (e.g. food, feed and fuel), and production factors (e.g. lack of water, nutrients and low animal productivity in some regions).

The largest price increases are observed in cereals, some oil crops, and tubers like sweet potato where demand comes from multiple sources, notably from the feed industry and the energy sector (first generation biofuels). For example, the prices of maize, wheat, sorghum, sweet potato and oil grains is likely to more than double by 2030. It is important to note that all mandate crops for the CGIAR are the ones experiencing the largest price increases. At the same time these are the ones with potential for developing dual or triple purpose crop varieties.

Under the biofuel scenario, with increasing demands for grains for energy production, some of these prices, notably maize and oil grains, increase dramatically. This will have serious repercussions for poor consumers whose food security will be compromised as they will not have the ability to purchase basic staples.

The prices of animal products are also likely to increase but less so, as a result of less sources of competing demands, in this case only a fraction of the increasing human population, and the relative change in demand relative to the change in supply. Livestock breeds that are more efficient in converting feeds to animal products will experience lower price increases since they buffer the increased needs for feeds through increasing productivity per animal. This is particularly true for poultry and pigs, and for milk production, all of which can be produced in larger volumes by relatively modest modifications in the quality of diet. In the case of small ruminants, an increased supply from pastoral and mixed systems will lower price increases relative to other products.

Even though the relative price increases of animal products are lower, with the exception of milk, the baseline prices are higher. Although incomes are increasing, this also has important repercussions for the poorer communities which, apart from milk and perhaps eggs and poultry, will have difficulty in accessing other sources of animal protein. Beef and lamb, with their inefficient production and substantial use of natural resources (water and land), will become almost niche markets for the rich in developing countries.

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Table 21. World food prices by scenario

World food prices ($/ton)										
							% change from 2000 prices			
	2000	baseline 2030	biofuels 2030	irrigation expansion 2030	low meat demand 2030		baseline 2030	biofuels 2030	irrigation expansion 2030	low meat demand 2030
beef	1917	2435	2527	1919	2461		27	32	0	28
pork	906	1109	1165	855	1124		22	29	-6	24
lamb	2705	3089	3164	2072	3110		14	17	-23	15
poultry	1196	1403	1495	1649	1427		17	25	38	19
eggs	761	810	848	591	820		6	12	-22	8
milk	302	264	273	207	266		-13	-10	-31	-12
rice	185	284	324	281	297		54	75	52	61
wheat	109	216	268	236	232		97	145	115	112
maize	91	203	347	240	231		121	279	162	152
ogrn	68	181	266	218	207		165	289	219	203
soybeans	206	327	332	301	315		59	61	46	53
potatos	213	325	373	363	343		53	75	71	61
sweet potatos	472	1105	1376	1410	1201		134	192	199	155
cassava	65	125	163	152	134		93	152	135	107
meal	195	292	312	137	297		50	60	-29	53
oils	481	721	919	390	730		50	91	-19	52
vegetables	434	530	619	592	590		22	42	36	36
subf	344	514	551	543	524		50	60	58	52
temf	354	575	651	623	617		62	84	76	74
sugar cane	271	465	596	512	494		72	120	89	83
sugar beet	267	390	410	426	413		46	54	59	54
millet	255	485	578	595	512		90	127	134	101
sorghum	93	234	297	290	251		152	220	213	171
chickpea	534	863	1238	1224	1118		62	132	130	110
pigeon pea	470	790	911	876	825		68	94	87	76
groundnut	431	823	999	794	870		91	132	84	102
cotton	1258	1396	1482	1389	1423		11	18	10	13
other	220	602	777	622	638		174	254	183	191
swtn	214	202	213	180	206		-6	-1	-16	-4

US Census Bureau (2010).

5.3 Livestock numbers and their production under alternative scenarios 2000–2030

Distribution of cattle and its production

Figure 30 presents the density of ruminants for 2000 and projected to 2030 for the baseline scenario. Table 22 shows changes in their numbers under different scenarios while Tables 23, 24, and 25 present their production of milk, beef and lamb, respectively.

Most cattle are in the mixed crop–livestock systems, with the highest numbers in the most intensive systems. Due to the relatively small area they occupy, their density is very high, as with human population. In contrast, agropastoral systems have a large number of cattle but also distributed in a much larger area. Animal densities in mixed systems are close to five to sixfold to those of the pastoral areas. This is partly due to the agro-ecological conditions of agropastoral areas which support fewer animals and to the more intensive feeding practices employed in mixed systems. Intensification of cattle production needs not to be mediated by increased use of land in these systems. This is a key characteristic of animal production systems.

Table 22. Bovine numbers by farming system under different scenarios 2000–2030

NAME	REGION	Cattle 2000 (10^6 of LU)	Baseline 2030 (10^6 of LU)	Biofuels 2030 (10^6 of LU)	Irrigation expansion 2030 (10^6 of LU)	Low meat demand 2030 (10^6 of LU)
(Agro-) pastoral	CSA	64.18	95.28	93.74	96.59	94.84
	EA	12.67	23.56	23.34	26.95	23.49
	SA	6.19	7.83	7.80	9.43	7.82
	SEA	1.70	2.57	2.54	3.21	2.56
	SSA	36.68	37.03	36.65	40.04	36.92
	WANA	8.46	10.61	10.50	11.01	10.58
Total		129.88	176.88	174.57	187.22	176.21
Mixed extensive	CSA	67.24	109.04	106.73	109.73	108.40
	EA	20.32	44.72	44.29	51.08	44.57
	SA	71.96	73.30	70.75	92.09	72.54
	SEA	10.20	14.30	14.13	17.57	14.26
	SSA	55.53	70.16	69.19	76.25	69.90
	WANA	5.32	5.64	5.53	5.83	5.61
Total		**230.55**	**317.17**	**310.61**	**352.54**	**315.27**
Mixed intensive	CSA	69.43	99.26	97.65	100.61	98.83
	EA	34.38	63.08	62.47	72.03	62.88
	SA	109.52	118.46	115.10	145.93	117.45
	SEA	13.84	25.06	24.72	30.73	24.97
	SSA	11.71	15.97	15.80	17.09	15.92
	WANA	6.01	7.31	7.22	7.36	7.29
Total		**244.89**	**329.14**	**322.97**	**373.75**	**327.34**
Other	CSA	41.83	63.79	63.09	65.14	63.60
	EA	9.79	19.26	19.07	21.96	19.19
	SA	8.65	9.59	9.31	11.77	9.50
	SEA	7.07	11.08	10.93	13.81	11.05
	SSA	6.77	9.03	8.94	9.66	9.01
	WANA	1.39	1.46	1.43	1.51	1.45
Total		**75.50**	**114.20**	**112.78**	**123.85**	**113.80**
Total—all regions	CSA	242.68	367.38	361.22	372.08	365.67
	EA	77.16	150.62	149.17	172.01	150.13
	SA	196.32	209.18	202.96	259.20	207.31
	SEA	32.80	53.01	52.32	65.33	52.84
	SSA	110.69	132.19	130.58	143.04	131.75
	WANA	21.18	25.03	24.68	25.71	24.92
	Others	280.94	278.67	274.26	271.59	277.35

Table 23. Milk production by farming system under different scenarios 2000–2030

Farming system	Region	Milk in 2000 (10^3 MT)	Baseline 2030 (10^3 MT)	Biofuels 2030 (10^3 MT)	Irrigation expansion 2030 (10^3 MT)	Low meat demand 2030 (10^3 MT)
(Agro-) pastoral	CSA	12,615.9	16,880.9	16,610.8	19,650.7	16,801.4
	EA	2207.8	6207.9	6161.0	4085.8	6194.8
	SA	5578.3	9558.7	9187.6	13,906.6	9444.4
	SEA	90.5	226.3	218.6	283.8	224.0
	SSA	8522.4	13,487.5	13,160.2	9390.7	13,386.5
	WANA	13,265.0	23,117.6	22,482.1	26,126.6	22,924.7
Total		**42,279.9**	**69,479.0**	**67,820.4**	**73,444.1**	**68,975.8**
Mixed extensive	CSA	16,330.7	24,651.7	24,223.8	27,784.8	24,526.8
	EA	2901.0	10,112.4	10,049.5	6117.1	10,095.4
	SA	37,623.4	68,374.0	66,403.2	115,516.3	67,783.8
	SEA	682.8	1,384.9	1337.8	1349.1	1370.5
	SSA	7666.6	17,160.5	16,709.8	10,369.3	17,021.8
	WANA	7961.4	12,166.9	11,811.1	13,255.7	12,057.2
Total		**73,166.0**	**133,850.4**	**130,535.2**	**174,392.3**	**132,855.5**
Mixed intensive	CSA	16,845.7	23,683.5	23,271.8	26,651.1	23,566.1
	EA	6487.5	18,394.1	18,283.4	10,982.4	18,364.3
	SA	63,395.4	112,489.1	108,998.6	183,469.2	111,435.3
	SEA	802.0	2106.0	2034.5	2290.5	2084.1
	SSA	1956.3	4555.5	4432.4	2632.9	4517.8
	WANA	6527.7	10,547.6	10,301.9	12,906.6	10,476.0
Total		**96,014.7**	**171,775.8**	**167,322.6**	**238,932.6**	**170,443.5**
Other	CSA	11,597.4	16,749.8	16,510.5	19,469.7	16,679.5
	EA	1524.2	4539.9	4510.3	2795.6	4531.9
	SA	5303.8	9398.0	9100.7	15,235.8	9308.1
	SEA	401.4	931.9	900.2	1151.7	922.2
	SSA	986.3	1875.6	1828.7	1185.6	1861.2
	WANA	1933.7	2835.9	2748.5	3264.0	2809.0
Total		**21,746.8**	**36,331.2**	**35,599.1**	**43,102.4**	**36,111.7**
Total (all systems)	CSA	57,389.7	81,966.0	80,617.0	93,556.3	81,573.7
	EA	13,120.5	39,254.3	39,004.2	23,980.8	39,186.4
	SA	111,900.9	199,819.9	193,690.2	328,127.9	197,971.7
	SEA	1976.8	4649.1	4491.1	5075.0	4600.7
	SSA	19,131.6	37,079.2	36,131.1	23,578.6	36,787.2
	WANA	29,687.8	48,668.0	47,343.7	55,552.9	48,266.8
	Others	341,390.70	394,215.70	395,351.10	365,878.20	394,334.50

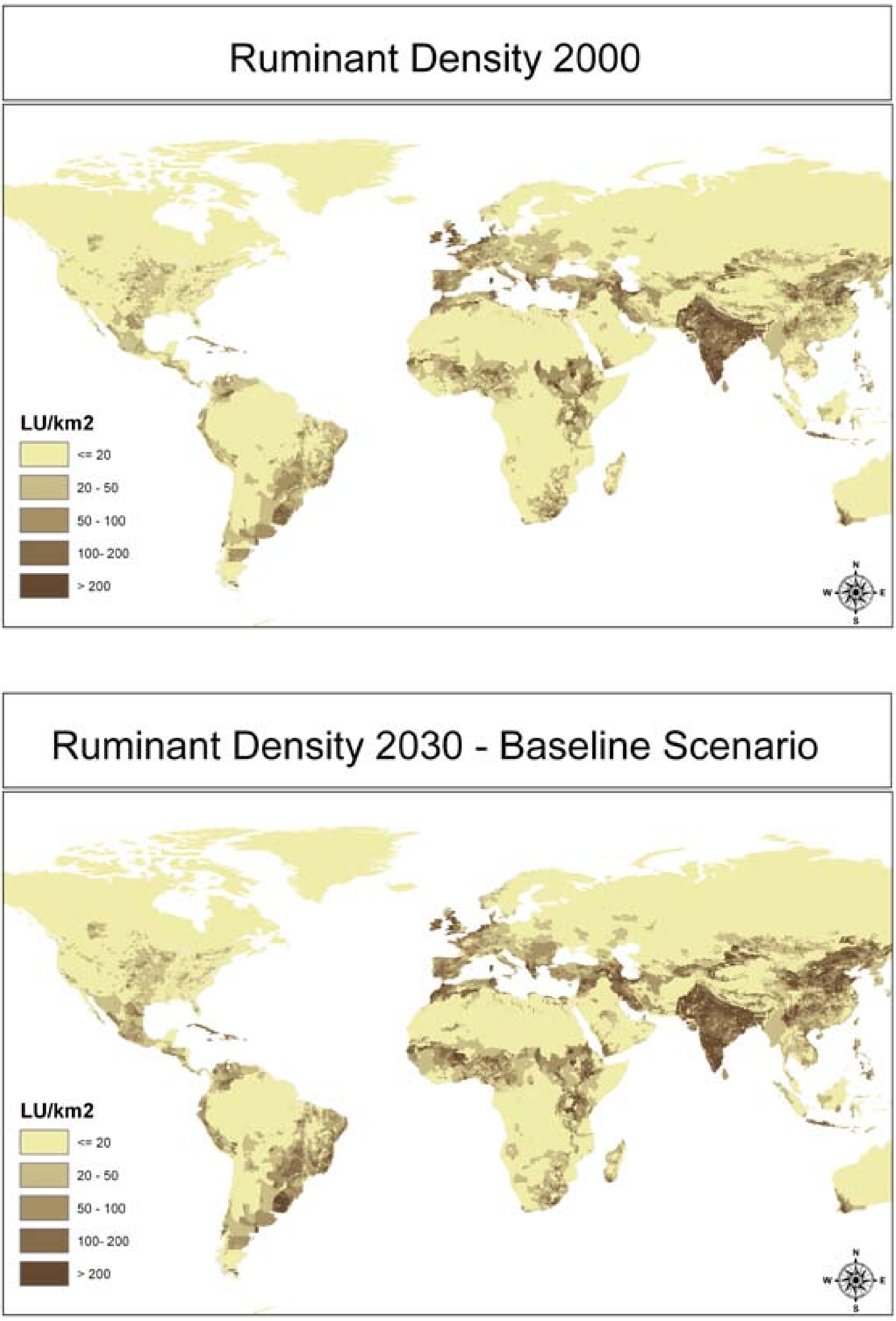
Table 24. Meat production by farming system under different scenarios 2000–2030

Farming system	Region	Beef in 2000 (10^3 MT)	Baseline 2030 (10^3 MT)	Biofuels 2030 (10^3 MT)	Irrigation expansion 2030 (10^3 MT)	Low meat demand 2030 (10^3 MT)
(Agro-) pastoral	CSA	2925.68	5826.19	5720.10	6508.20	5795.97
	EA	378.08	991.94	982.82	1255.21	988.91
	SA	127.32	307.83	306.51	451.06	307.30
	SEA	36.86	78.96	78.03	111.93	78.75
	SSA	1131.31	1617.45	1598.97	1937.03	1612.15
	WANA	736.93	1316.94	1299.53	1619.10	1311.82
Total		**5336.17**	**10,139.32**	**9985.96**	**11,882.53**	**10,094.90**
Mixed extensive	CSA	3899.88	8711.59	8517.63	9722.99	8657.10
	EA	1311.61	4180.59	4140.22	5276.93	4166.95
	SA	1375.69	2512.21	2429.86	3702.87	2487.39
	SEA	379.24	732.48	722.63	1028.57	729.91
	SSA	1596.54	2752.78	2710.77	3224.50	2741.35
	WANA	461.34	769.49	755.03	948.27	765.07
Total		**9024.30**	**19,659.14**	**19,276.14**	**23,904.13**	**19,547.78**
Mixed intensive	CSA	3995.29	8061.34	7905.12	9071.10	8018.66
	EA	2962.62	7694.97	7620.40	9709.88	7669.75
	SA	2393.55	4532.19	4423.76	6681.18	4499.03
	SEA	566.32	1570.71	1547.14	2278.58	1564.43
	SSA	392.52	719.54	711.73	834.67	717.37
	WANA	563.71	1050.38	1036.17	1244.39	1046.16
Total		**10,874.01**	**23,629.13**	**23,244.32**	**29,819.79**	**23,515.40**
Other	CSA	2565.13	5269.06	5182.30	5903.04	5244.82
	EA	667.25	1883.98	1865.89	2374.92	1877.89
	SA	202.37	404.68	394.08	582.25	401.44
	SEA	200.20	499.87	492.55	730.79	497.96
	SSA	227.26	400.84	396.65	476.20	399.64
	WANA	137.37	228.37	223.55	282.80	226.89
Total		**3999.57**	**8686.79**	**8555.02**	**10,350.02**	**8648.65**
Total (all systems)	CSA	13,385.97	27,868.18	27,325.15	31,205.33	27,716.56
	EA	5319.56	14,751.48	14,609.33	18,616.94	14,703.50
	SA	4098.93	7756.91	7554.22	11,417.36	7695.17
	SEA	1182.62	2882.02	2840.34	4149.88	2871.05
	SSA	3347.63	5490.62	5418.12	6472.40	5470.51
	WANA	1899.34	3365.18	3314.28	4094.56	3349.94
	Others	29,346.90	36,106.80	35,519.30	37,501.90	35,932.20

Table 25. Livestock production, farming systems vs. lamb production

Farming system	Region	Lamb in 2000 (10^3 MT)	Baseline 2030 (10^3 MT)	Biofuels 2030 (10^3 MT)	Irrigation expansion 2030 (10^3 MT)	Low meat demand 2030 (10^3 MT)
(Agro-) pastoral	CSA	155.4	303.0	299.7	362.1	302.1
	EA	1119.6	3108.2	3090.4	3826.9	3104.5
	SA	190.0	486.2	480.8	590.1	484.6
	SEA	2.5	6.7	6.7	8.2	6.7
	SSA	543.4	1031.0	1032.0	1342.0	1031.1
	WANA	1091.2	2139.1	2099.5	2563.2	2127.9
Total		**3102.0**	**7074.2**	**7009.2**	**8692.5**	**7056.9**
Mixed extensive	CSA	98.3	219.4	218.0	263.3	219.0
	EA	456.7	1547.0	1537.6	1909.5	1545.0
	SA	423.6	1078.5	1081.9	1482.5	1079.4
	SEA	22.6	49.2	49.4	65.5	49.3
	SSA	546.7	1225.0	1226.6	1536.0	1225.1
	WANA	434.7	787.6	772.9	954.1	783.4
Total		**1982.5**	**4906.7**	**4886.5**	**6210.8**	**4901.3**
Mixed intensive	CSA	64.3	132.4	131.0	161.4	132.0
	EA	1036.3	2713.6	2696.8	3353.2	2710.1
	SA	680.4	1665.8	1666.6	2190.1	1666.0
	SEA	77.2	195.4	196.7	260.2	195.7
	SSA	178.1	365.0	365.5	430.0	365.1
	WANA	300.6	571.7	561.5	692.6	568.8
Total		**2336.9**	**5643.9**	**5618.0**	**7087.4**	**5637.7**
Other	CSA	84.5	190.6	187.7	227.6	189.8
	EA	242.9	688.4	684.3	848.9	687.5
	SA	71.7	182.6	182.0	236.1	182.4
	SEA	13.8	35.2	35.4	45.6	35.2
	SSA	73.1	164.0	164.3	199.6	164.0
	WANA	70.9	121.0	119.0	150.1	120.4
Total		**557.0**	**1381.7**	**1372.6**	**1707.9**	**1379.4**
Total (all systems)	CSA	402.5	845.5	836.4	1014.3	843.0
	EA	2855.4	8057.3	8009.1	9938.5	8047.1
	SA	1365.7	3413.0	3411.3	4498.9	3412.5
	SEA	116.1	286.4	288.1	379.5	286.9
	SSA	1341.3	2785.0	2788.5	3507.5	2785.3
	WANA	1897.4	3619.3	3552.8	4360.0	3600.5
	Others	3167.84	4919.87	4848.88	5439.51	4897.17

Figure 30. Density of ruminants 2000–2030 for the baseline scenario



In the intensive crop–livestock systems, the largest numbers of cattle are in East and South Asia and in Latin America. The last two regions also have significant numbers of animals in mixed extensive systems. Most cattle in SSA are in extensive agropastoral and mixed systems.

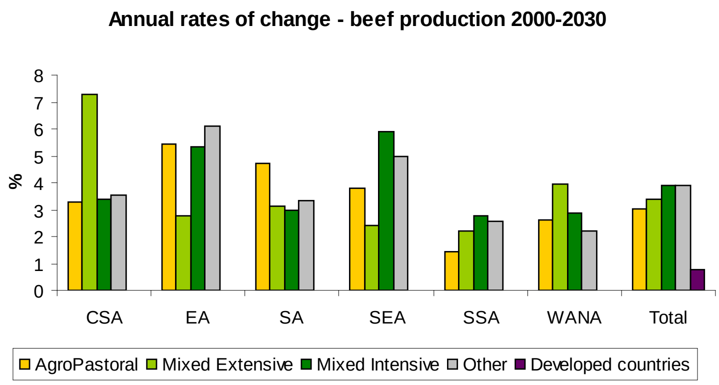
In terms of production, a similar trend follows. Most of the milk and meat are produced in mixed crop–livestock systems but there are important regional differences in this observation. Latin America, WANA and SSA produce large volumes of meat from extensive agropastoral and mixed systems. In contrast, most beef in different Asian regions is also produced in the mixed systems. Milk, on the other hand, is largely produced in the most intensive mixed systems in each region, with the notable example of WANA where most milk comes from pastoral systems.

Milk and beef—Scenarios to 2030

Cattle numbers are projected to increase between 31 and 49% under the reference scenario depending on the systems. The largest growth rates will be observed in the most extensive systems (agropastoral and mixed extensive). These have more land and feed resources to accommodate these changes, though their ecosystem balance is fragile, especially in the more arid areas. There are marked differences between regions in the growth rates of cattle numbers. Though their cattle populations are not the highest relative to their land area, cattle numbers in East Asia are predicted to roughly double by 2030 across all systems. This is a result of the sharp rise in demand caused by economic growth and diet changes towards more animal products of the East Asia human population. Large increases will also be observed in Latin America, through a mixture of increases in the productivity of animals and area expansion. The Latin American beef industry has been often under criticism due to its link with deforestation in the humid tropics, though most recently expansion of soybean cultivation has been an important cause of this phenomenon, particularly in Brazil (see Box 1).

In terms of milk and beef production, rates of growth outpace the rates of growth of animal numbers, suggesting increases in the technical efficiency for producing these two commodities. Nevertheless, most growth is still mediated through increases in animal numbers. This happens across systems, but is particularly evident in the intensive crop–livestock systems, where milk production is projected to increase by 64% by 2030 under the baseline run and more than double if irrigation expansion were to occur. Dramatic increases are observed across Asia and less so in Latin America and WANA. Mixed extensive systems in general will also experience very high rates of growth in milk production, as well as some agropastoral systems (i.e. EA, SEA, SSA). A similar trend as with milk occurs with beef, but with higher growth rates observed in the pastoral and mixed extensive systems than in the mixed extensive systems, although across Asia the mixed intensive systems will also increase drastically meat production. Note that growth rates in the developing world are far higher than in the developed countries (Figure 31).

Figure 31. Rates of growth in meat and milk production under the references scenario 2000–2030



Since the biofuels scenario employed in this study does not consider second generation biofuels like stovers, which would compete with feeds for ruminants, the animal numbers predicted to 2030 are not very different from the results of the reference run to 2030. This might be an over-estimation in this study, and is also partly an artefact of the IMPACT model which is based on grain trade and does not consider fodder requirements for ruminants (see section on feeds in the next pages).

Box 1. Soybeans and beef, deforestation and conservation in the Amazon

The drivers of Amazon deforestation have recently shifted from Brazil's domestic economy and policies to the international market. Surges in deforestation in the early 2000s were primarily due to annual growth of around 11% of the national cattle herd. The causes of this expansion include progress in eradicating foot-and-mouth disease (FMD), devaluation of the Brazilian currency, bovine spongiform encephalopathy (BSE) outbreaks in Europe, and improvements in beef production systems. A key change was the conferring of FMD-free status that allowed the export of beef outside the Amazon. Improvements in the health, productivity, and 'traceability' of the Amazon cattle herd and the trend toward trade liberalization coincide with growing international demand for open-range beef. BSE has expanded markets for open-range, grass-fed cattle, such as produced in the Amazon, because of health concerns associated with ration-fed systems of cattle production.

Soybean expansion into the Amazon began in the late 1990s as new varieties were developed that tolerated the moist, hot Amazon climate and as a worldwide shortage of animal-feed protein boosted soybean prices. This prompted substantial investment in soybean storage and processing facilities in the region. The production of soybeans in the closed-canopy forest region of the Amazon increased 15% per year from 1999 to 2004. The EU became an important new market for these soybeans. These trends were enhanced by the devaluation of the Brazilian Real. The expansion of the Brazilian soybean industry into the Amazon may have driven expansion of the Amazon cattle herd indirectly through its effect on land prices, which have increased five to tenfold in some areas. The overarching trend in Brazil is continued agro-industrial expansion, with the threat of sustaining the high levels of Amazon deforestation seen in 2002–2004, caused by several economic teleconnections that will have an increasingly important role in driving Amazon land-use activities. These teleconnections drove up demand for Brazilian beef and soybean as the value of the Brazilian Real plummeted, lowering the price of Brazilian commodities in the international marketplace.

The conservation opportunities presented by Brazil's agro-industrial growth are found in the growing pressures on soy farmers and cattle ranchers from a range of players, to reduce the negative ecological and social impacts of their production systems. Finance institutions in Brazil are developing environmental and social standards and beginning to apply these standards as conditions of loans to the private sector. Importing countries, especially in the European Union, are also applying pressure, although some of these concerns have an element of protectionism as well. There are also pressures from within Brazil, as consumers demand beef produced with lower environmental and social impacts.

Reduction of the environmental and social costs of ranching and agro-industrial expansion in the Amazon might be achieved through a threefold program that:

- forces producers to comply with ambitious environmental legislation through improved monitoring and enforcement capacity among government agencies.
- rewards compliance through socio-environmental certification that facilitates access to lucrative international and domestic markets and to the credit of finance institutions.
- adopts an FMD-type model of zoning to prevent runaway expansion of cattle ranching and agro-industry into inappropriate areas. The considerable transaction costs of certification might be reduced by certifying zones of producers, instead of individual properties.

In those Amazon regions where cattle ranching and agro-industry are highly lucrative, it will be difficult to achieve forest conservation purely through command-and-control approaches. By restricting access to world markets to those producers who implement sound environmental management of their properties in regions with effective land-use zoning systems, the rainforest 'hamburger connection' denounced two decades ago could become an important new mechanism for protecting, not destroying, the world's largest tropical rainforest.

Under a biofuels scenario that considered reductions in the availability of stovers, fewer ruminants are likely to be able to be maintained. In contrast, the irrigation expansion scenario increases ruminant numbers in all systems, but more sharply in the mixed intensive systems, which include the irrigated areas of the world. Noticeable large increases would occur in South Asia as a result of large irrigation expansion in this region. This is a result of a boost in supply and lower prices generated by an increased availability of food and feed for humans and livestock. The scenario of low meat demand does not affect cattle numbers drastically in comparison to the baseline run as the prices of beef are higher than those of monogastrics and milk. A similar trend is observed for milk and meat production under the alternative scenarios, with the difference that under irrigation scenario, the technological efficiency for meat production is also higher and therefore yields higher rates of production than in the other scenarios.

Numbers and production of small ruminants under different scenarios

Small ruminants are more numerous in agropastoral areas than elsewhere. SSA, East Asia and WANA have the highest numbers in these systems, which are predominantly semi-arid and which have vegetation types more suited for smaller, hardier species. SSA and SA have also considerable numbers of small ruminants in the mixed extensive systems. Only in parts of South Asia, large numbers exist in mixed intensive systems.

Rates of growth in small ruminant numbers are higher than for bovines under all scenarios, with the extensive systems (agropastoral and mixed systems) having the highest rates of growth of all systems. For example, the study predicts that East Asia will almost double the number of small ruminants in agropastoral systems by 2030. Due to the rising demands of the human population, EA will also experience very high rates of growth in small ruminants in the mixed systems (i.e. China is projected to increase their growth by 4%/year). Under all scenarios lamb production will more than double across all systems. This is also a partial reflection of the lower feed demands to produce small ruminants, especially under resource constrained smallholder situations. The irrigation scenario increases production more than the other scenarios, but in this case mostly in SSA and East Asia. These kinds of differential rates of growth between cattle and small ruminants were also observed by Herrero et al. (2008) for SSA. In marginal environments, like in the semi-arid tropics, resource constraints create the need for species shifts (i.e. bovines to small ruminants) to create efficiency gains and support livelihoods adequately, while matching resources to the environment.

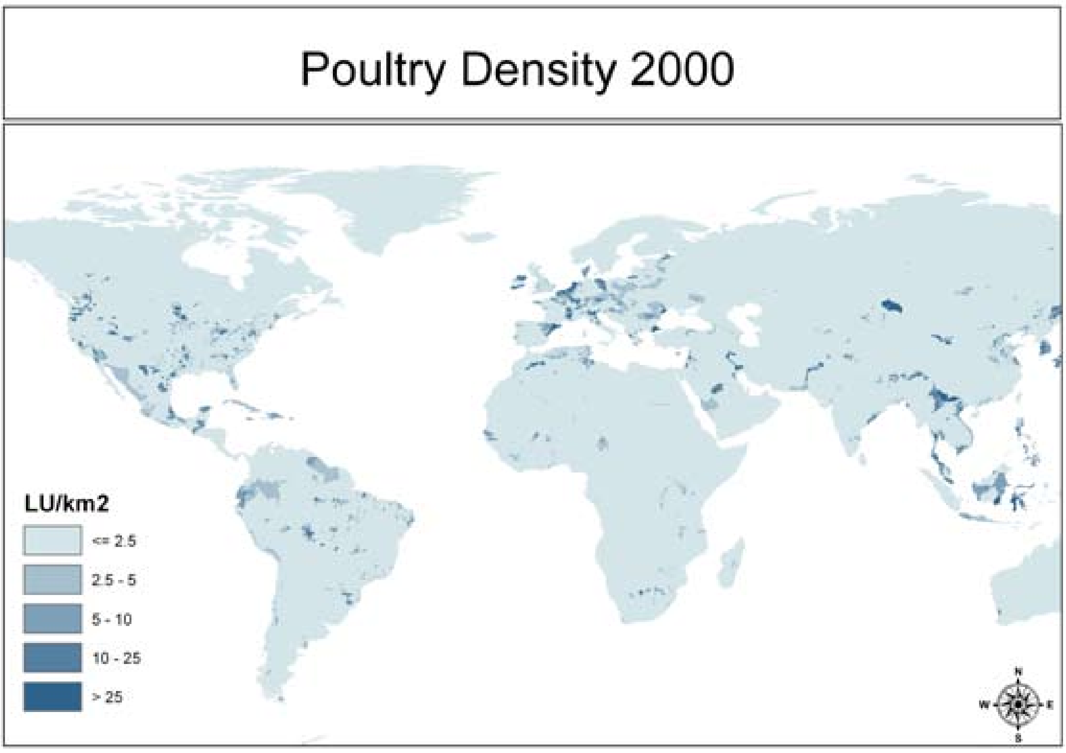
Table 26. Livestock production, farming systems vs. small ruminants

Farming system	Region	Small ruminants 2000 (10^6 of LU)	Baseline 2030	Biofuels 2030	Irrigation expansion 2030	Low meat demand 2030
(Agro-) pastoral	CSA	4.74	6.43	6.34	6.72	6.41
	EA	15.77	30.09	29.93	33.33	30.06
	SA	3.41	5.34	5.29	5.63	5.33
	SEA	0.03	0.06	0.06	0.06	0.06
	SSA	14.14	17.63	17.65	19.64	17.63
	WANA	13.58	19.98	19.58	20.80	19.87
Total		**51.67**	**79.53**	**78.85**	**86.18**	**79.35**
Mixed extensive	CSA	2.25	3.26	3.23	3.43	3.25
	EA	5.18	12.11	12.04	13.44	12.10
	SA	10.20	14.29	14.35	16.70	14.30
	SEA	0.52	0.61	0.61	0.69	0.61
	SSA	15.48	22.88	22.92	25.23	22.89
	WANA	4.57	6.62	6.49	6.92	6.58
Total		**38.18**	**59.77**	**59.63**	**66.42**	**59.73**
Mixed intensive	CSA	2.01	2.96	2.93	3.14	2.95
	EA	7.34	12.64	12.56	14.04	12.62
	SA	14.46	20.88	20.94	23.72	20.90
	SEA	1.68	2.13	2.14	2.34	2.13
	SSA	4.44	6.44	6.45	6.81	6.44
	WANA	3.35	4.81	4.71	5.04	4.78
Total		**33.28**	**49.85**	**49.74**	**55.10**	**49.82**
Other	CSA	2.53	3.75	3.68	3.92	3.73
	EA	2.34	4.60	4.57	5.09	4.59
	SA	1.33	1.98	1.98	2.22	1.98
	SEA	0.46	0.60	0.60	0.65	0.60
	SSA	1.90	2.90	2.90	3.12	2.90
	WANA	0.64	0.87	0.85	0.90	0.86
Total		**9.20**	**14.69**	**14.59**	**15.91**	**14.66**
Total—all regions	CSA	11.53	16.40	16.18	17.21	16.35
	EA	30.62	59.44	59.10	65.91	59.37
	SA	29.40	42.49	42.56	48.26	42.51
	SEA	2.69	3.40	3.42	3.74	3.40
	SSA	35.96	49.85	49.92	54.81	49.86
	WANA	22.14	32.27	31.63	33.67	32.09
	Others	37.60	45.32	44.64	45.66	45.10

Monogastrics and their production to 2030

Figure 32 shows the global density of poultry for the 2000 baseline and the reference scenario to 2030 while Tables 27–29 show poultry numbers and egg and poultry meat production under alternative scenarios. Figure 33 presents the global density of pigs while Tables 30 and 31show pig numbers and production under different scenarios, respectively.

Figure 32. Density of poultry 2000–2030 for the baseline scenario



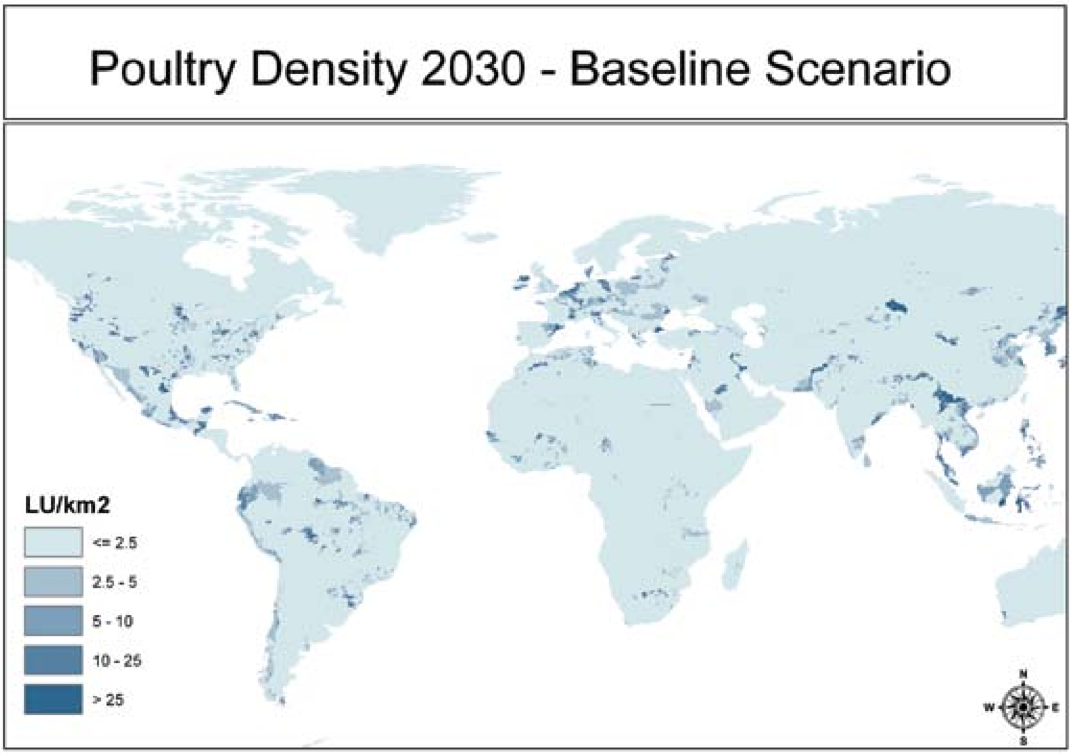
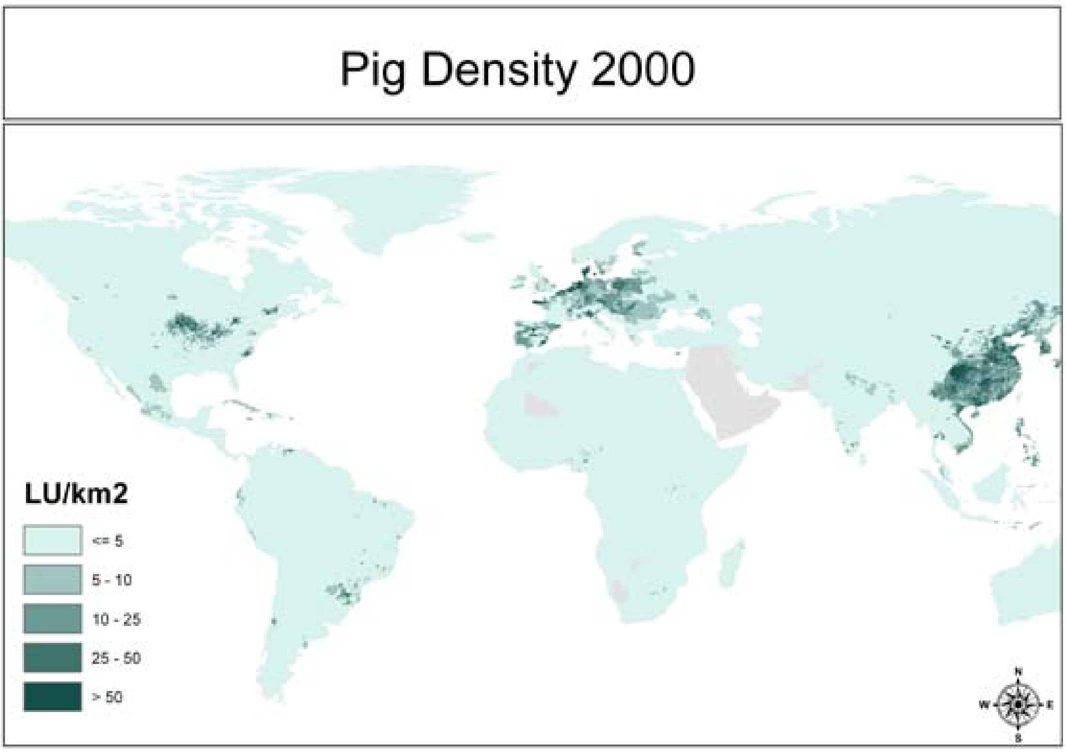


Figure 33. *Density of pigs 2000–2030 for the baseline scenario*



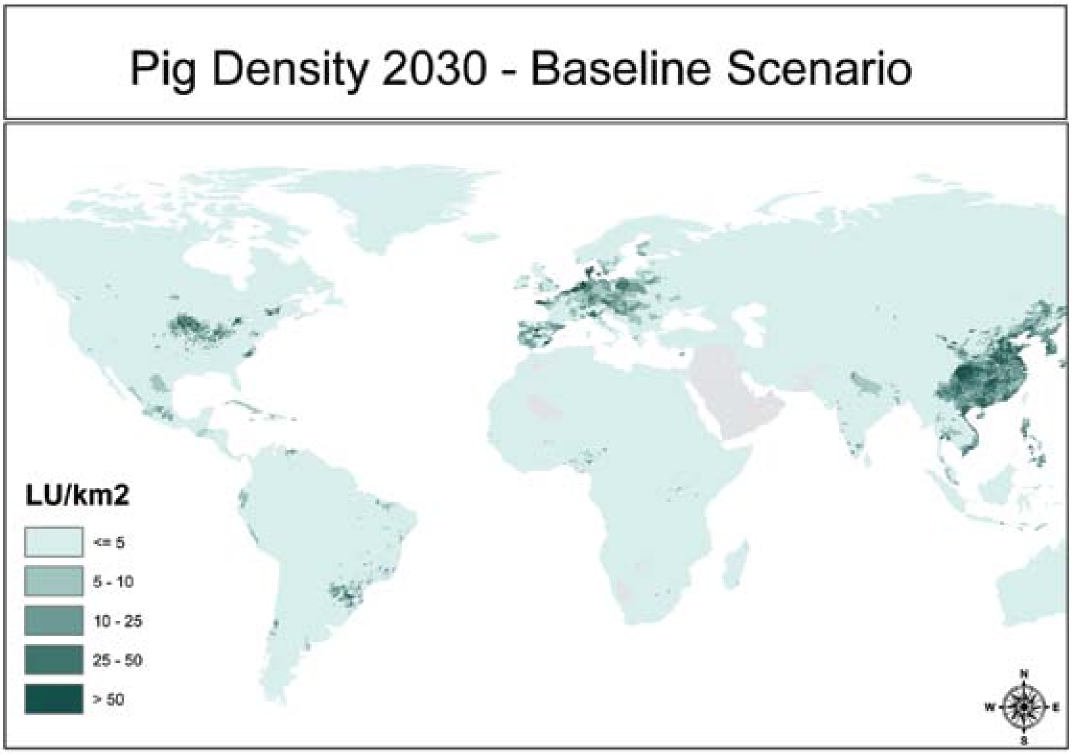


Table 27. Chicken numbers by farming system under alternative development scenarios

Farming system	Region	Poultry 2000 (10^6 of LU)	Baseline 2030 (10^6 of LU)	Biofuels 2030 (10^6 of LU)	Irrigation expansion 2030 (10^6 of LU)	Low meat demand 2030 (10^6 of LU)
(Agro-) pastoral	CSA	4.23	6.64	6.50	4.69	6.60
	EA	16.22	27.97	27.14	14.70	27.75
	SA	3.85	8.47	8.38	3.74	8.44
	SEA	0.54	1.16	1.15	0.55	1.16
	SSA	2.53	3.10	3.01	2.95	3.08
	WANA	7.07	6.54	6.27	7.02	6.46
Total		**34.45**	**53.88**	**52.45**	**33.67**	**53.49**
Mixed extensive	CSA	5.36	8.26	8.06	5.87	8.20
	EA	8.11	14.26	13.84	7.49	14.15
	SA	6.79	12.14	11.81	6.22	12.05
	SEA	3.69	3.71	3.65	2.54	3.69
	SSA	3.99	5.63	5.47	5.29	5.59
	WANA	2.62	3.72	3.56	3.31	3.67
Total		**30.56**	**47.72**	**46.39**	**30.73**	**47.36**
Mixed intensive	CSA	4.32	7.56	7.38	5.44	7.51
	EA	4.07	6.70	6.51	3.52	6.65
	SA	2.29	4.45	4.35	2.16	4.42
	SEA	8.08	11.31	11.12	9.35	11.26
	SSA	0.95	1.35	1.32	1.25	1.34
	WANA	1.86	1.16	1.11	1.24	1.15
Total		**21.58**	**32.54**	**31.79**	**22.97**	**32.34**
Other	CSA	9.02	14.37	14.02	10.34	14.27
	EA	9.76	16.84	16.35	8.85	16.71
	SA	2.27	4.92	4.90	2.18	4.91
	SEA	3.92	4.24	4.16	3.77	4.22
	SSA	0.65	0.84	0.82	0.88	0.83
	WANA	0.59	0.77	0.74	0.59	0.76
Total		**26.22**	**41.98**	**40.98**	**26.62**	**41.71**
Total—all regions	CSA	22.92	36.82	35.96	26.33	36.58
	EA	38.16	65.77	63.84	34.57	65.27
	SA	15.20	29.98	29.43	14.31	29.83
	SEA	16.24	20.41	20.08	16.21	20.33
	SSA	8.13	10.93	10.61	10.38	10.84
	WANA	12.15	12.20	11.68	12.17	12.05
	Others	89.88	139.30	135.65	87.64	138.31

Table 28. Egg production by farming system under alternative development scenarios

Farming system	Region	Eggs in 2000 (10^6 MT)	Baseline 2030 (10^6 MT)	Irrigation expansion 2030 (10^6 MT)	Low meat demand 2030 (10^6 MT)	Biofuels 2030 (10^6 MT)
(Agro-) pastoral	CSA	740.5	1136.8	1618.1	1134.1	1126.2
	EA	263.5	466.2	465.8	463.4	455.6
	SA	56.6	122.2	113.7	121.3	119.7
	SEA	26.7	56.0	82.2	55.7	54.9
	SSA	265.5	301.0	564.0	298.6	292.5
	WANA	1087.9	1724.0	1506.5	1701.1	1652.0
Total		**2440.8**	**3806.1**	**4350.3**	**3774.2**	**3700.9**
Mixed extensive	CSA	1321.5	2140.2	2877.6	2134.1	2116.9
	EA	2922.2	5641.0	5638.9	5606.6	5513.1
	SA	766.2	2058.5	2551.5	2062.7	2074.0
	SEA	512.7	784.9	1438.7	780.9	769.4
	SSA	518.5	762.5	1441.0	757.1	742.7
	WANA	578.6	772.7	637.3	762.2	739.8
Total		**6619.8**	**12,159.8**	**14,585.0**	**12,103.6**	**11,955.9**
Mixed intensive	CSA	1561.7	2282.2	3285.9	2272.1	2239.4
	EA	18,194.7	28,043.9	28,046.4	27,872.6	27,407.8
	SA	1359.8	3456.3	4121.4	3459.4	3468.4
	SEA	1810.0	3645.1	5816.0	3627.0	3575.6
	SSA	437.8	542.3	960.8	539.1	530.1
	WANA	443.8	761.5	608.6	753.1	733.1
Total		**22,246.1**	**36,449.1**	**39,553.3**	**36,251.1**	**35,714.9**
Other	CSA	1386.8	2211.2	2937.3	2207.7	2198.3
	EA	1276.2	2047.1	2072.7	2034.6	2000.4
	SA	172.0	439.1	526.2	439.5	440.6
	SEA	341.5	633.4	873.9	630.4	622.0
	SSA	100.8	125.1	225.8	124.2	121.9
	WANA	209.2	274.2	205.4	270.4	262.4
Total		**3486.4**	**5730.1**	**6841.4**	**5706.8**	**5645.6**
Total—all systems	CSA	5010.4	7770.3	10,718.9	7747.9	7680.7
	EA	22,656.6	36,198.3	36,223.9	35,977.1	35,376.9
	SA	2354.6	6076.1	7312.8	6082.8	6102.6
	SEA	2691.0	5119.4	8210.8	5094.0	5021.9
	SSA	1322.6	1730.8	3191.6	1719.0	1687.2
	WANA	2319.4	3532.4	2957.8	3487.0	3387.3
	Others	17,092.8	16,975.8	20,516.9	16,876.9	16,638.5

Table 29. Poultry production under alternative development scenarios

Farming system	Region	Poultry 2000 meat (10^6 MT)	Baseline 2030 (10^6 MT)	Irrigation expansion 2030 (10^6 MT)	Low meat demand 2030 (10^6 MT)	Biofuels 2030 (10^6 MT)
(Agro-) pastoral	CSA	1799.76	3970.70	4001.69	3948.97	3890.63
	EA	143.92	383.94	345.79	380.98	372.62
	SA	50.43	175.79	129.58	172.81	167.19
	SEA	49.07	115.57	134.25	115.35	114.53
	SSA	424.83	669.30	819.79	662.35	645.84
	WANA	1821.79	3346.56	3847.16	3303.94	3203.03
Total		**4289.80**	**8661.87**	**9278.27**	**8584.40**	**8393.84**
Mixed extensive	CSA	3043.41	7415.71	6924.89	7365.15	7229.37
	EA	1594.71	4641.80	4180.45	4606.00	4504.90
	SA	473.46	2247.95	1314.90	2244.09	2235.19
	SEA	738.98	1273.75	1358.55	1268.13	1249.70
	SSA	654.98	1381.57	1730.22	1368.38	1336.31
	WANA	714.94	1537.51	1306.04	1517.41	1469.99
Total		**7220.47**	**18,498.28**	**16,815.05**	**18,369.16**	**18,025.46**
Mixed intensive	CSA	4460.95	10,463.30	9347.11	10,394.25	10,202.82
	EA	9921.36	23,056.57	20,761.50	22,878.82	22,376.57
	SA	892.46	3868.51	2357.84	3855.88	3827.59
	SEA	2483.60	5694.10	5930.31	5667.00	5584.02
	SSA	393.56	573.07	819.06	568.63	557.08
	WANA	898.96	2025.33	1741.59	2004.45	1953.90
Total		**19,050.88**	**45,680.89**	**40,957.40**	**45,369.03**	**44,501.97**
Other	CSA	2727.07	6177.93	6213.85	6138.20	6034.25
	EA	684.29	1652.13	1482.39	1639.46	1603.68
	SA	119.20	494.68	328.69	492.84	488.91
	SEA	569.53	1120.58	1195.26	1115.12	1099.27
	SSA	153.64	279.13	374.92	276.56	270.24
	WANA	234.01	572.62	398.52	565.09	547.35
Total		**4487.74**	**10,297.06**	**9993.62**	**10,227.26**	**10,043.70**
Total—all systems	CSA	12,031.19	28,027.63	26,487.53	27,846.57	27,357.07
	EA	12,344.27	29,734.44	26,770.13	29,505.26	28,857.78
	SA	1535.54	6786.93	4131.02	6765.61	6718.87
	SEA	3841.18	8204.00	8618.37	8165.59	8047.51
	SSA	1627.00	2903.07	3743.98	2875.92	2809.48
	WANA	3669.71	7482.02	7293.31	7390.90	7174.27
	Others	31,773.69	44,319.38	42,877.50	40,450.45	43,905.25

Pig numbers and production under different scenarios

Table 30. Numbers of pigs by farming system under alternative development scenarios

Farming systems	Region	Pigs 2000 (10^6 of LU)	Baseline 2030 (10^6 of LU)	Biofuels 2030 (10^6 of LU)	Irrigation expansion 2030 (10^6 of LU)	Low meat demand 2030 (10^6 of LU)
(Agro-) pastoral	CSA	4.13	5.25	5.23	4.97	5.24
	EA	2.45	2.90	2.82	3.45	2.88
	SA	0.01	0.00	0.00	0.00	0.00
	SEA	0.32	0.46	0.45	0.35	0.46
	SSA	0.69	0.72	0.71	0.84	0.71
	WANA	0.02	0.02	0.02	0.02	0.02
Total		**7.62**	**9.34**	**9.24**	**9.63**	**9.32**
Mixed extensive	CSA	5.03	6.69	6.64	5.57	6.68
	EA	21.80	27.12	26.37	32.22	26.94
	SA	1.17	1.78	1.77	1.61	1.77
	SEA	2.86	4.22	4.22	2.95	4.22
	SSA	1.31	2.25	2.22	2.23	2.24
	WANA	0.01	0.01	0.01	0.01	0.01
Total		**32.17**	**42.07**	**41.23**	**44.60**	**41.87**
Mixed intensive	CSA	5.70	8.19	8.12	6.43	8.18
	EA	54.71	59.01	57.38	69.97	58.61
	SA	2.26	3.49	3.48	3.16	3.49
	SEA	7.20	12.49	12.48	8.70	12.49
	SSA	1.09	1.41	1.39	1.33	1.41
	WANA	0.01	0.01	0.01	0.01	0.01
Total		**70.95**	**84.60**	**82.85**	**89.60**	**84.18**
Other	CSA	4.91	6.55	6.52	5.78	6.55
	EA	8.95	10.42	10.14	11.86	10.35
	SA	0.17	0.24	0.24	0.22	0.24
	SEA	2.33	3.44	3.43	2.65	3.44
	SSA	0.68	0.97	0.96	1.08	0.96
	WANA	0.00	0.00	0.00	0.00	0.00
Total		**17.04**	**21.63**	**21.29**	**21.58**	**21.55**
Total—all regions	CSA	19.77	26.68	26.51	22.74	26.65
	EA	87.91	99.46	96.72	117.51	98.79
	SA	3.60	5.51	5.49	5.00	5.51
	SEA	12.71	20.61	20.58	14.65	20.60
	SSA	3.76	5.35	5.28	5.48	5.33
	WANA	0.04	0.03	0.03	0.04	0.03
	Others	73.77	67.71	65.97	65.95	67.16

Table 31. Livestock production, farming systems vs. pork production

Farming system	Region	Pork in 2000 (10^3 MT)	Baseline 2030 (10^3 MT)	Biofuels 2030 (10^3 MT)	Irrigation expansion 2030 (10^3 MT)	Low meat demand 2030 (10^3 MT)
(Agro-) pastoral	CSA	625.5	1226.2	1220.3	1200.3	1224.9
	EA	1009.6	1677.6	1631.1	2128.9	1666.3
	SA	14.5	31.8	31.5	34.5	31.8
	SEA	60.6	152.6	151.4	117.0	152.3
	SSA	125.7	196.8	193.4	235.3	195.7
	WANA	10.8	13.8	13.3	16.2	13.6
Total		**1846.6**	**3298.8**	**3241.0**	**3732.1**	**3284.7**
Mixed extensive	CSA	1261.9	2434.0	2421.4	2339.4	2431.4
	EA	10,598.6	18,225.5	17,719.8	23,126.8	18,102.5
	SA	222.4	611.9	609.2	617.9	611.5
	SEA	786.7	1849.9	1850.0	1314.8	1850.3
	SSA	246.6	640.1	628.8	686.1	636.6
	WANA	4.1	4.0	3.9	6.0	3.9
Total		**13,120.3**	**23,765.3**	**23,233.1**	**28,090.9**	**23,636.2**
Mixed intensive	CSA	1366.3	3013.3	2988.9	2692.7	3008.5
	EA	26,159.8	38,903.8	37,825.1	49,334.1	38,641.6
	SA	356.8	1003.9	1000.0	1010.8	1003.4
	SEA	2029.5	5327.2	5329.6	3819.6	5328.7
	SSA	211.7	384.5	377.3	385.4	382.4
	WANA	17.6	5.3	5.1	6.2	5.2
Total		**30,141.8**	**48,638.1**	**47,525.9**	**57,248.7**	**48,369.7**
Other	CSA	1055.1	2115.3	2106.9	2108.6	2113.6
	EA	4359.8	6848.6	6661.2	8587.0	6803.1
	SA	52.8	144.6	144.0	145.9	144.5
	SEA	622.2	1427.7	1423.6	1117.3	1426.9
	SSA	72.5	156.7	154.8	177.7	156.1
	WANA	75.3	68.4	66.7	95.2	67.9
Total		**6237.7**	**10,761.4**	**10,557.2**	**12,231.7**	**10,712.1**
Total—all systems	CSA	4308.7	8788.8	8737.5	8341.0	8778.4
	EA	42,127.8	65,655.6	63,837.1	83,176.7	65,213.5
	SA	646.5	1792.3	1784.7	1809.0	1791.2
	SEA	3499.0	8757.4	8754.6	6368.6	8758.2
	SSA	656.5	1378.1	1354.3	1484.5	1370.8
	WANA	107.8	91.4	88.9	123.6	90.7
	Others	38,971.20	45,262.30	44,122.50	50,229.20	44,905.10

Notwithstanding the problems of spatial allocation of monogastrics in this study, chicken and pig numbers are highest in the most intensive systems and mainly in East Asia, while significant numbers of poultry also exist across several systems in Latin America (this is a reflection of the difficulty of allocating monogastrics from industrial systems, which predominate in these regions). Under all scenarios, the growth rates of monogastric animal numbers are slower than the growth in pork and poultry meat production. This is a reflection of gains in feed conversion efficiency over short generation intervals in these species. Pigs have the ability to achieve genetic progress in feed conversion in a short time due to their short cycles of production. At the same time feeding practices have improved significantly, mainly in industrial production systems. This ultimately leads to requiring less animals and less grains to produce the increasing volume of poultry and pork meat globally. Due to cultural factors and dietary preferences, some regions do not experience large growth in pig numbers and production, while in others like SEA, pig production more than doubles though its volume of production is low.

In terms of alternative scenarios, the main trends are that the biofuels scenario does not significantly reduce the volume of poultry and pork meat production. Although in direct competition for the demand of grains for energy vs. feed for pig production, the increased conversion efficiency of pigs over time, smoothes this response and diminishes the demand for feed. This also translates in modest price increases in the price of poultry and pork meat. On the other hand, the irrigation expansion scenario, with its increased crop production, increases further the production of this commodity, especially in the more intensive systems with more access to irrigation. The low meat demand scenario reduces slightly the volume of poultry and pork meat produced in comparison to the baseline scenario.

These results suggest that these large efficiency gains in monogastrics reduce pressure on agro-ecosystems services, especially in the mixed intensive systems. Not even under a drastic biofuels scenario, the trade-off between feed demand and energy becomes so detrimental for poultry and pork production, though these multiple demands contribute significantly to large increases in the price of grains, in this case cereals which compose up to 60% of the diet of poultry and pigs (Steinfeld et al. 2006). Increases in the prices of grains have a serious detrimental effect on human wellbeing and their accessibility to food. The poor get squeezed as they simply do not have the money to buy more expensive staples. This trade-off is essential for the development of a pro-poor livestock revolution and should be the subject of significant research.

5.4 Crop production

This section focuses on the production of the main cereals and root crops (cassava and sweetpotato), as these are the crops facing the largest demands from multiple sources and as a consequence the largest price increases. At the same time these are the crops, apart from some legumes, that largely represent the interests of the SLP as sources of food, feed and fuel and also the interests of different CGIAR crop improvement centres.

Area and production of these main crops are presented in Tables 32 and 33 for maize, Tables 34 and 35 for wheat, Tables 36 and 37 for rice, Tables 38 and 39 for sorghum, Tables 40 and 41 for millet, Tables 42 and 43 for barley, Tables 44 and 45 for cassava, Tables 46 and 47 for sweetpotato and Tables 48 and 49 for potatoes.

General characteristics of global crop production trends under the reference scenario

In general terms, mixed crop–livestock systems in the developing world are significant producers of global cereals (1a). About 50% of global cereal production is produced in the developing world, with the mixed intensive crop–livestock systems contributing 35% of global cereal production. This is a significant characteristic as it means that at least half of the global production of staples is in the hands of millions of smallholder farmers in largely fragmented landscapes in rural areas of Africa, Asia and Latin America. This characteristic demands very novel forms of support in services, technology and policies, as it is difficult to reach large numbers of small heterogeneous farms.

Table 32. Global area of maize by system, region and scenario 2000–2030

Farming system	Region	Maize 2000 (10^3 ha)	Reference run 2030 (10^3 ha)	Biofuels 2030 (10^3 ha)	Irrigation expansion 2030 (10^3 ha)	Low meat demand 2030 (10^3 ha)
(Agro-) pastoral	CSA	1263	1530	1659	1552	1557
	EA	961	1125	1138	1165	1106
	SA	2173	2458	2681	2488	2503
	SEA	20	26	28	28	26
	SSA	758	716	787	703	728
	WANA	170	200	202	195	192
Total		**5345**	**6054**	**6495**	**6131**	**6113**
Mixed extensive	CSA	12,501	14,951	16,133	15,207	15,258
	EA	2559	4107	4167	4251	4011
	SA	1489	1751	1903	1851	1775
	SEA	2751	2510	2689	2590	2549
	SSA	16,649	18,771	20,610	18,512	19,094
	WANA	694	851	848	816	802
Total		**36,644**	**42,941**	**46,350**	**43,227**	**43,490**
Mixed intensive	CSA	12,210	14,344	15,486	14,453	14,600
	EA	20,466	21,938	22,772	22,805	21,637
	SA	2923	2971	3231	3149	3017
	SEA	5050	5950	6361	6125	6041
	SSA	6619	7757	8453	7650	7888
	WANA	1271	1421	1475	1417	1390
Total		**48,539**	**54,382**	**57,777**	**55,600**	**54,573**
Other	CSA	1040	1282	1391	1304	1307
	EA	657	800	831	833	788
	SA	1166	1297	1414	1316	1320
	SEA	88	106	113	110	108
	SSA	329	411	446	407	418
	WANA	12	13	13	12	12
Total		**3291**	**3909**	**4209**	**3983**	**3953**
Total—all systems	CSA	27,014	32,107	34,669	32,516	32,722
	EA	24,643	27,970	28,908	29,054	27,542
	SA	7751	8477	9229	8804	8615
	SEA	7909	8592	9191	8853	8724
	SSA	24,355	27,655	30,296	27,272	28,128
	WANA	2147	2485	2538	2440	2396
	Others	43,985	52,321	56,530	53,973	52,751

Table 33. Global maize production by system, region and scenario 2000–2030

Farming system	Region	Maize 2000 (10^3 ha)	Reference run 2030 (10^3 ha)	Biofuels 2030 (10^3 ha)	Irrigation expansion 2030 (10^3 ha)	Low meat demand 2030 (10^3 ha)
(Agro-) pastoral	CSA	4383	10,504	11,983	10,782	10,750
	EA	5215	8,960	9,301	9293	8533
	SA	4884	9,892	11,755	10,444	10,283
	SEA	55	153	173	168	157
	SSA	1773	3,637	4,395	3686	3796
	WANA	720	1,748	1,702	1593	1559
Total		**17,031**	**34,893**	**39,310**	**35,967**	**35,078**
Mixed extensive	CSA	34,022	72,333	82,121	74,295	74,204
	EA	10,796	25,859	27,576	27,111	25,117
	SA	2285	5006	5865	5521	5136
	SEA	6419	11,413	12,957	12,193	11,734
	SSA	22,407	48,667	58,319	49,551	50,660
	WANA	1707	4211	4208	3905	3815
Total		**77,634**	**167,489**	**191,045**	**172,576**	**170,665**
Mixed intensive	CSA	37,150	86,694	98,614	88,294	88,671
	EA	97,112	161,619	180,827	172,803	162,066
	SA	5775	11,666	13,707	12,899	12,031
	SEA	13,701	33,514	37,922	35,649	34,406
	SSA	10,961	22,948	27,341	23,315	23,950
	WANA	7964	15,708	16,291	15,388	15,192
Total		**172,663**	**332,149**	**374,701**	**348,349**	**336,315**
Other	CSA	4275	9711	11,167	10,092	9997
	EA	4164	7841	8346	8065	7546
	SA	1845	3659	4347	3878	3802
	SEA	426	1030	1165	1101	1057
	SSA	1029	2398	2843	2431	2487
	WANA	49	113	108	98	98
Total		**11,788**	**24,753**	**27,975**	**25,666**	**24,987**
Total—all systems	CSA	79,830	179,242	203,886	183,464	183,622
	EA	117,287	204,279	226,049	217,271	203,261
	SA	14,789	30,222	35,674	32,741	31,253
	SEA	20,600	46,111	52,217	49,112	47,354
	SSA	36,169	77,651	92,898	78,983	80,892
	WANA	10,440	21,779	22,309	20,985	20,663
	Others	329,928	572,989	517,107	528,799	532,588

Table 34. Global area of wheat by system, region and scenario 2000–2030

Name	Region	Wheat 2000 (10^3 ha)	Reference run 2030 (10^3 ha)	Biofuels 2030 (10^3 ha)	Irrigation expansion 2030 (10^3 ha)	Low meat demand 2030 (10^3 ha)
(Agro-) pastoral	CSA	1570	1699	1714	1630	1709
	EA	851	677	681	709	679
	SA	3549	3242	3315	3222	3272
	SEA	28	32	33	33	32
	SSA	163	295	293	303	295
	WANA	2767	4003	3987	4310	3989
Total		**8928**	**9948**	**10,022**	**10,207**	**9976**
Mixed extensive	CSA	4551	4898	4941	4717	4927
	EA	5508	6248	6276	6571	6263
	SA	12,481	11,485	11,919	12,620	11,788
	SEA	70	79	81	82	80
	SSA	1337	2015	2013	1923	2023
	WANA	13,687	16,167	16,162	16,275	16,165
Total		**37,633**	**40,892**	**41,393**	**42,188**	**41,246**
Mixed intensive	CSA	3064	4236	4277	4013	4261
	EA	19,598	15,985	16,058	16,597	16,023
	SA	15,893	12,722	13,198	13,896	13,045
	SEA	0	0	1	1	1
	SSA	789	933	931	883	935
	WANA	6332	7560	7578	7740	7566
Total		**45,676**	**41,436**	**42,043**	**43,130**	**41,831**
Other	CSA	331	415	416	396	416
	EA	530	416	418	429	417
	SA	2561	2130	2205	2197	2180
	SEA	0	0	0	0	0
	SSA	26	39	40	38	40
	WANA	165	187	187	184	187
Total		**3613**	**3187**	**3265**	**3243**	**3240**
Total—all systems	CSA	9516	11,247	11,349	10,756	11,313
	EA	26,486	23,327	23,432	24,306	23,382
	SA	34,484	29,579	30,637	31,935	30,286
	SEA	98	112	114	116	112
	SSA	2314	3283	3277	3146	3293
	WANA	22,951	27,917	27,915	28,508	27,907
	Others	111,849	120,854	121,524	119,755	121,131

Table 35. Global production of wheat by system, region and scenario 2000–2030

Farming system	Region	Wheat 2000 (10^3 ha)	Reference run 2030 (10^3 ha)	Irrigation expansion 2030 (10^3 ha)	Low meat demand 2030 (10^3 ha)	Biofuels 2030 (10^3 ha)
(Agro-) pastoral	CSA	1614	2677	2578	2703	2758
	EA	7860	8088	8865	8331	8545
	SA	5910	9014	9064	9195	9567
	SEA	1	2	1	2	2
	SSA	342	656	565	579	594
	WANA	11,393	28,258	28,333	27,177	27,780
Total		**27,120**	**48,694**	**49,405**	**47,988**	**49,245**
Mixed extensive	CSA	10,827	17,392	16,918	17,597	17,908
	EA	11,040	16,848	17,470	16,425	16,840
	SA	9596	12,614	13,520	12,587	13,084
	SEA	26	51	41	41	42
	SSA	2385	5688	5588	5799	5920
	WANA	18,523	38,163	38,610	37,664	38,467
Total		**52,397**	**90,756**	**92,145**	**90,114**	**92,260**
Mixed intensive	CSA	8575	13,477	12,880	13,378	13,699
	EA	79,126	85,680	88,419	84,622	86,768
	SA	69,568	88,161	96,885	89,831	93,369
	SEA	73	135	106	109	111
	SSA	1451	2733	2548	2703	2766
	WANA	15,239	32,691	31,858	30,942	31,651
Total		174,031	222,878	232,697	221,586	228,364
Other	CSA	820	1345	1310	1358	1389
	EA	2161	2220	2338	2232	2290
	SA	4224	6331	6372	6454	6723
	SEA	3	5	4	4	4
	SSA	296	449	435	440	451
	WANA	960	2416	2439	2394	2466
Total		**8464**	**12,766**	**12,898**	**12,882**	**13,323**
Total—all systems	CSA	21,836	34,891	33,685	35,037	35,752
	EA	100,187	112,836	117,092	111,611	114,443
	SA	89,297	116,120	125,841	118,066	122,743
	SEA	103	193	153	156	159
	SSA	4474	9526	9136	9521	9730
	WANA	46,115	101,528	101,239	98,178	100,363
	Others	309,589	419,637	432,884	423,885	424,468

Table 36. Global area of rice by system, region and scenario 2000–2030

Name	Region	Rice 2000 (10^3 ha)	Reference run 2030 (10^3 ha)	Biofuels 2030 (10^3 ha)	Irrigation expansion 2030 (10^3 ha)	Low meat demand 2030 (10^3 ha)
(Agro-) pastoral	CSA	459	450	456	451	453
	EA	541	522	519	550	519
	SA	5402	3872	3756	3692	3840
	SEA	198	201	200	200	201
	SSA	397	344	332	351	340
	WANA	124	140	135	136	139
Total		**7120**	**5529**	**5399**	**5379**	**5492**
Mixed extensive	CSA	2281	2253	2283	2238	2270
	EA	6079	6307	6295	6702	6288
	SA	13,305	14,350	13,960	15,053	14,239
	SEA	12,276	10,062	9991	9917	10,057
	SSA	3,945	4,905	4858	4763	4893
	WANA	415	436	421	423	431
Total		**38,301**	**38,313**	**37,808**	**39,096**	**38,177**
Mixed intensive	CSA	2755	2945	3005	2965	2974
	EA	22,653	17,534	17,516	18,536	17,504
	SA	35,255	37,130	36,425	38,577	36,875
	SEA	27,606	30,013	29,704	29,675	29,981
	SSA	2072	2638	2577	2538	2622
	WANA	851	851	807	824	838
Total		**91,192**	**91,111**	**90,035**	**93,116**	**90,795**
Other	CSA	417	449	462	448	455
	EA	1364	1169	1168	1236	1167
	SA	2871	2084	2022	2001	2067
	SEA	629	646	640	640	646
	SSA	273	304	294	305	302
	WANA	4	4	4	4	4
Total		**5557**	**4657**	**4592**	**4635**	**4640**
Total—all systems	CSA	5911	6097	6206	6102	6151
	EA	30,636	25,532	25,498	27,024	25,478
	SA	56,834	57,436	56,164	59,323	57,020
	SEA	40,709	40,923	40,536	40,433	40,885
	SSA	6687	8192	8062	7957	8157
	WANA	1394	1432	1368	1386	1412
	Others	5055	4514	4544	4564	4544

Table 37. Global rice production by system, region and scenario 2000–2030

Farming system	Region	2000 (10^3 MT)	Reference run 2030 (10^3 MT)	Biofuels 2030 (10^3 MT)	Irrigation expansion 2030 (10^3 MT)	Low meat demand 2030 (10^3 MT)
(Agro-) pastoral	CSA	1379	1965	2023	1983	1987
	EA	2358	2410	2396	2551	2370
	SA	6638	5658	5561	5390	5637
	SEA	775	1142	1153	1138	1148
	SSA	616	1075	959	989	962
	WANA	339	585	599	607	603
Total		**12,105**	**12,836**	**12,692**	**12,658**	**12,708**
Mixed Extensive	CSA	4130	6161	6434	6179	6269
	EA	24,673	28,890	29,468	30,860	29,110
	SA	21,834	32,680	32,103	34,171	32,364
	SEA	20,401	24,185	24,350	23,964	24,287
	SSA	3760	8442	8165	7963	8110
	WANA	1020	1687	1691	1693	1707
Total		**75,818**	**102,045**	**102,211**	**104,829**	**101,846**
Mixed Intensive	CSA	7454	11,239	11,667	11,410	11,413
	EA	92,366	84,838	86,294	89,347	85,303
	SA	82,799	121,167	119,959	125,405	120,007
	SEA	71,455	104,774	105,020	103,973	105,143
	SSA	2473	4909	4657	4575	4662
	WANA	4292	5993	5829	5893	5985
Total		**260,839**	**332,920**	**333,427**	**340,604**	**332,512**
Other	CSA	1244	1970	2079	1996	2011
	EA	6708	6839	6890	7115	6811
	SA	7256	6574	6462	6327	6545
	SEA	2518	3535	3547	3509	3548
	SSA	412	940	900	931	905
	WANA	11	21	21	22	22
Total		**18,149**	**19,880**	**19,898**	**19,900**	**19,841**
Total—All systems	CSA	14,207	21,335	22,203	21,568	21,680
	EA	126,104	122,978	125,049	129,873	123,595
	SA	118,528	166,079	164,086	171,293	164,552
	SEA	95,149	133,636	134,070	132,584	134,124
	SSA	7261	15,367	14,680	14,458	14,639
	WANA	5662	8285	8141	8215	8317
	Others	21,375	22,751	23,293	23,325	23,094

Table 38. Global area of sorghum by system, region and scenario 2000–2030

Farming system	Region	Sorghum 2000 (10^3 ha)	Reference run 2030 (10^3 ha)	Biofuels 2030 (10^3 ha)	Irrigation expansion 2030 (10^3 ha)	Low meat demand 2030 (10^3 ha)
(Agro-) pastoral	CSA	188	258	256	256	257
	EA	79	54	55	53	55
	SA	13	11	11	11	11
	SEA	0	0	0	0	0
	SSA	775	1035	1030	1009	1034
	WANA	128	120	123	139	123
Total		**1182**	**1478**	**1476**	**1468**	**1480**
Mixed extensive	CSA	2292	2849	2822	2887	2842
	EA	167	124	126	126	125
	SA	2028	1720	1755	1748	1736
	SEA	47	21	21	23	21
	SSA	19,056	27,860	27,446	27,112	27,707
	WANA	389	362	372	419	371
Total		**23,979**	**32,937**	**32,542**	**32,315**	**32,802**
Mixed intensive	CSA	1296	1398	1387	1431	1395
	EA	460	303	307	314	304
	SA	2180	1724	1756	1752	1737
	SEA	40	30	29	32	30
	SSA	2436	3993	3934	3887	3976
	WANA	193	197	197	209	198
Total		**6606**	**7645**	**7610**	**7625**	**7639**
Other	CSA	160	214	213	215	214
	EA	20	13	13	13	13
	SA	26	22	23	23	23
	SEA	1	1	1	1	1
	SSA	93	169	167	161	168
	WANA	2	2	2	2	2
Total		**301**	**421**	**418**	**415**	**420**
Total—all systems	CSA	3935	4719	4677	4789	4708
	EA	725	495	501	507	496
	SA	4248	3477	3545	3534	3506
	SEA	88	52	51	55	52
	SSA	22,360	33,057	32,577	32,169	32,885
	WANA	711	681	694	769	694
	Others	4273	3653	3639	3686	3648

Table 39. Global sorghum production by system, region and scenario 2000–2030

Farming system	Region	Sorghum 2000 (10³ MT)	Baseline 2030 (10³ MT)	Biofuels 2030 (10³ MT)	Irrigation expansion 2030 (10³ MT)	Low meat demand 2030 (10³ MT)
(Agro-) pastoral	CSA	474	1012	1028	1025	1017
	EA	237	243	253	247	246
	SA	16	19	21	22	21
	SEA	0	0	0	0	0
	SSA	612	1341	1365	1336	1339
	WANA	190	239	253	289	249
Total		**1529**	**2855**	**2921**	**2920**	**2872**
Mixed extensive	CSA	6296	10,627	10,804	11,135	10,701
	EA	484	586	613	615	596
	SA	1531	2102	2225	2276	2155
	SEA	78	67	67	74	67
	SSA	15312	36,269	36,498	36,173	36,161
	WANA	402	511	538	617	530
Total		**24,102**	**50,161**	**50,746**	**50,890**	**50,210**
Mixed intensive	CSA	3828	5525	5653	5881	5585
	EA	1621	1385	1460	1523	1421
	SA	1681	2174	2292	2348	2221
	SEA	69	101	101	111	101
	SSA	2506	6693	6768	6690	6698
	WANA	947	1182	1225	1252	1206
Total		**10,653**	**17,059**	**17,498**	**17,804**	**17,232**
Other	CSA	442	897	915	930	904
	EA	190	66	69	68	67
	SA	25	35	37	38	36
	SEA	4	5	5	5	5
	SSA	246	691	705	677	695
	WANA	1	2	2	3	2
Total		**908**	**1696**	**1732**	**1720**	**1708**
Total—all systems	CSA	11,039	18,061	18,400	18,972	18,206
	EA	2533	2279	2395	2454	2330
	SA	3254	4330	4576	4684	4433
	SEA	151	172	173	189	172
	SSA	18,676	44,994	45,336	44,877	44,893
	WANA	1540	1935	2019	2161	1988
	Others	16,389	16,360	16,612	16,936	16,426

Table 40. Global area of millet by system, region and scenario 2000–2030

Farming system	Region	Millet 2000 (10^3 ha)	Reference run 2030 (10^3 ha)	Biofuels 2030 (10^3 ha)	Irrigation expansion 2030 (10^3 ha)	Low meat demand 2030 (10^3 ha)
(Agro-) pastoral	CSA	2	1	1	2	1
	EA	134	97	97	96	97
	SA	N/A	N/A	N/A	N/A	N/A
	SEA	11	12	12	13	12
	SSA	780	983	964	965	978
	WANA	14	16	16	17	16
Total		**955**	**1120**	**1101**	**1102**	**1115**
Mixed extensive	CSA	22	17	16	18	17
	EA	312	229	229	234	229
	SA	2482	1871	1886	1886	1882
	SEA	129	134	133	137	133
	SSA	17,313	21,103	20,527	20,585	20,934
	WANA	113	115	116	125	116
Total		**20,370**	**23,467**	**22,907**	**22,985**	**23,311**
Mixed intensive	CSA	3	2	2	3	2
	EA	473	338	338	344	338
	SA	3015	2198	2215	2214	2211
	SEA	94	108	107	111	107
	SSA	1661	2120	2047	2051	2096
	WANA	18	21	21	22	21
Total		**5264**	**4787**	**4731**	**4745**	**4776**
Other	CSA	0	0	0	0	0
	EA	124	89	90	89	89
	SA	56	49	49	49	49
	SEA	16	17	17	17	17
	SSA	60	79	77	76	78
	WANA	2	2	2	2	2
Total		**257**	**236**	**234**	**235**	**236**
Total—all regions	CSA	27	21	20	23	21
	EA	1042	753	754	763	753
	SA	5567	4127	4160	4159	4152
	SEA	249	271	268	278	270
	SSA	19,814	24,284	23,615	23,678	24,087
	WANA	148	154	155	167	156
	Others	1664	1190	1179	1166	1186

Table 41. Global millet production by system, region and scenario 2000–2030

Farming system	Region	Millet 2000 (10^3 MT)	Reference run 2030 (10^3 MT)	Biofuels 2030 (10^3 MT)	Irrigation expansion 2030 (10^3 MT)	Low meat demand 2030 (10^3 MT)
(Agro-) pastoral	CSA	4	5	5	6	5
	EA	215	252	258	258	254
	SA	6194	8540	8757	8972	8604
	SEA	10	15	15	15	15
	SSA	531	1279	1281	1283	1279
	WANA	63	93	95	104	95
Total		**7016**	**10,184**	**10,411**	**10,639**	**10,251**
Mixed extensive	CSA	26	30	30	35	30
	EA	474	577	589	617	580
	SA	1753	2253	2340	2422	2300
	SEA	141	188	190	193	188
	SSA	10,627	24,446	24,129	24,366	24,341
	WANA	25	41	42	45	42
Total		**13,046**	**27,535**	**27,320**	**27,679**	**27,481**
Mixed intensive	CSA	6	5	5	5	5
	EA	896	888	907	945	893
	SA	2469	3107	3222	3339	3167
	SEA	61	100	100	105	100
	SSA	1710	4044	3973	4011	4011
	WANA	22	35	36	38	35
Total		**5164**	**8179**	**8243**	**8444**	**8210**
Other	CSA	1	1	1	1	1
	EA	171	74	75	80	74
	SA	75	100	103	106	101
	SEA	28	36	37	37	37
	SSA	100	252	250	251	251
	WANA	2	3	3	3	3
Total		**376**	**466**	**469**	**478**	**467**
Total—all regions	CSA	37	41	40	47	40
	EA	1756	1790	1829	1900	1800
	SA	10,490	14,000	14,422	14,839	14,171
	SEA	240	338	342	350	339
	SSA	12,967	30,021	29,633	29,912	29,882
	WANA	112	173	176	190	175
	Others	1649	1892	1904	1907	1893

Table 42. Global area of barley production under different scenarios

Farming system	Region	Barley 2000 (10^3 ha)	Reference run 2030 (10^3 ha)	Biofuels 2030 (10^3 ha)	Irrigation expansion (10^3 ha)	Low meat demand 2030 (10^3 ha)
(Agro-) pastoral	CSA	119	155	160	158	154
	EA	92	77	81	77	78
	SA	264	254	268	262	259
	SEA	0	0	0	0	0
	SSA	14	19	20	20	20
	WANA	1424	2007	2128	2040	2055
Total		1913	2513	2657	2557	2566
Mixed extensive	CSA	463	614	647	637	625
	EA	152	168	177	169	172
	SA	151	147	154	154	150
	SEA	6	5	5	5	5
	SSA	990	1746	1834	1670	1784
	WANA	6506	8135	8644	8419	8346
Total		**8268**	**10,815**	**11,462**	**11,055**	**11,081**
Mixed intensive	CSA	383	647	676	655	654
	EA	797	565	595	569	578
	SA	265	222	230	230	225
	SEA	1	6	6	6	6
	SSA	107	283	297	270	289
	WANA	2549	3393	3604	3495	3481
Total		**4102**	**5116**	**5408**	**5225**	**5232**
Other	CSA	84	127	134	132	129
	EA	42	35	36	35	35
	SA	138	131	138	135	133
	SEA	0	0	0	0	0
	SSA	6	8	9	8	9
	WANA	101	148	158	150	152
Total		**370**	**449**	**475**	**461**	**459**
Total—all regions	CSA	1050	1544	1617	1583	1562
	EA	1083	844	889	850	863
	SA	818	753	791	781	767
	SEA	7	11	11	12	11
	SSA	1116	2056	2160	1968	2101
	WANA	10,579	13,684	14,533	14,104	14,034
	Others	39,136	41,840	44,384	42,299	42,798

Table 43. Global production of barley by system, region and scenario

Farming system	Region	Barley 2000 (10^3 MT)	Reference run 2030 (10^3 MT)	Biofuels 2030 (10^3 MT)	Irrigation expansion 2030 (10^3 MT)	Low meat demand 2030 (10^3 MT)
(Agro-) pastoral	CSA	212	553	602	579	569
	EA	266	426	464	443	441
	SA	513	805	885	839	836
	SEA	0	0	0	0	0
	SSA	34	116	124	115	117
	WANA	1926	5288	5717	5484	5475
Total		**2951**	**7188**	**7793**	**7461**	**7437**
Mixed extensive	CSA	797	2017	2182	2130	2061
	EA	349	680	751	716	712
	SA	235	382	422	419	396
	SEA	12	11	12	12	11
	SSA	1015	3954	4344	3866	4089
	WANA	7103	19,298	20,806	20,154	20,023
Total		**9512**	**26,342**	**28,518**	**27,299**	**27,294**
Mixed intensive	CSA	783	2592	2759	2635	2602
	EA	2238	2540	2801	2660	2651
	SA	400	591	645	636	610
	SEA	1	28	30	31	29
	SSA	102	554	607	539	572
	WANA	3702	10,228	11,016	10,650	10,593
Total		**7226**	**16,532**	**17,859**	**17,151**	**17,057**
Other	CSA	147	456	493	478	465
	EA	124	164	180	172	170
	SA	260	402	442	419	417
	SEA	0	1	1	1	1
	SSA	13	39	42	39	40
	WANA	172	489	520	504	507
Total		**715**	**1551**	**1678**	**1613**	**1599**
Total—all regions	CSA	1939	5619	6037	5821	5696
	EA	2976	3809	4197	3992	3974
	SA	1408	2179	2394	2314	2259
	SEA	14	39	43	44	41
	SSA	1164	4663	5118	4559	4818
	WANA	12,903	35,303	38,059	36,792	36,599
	Others	113,832	161,840	177,910	166,535	167,632

Table 44. Global area of cassava by system, region and scenario 2000–2030

Name	Region	Cassava 2000 (10^3 ha)	Reference run 2030 (10^3 ha)	Irrigation expansion 2030 (10^3 ha)	Low meat 2030 (10^3 ha)	Biofuels 2030 (10^3 ha)
(Agro-) pastoral	CSA	162	174	175	175	177
	EA	39	44	38	39	39
	SA	24	30	28	29	29
	SEA	4	5	5	5	5
	SSA	238	260	226	231	234
	WANA	0	0	0	0	0
Total		**468**	**513**	**472**	**478**	**484**
Mixed extensive	CSA	1261	1301	1311	1304	1321
	EA	63	84	71	73	73
	SA	49	58	57	58	59
	SEA	1156	878	861	879	884
	SSA	8881	12,180	10,546	10,804	10,927
	WANA	0	0	0	0	0
Total		**11,410**	**14,501**	**12,846**	**13,118**	**13,264**
Mixed intensive	CSA	976	1157	1166	1161	1175
	EA	203	211	178	182	183
	SA	49	48	48	49	49
	SEA	1737	1835	1798	1836	1844
	SSA	3227	5262	4549	4658	4715
	WANA	0	0	0	0	0
Total		**6192**	**8513**	**7739**	**7885**	**7968**
Other	CSA	232	263	264	264	267
	EA	20	22	19	19	19
	SA	8	10	10	10	10
	SEA	73	80	78	80	80
	SSA	431	592	512	525	531
	WANA	0	0	0	0	0
Total		**764**	**967**	**882**	**897**	**908**
Total—all regions	CSA	2631	2896	2917	2904	2941
	EA	326	362	306	313	315
	SA	130	147	143	145	147
	SEA	2970	2797	2740	2799	2813
	SSA	12,777	18,293	15,833	16,217	16,407
	WANA	0	0	0	0	0
	Others	24	25	25	25	25

Table 45. Global cassava production by system, region and scenario 2000–2030

Farming system	Region	Cassava 2000 (10^3 ha)	Baseline 2030 (10^3 ha)	Biofuels 2030 (10^3 ha)	Irrigation expansion 2030 (10^3 ha)	Low meat demand (10^3 ha)
(Agro-) pastoral	CSA	2310	3283	3717	3658	3601
	EA	753	1051	1088	1050	1059
	SA	3	4	5	5	5
	SEA	103	136	139	133	136
	SSA	4657	6524	6626	6330	6355
	WANA	0	0	0	0	0
Total		**7827**	**10,997**	**11,575**	**11,176**	**11,155**
Mixed extensive	CSA	14,077	20,138	22,706	22,402	22,016
	EA	1370	2077	2141	2062	2085
	SA	251	263	350	340	336
	SEA	24,634	15,231	16,025	15,479	15,663
	SSA	71,664	114,214	114,256	109,295	110,212
	WANA	0	0	0	0	0
Total		**111,996**	**151,923**	**155,479**	**149,578**	**150,312**
Mixed intensive	CSA	12,006	19,616	22,441	22,122	21,753
	EA	3619	4121	4246	4090	4135
	SA	616	673	881	855	849
	SEA	22,072	45,526	46,432	44,827	45,425
	SSA	28,525	54,811	56,372	53,776	54,241
	WANA	0	0	0	0	0
Total		**66,838**	**124,748**	**130,373**	**125,670**	**126,402**
Other	CSA	3505	5686	6342	6224	6142
	EA	504	630	652	629	634
	SA	37	44	57	56	55
	SEA	2008	2588	2661	2590	2610
	SSA	6220	11,795	11,605	11,088	11,166
	WANA	0	0	0	0	0
Total		**12,275**	**20,742**	**21,318**	**20,586**	**20,607**
Total—all regions	CSA	31,898	48,723	55,206	54,406	53,512
	EA	6246	7878	8128	7831	7913
	SA	908	984	1293	1255	1245
	SEA	48,817	63,481	65,257	63,029	63,834
	SSA	111,067	187,344	188,859	180,489	181,973
	WANA	0	0	0	0	0
	Others	323	535	556	551	541

Table 46. Global area of sweetpotato by system, region and scenario 2000–2030

Name	Region	Sweetpotato 2000 (10^3 ha)	Reference run 2030 (10^3 ha)	Biofuels 2030 (10^3 ha)	Irrigation expansion 2030 (10^3 ha)	Low meat demand 2030 (10^3 ha)
(Agro-) pastoral	CSA	22	21	21	22	21
	EA	87	68	68	66	68
	SA	0	0	0	0	0
	SEA	2	2	2	2	2
	SSA	106	119	107	105	107
	WANA	0	0	0	0	0
Total		**217**	**210**	**199**	**195**	**198**
Mixed extensive	CSA	90	103	103	106	103
	EA	1148	955	962	932	958
	SA	17	14	14	14	14
	SEA	176	175	175	177	175
	SSA	4001	5583	4838	4791	4853
	WANA	1	1	1	1	1
Total		**5432**	**6830**	**6094**	**6022**	**6105**
Mixed intensive	CSA	161	194	194	201	194
	EA	3878	2885	2908	2819	2894
	SA	78	70	71	71	70
	SEA	419	384	394	393	394
	SSA	1904	2661	2453	2413	2456
	WANA	10	12	12	12	12
Total		**6449**	**6206**	**6032**	**5907**	**6021**
Other	CSA	38	47	47	49	47
	EA	114	87	88	85	88
	SA	2	1	1	1	1
	SEA	72	78	78	79	78
	SSA	70	98	90	89	91
	WANA	0	0	0	0	0
Total		**296**	**312**	**305**	**303**	**305**
Total—all regions	CSA	311	365	366	377	366
	EA	5226	3995	4027	3902	4007
	SA	96	85	87	87	86
	SEA	669	639	650	650	650
	SSA	6081	8461	7488	7398	7507
	WANA	11	13	13	13	13
	Others	113	105	105	105	105

Table 47. Global sweetpotato production by system, region and scenario 2000–2030

Farming system	Region	Sweetpotatoes 2000 (10^3 MT)	Baseline 2030 (10^3 MT)	Biofuels 2030 (10^3 MT)	Irrigation expansion 2030 (10^3 MT)	Low meat demand (10^3 MT)
(Agro-) pastoral	CSA	250	454	431	439	425
	EA	2326	2592	2660	2593	2612
	SA	713	1076	1119	1115	1092
	SEA	17	30	30	30	29
	SSA	1036	1694	1649	1640	1622
	WANA	6	13	11	11	11
Total		**4347**	**5859**	**5900**	**5829**	**5792**
Mixed extensive	CSA	787	1584	1502	1533	1482
	EA	22,093	26,502	27,872	27,183	27,365
	SA	158	204	213	212	208
	SEA	874	1574	1541	1571	1525
	SSA	47,327	67,304	66,566	66,292	65,741
	WANA	6	17	14	15	14
Total		**71,246**	**97,184**	**97,709**	**96,806**	**96,335**
Mixed intensive	CSA	1217	2937	2825	2911	2787
	EA	81,383	84,810	89,236	87,060	87,621
	SA	815	1066	1108	1118	1079
	SEA	3069	6552	6195	6219	6128
	SSA	14,657	24,725	26,194	25,842	25,751
	WANA	257	673	556	547	549
Total		**101,396**	**120,763**	**126,114**	**123,697**	**123,914**
Other	CSA	303	716	683	706	673
	EA	8324	8535	9012	8790	8848
	SA	17	23	24	25	24
	SEA	389	720	713	724	705
	SSA	776	1609	1573	1556	1546
	WANA	0	0	0	0	0
Total		**9808**	**11,604**	**12,005**	**11,801**	**11,795**
Total—all regions	CSA	2556	5691	5441	5589	5367
	EA	114,125	122,439	128,780	125,626	126,446
	SA	1702	2370	2464	2469	2403
	SEA	4348	8876	8478	8544	8387
	SSA	63,796	95,331	95,982	95,330	94,659
	WANA	269	703	582	573	574
	Others	2296	3032	3040	3045	3006

Table 48. Global area of potatoes by system, region and scenario 2000–2030

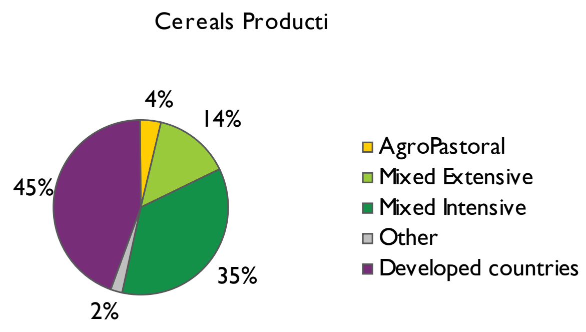
Farming system	Region	Potatoes 2000 (10^3 ha)	Baseline 2030 (10^3 ha)	Biofuels 2030 (10^3 ha)	Irrigation expansion 2030 (10^3 ha)	Low meat demand 2030 (10^3 ha)
(Agro-) pastoral	CSA	174	180	177	181	178
	EA	390	440	438	438	440
	SA	496	471	466	476	471
	SEA	2	2	2	2	2
	SSA	35	41	39	38	39
	WANA	69	83	82	85	82
Total		**1165**	**1217**	**1203**	**1220**	**1212**
Mixed extensive	CSA	396	440	430	433	431
	EA	1554	2105	2090	2100	2102
	SA	185	257	254	275	255
	SEA	51	54	54	53	54
	SSA	653	838	811	790	824
	WANA	328	341	339	348	340
Total		**3167**	**4035**	**3978**	**3999**	**4007**
Mixed intensive	CSA	396	411	403	408	405
	EA	2665	2530	2515	2529	2528
	SA	774	1040	1037	1084	1040
	SEA	72	88	88	87	88
	SSA	180	339	331	312	336
	WANA	324	400	393	400	394
Total		**4411**	**4808**	**4766**	**4819**	**4793**
Other	CSA	97	109	107	108	108
	EA	394	398	395	400	398
	SA	20	26	25	26	26
	SEA	7	8	8	8	8
	SSA	39	46	44	45	45
	WANA	12	16	16	16	16
Total		**569**	**601**	**595**	**603**	**600**
Total—all regions	CSA	1063	1139	1117	1131	1122
	EA	5003	5473	5438	5467	5469
	SA	1474	1793	1782	1862	1792
	SEA	131	152	151	149	152
	SSA	906	1263	1225	1184	1244
	WANA	734	840	829	849	832
	Others	10,406	8832	8758	8724	8824

Table 49. Global production of potatoes by system, region and scenario 2000–2030

Farming system	Region	Potatoes 2000 (10^3 ha)	Baseline 2030 (10^3 ha)	Biofuels 2030 (10^3 ha)	Irrigation expansion 2030 (10^3 ha)	Low meat demand (10^3 ha)
(Agro-) pastoral	CSA	2199	3006	2887	2963	2868
	EA	6707	8600	8660	8770	8612
	SA	14,734	19,681	19,912	20,352	19,844
	SEA	21	37	37	36	37
	SSA	308	506	466	462	466
	WANA	1938	3432	3284	3399	3263
Total		**25,907**	**35,262**	**35,246**	**35,983**	**35,090**
Mixed extensive	CSA	5568	8790	8246	8333	8202
	EA	18,840	28,038	28,321	28,656	28,167
	SA	2827	5552	5409	6001	5381
	SEA	557	834	845	822	839
	SSA	5520	10,042	9830	9495	9839
	WANA	5523	7873	7586	7773	7538
Total		**38,835**	**61,129**	**60,237**	**61,079**	**59,967**
Mixed intensive	CSA	7150	10,980	10,634	10,780	10,574
	EA	35,454	35,263	35,628	36,051	35,427
	SA	12,872	24,722	24,531	26,292	24,332
	SEA	913	1707	1726	1719	1717
	SSA	1245	3715	3626	3381	3630
	WANA	7720	14,247	13,679	13,967	13,592
Total		**65,354**	**90,634**	**89,824**	**92,190**	**89,273**
Other	CSA	1582	2470	2418	2449	2404
	EA	3153	2336	2373	2388	2361
	SA	579	972	980	1012	974
	SEA	120	206	208	205	207
	SSA	219	469	459	460	460
	WANA	232	409	404	419	401
Total		**5885**	**6863**	**6841**	**6933**	**6807**
Total—all regions	CSA	16,500	25,245	24,184	24,525	24,048
	EA	64,153	74,237	74,982	75,865	74,567
	SA	31,011	50,927	50,833	53,658	50,532
	SEA	1611	2785	2816	2783	2801
	SSA	7293	14,733	14,381	13,797	14,395
	WANA	15,413	25,961	24,953	25,558	24,795
	Others	178,177	199,086	199,763	199,847	199,555

Figure 34. Global cereal production–2000

Food production



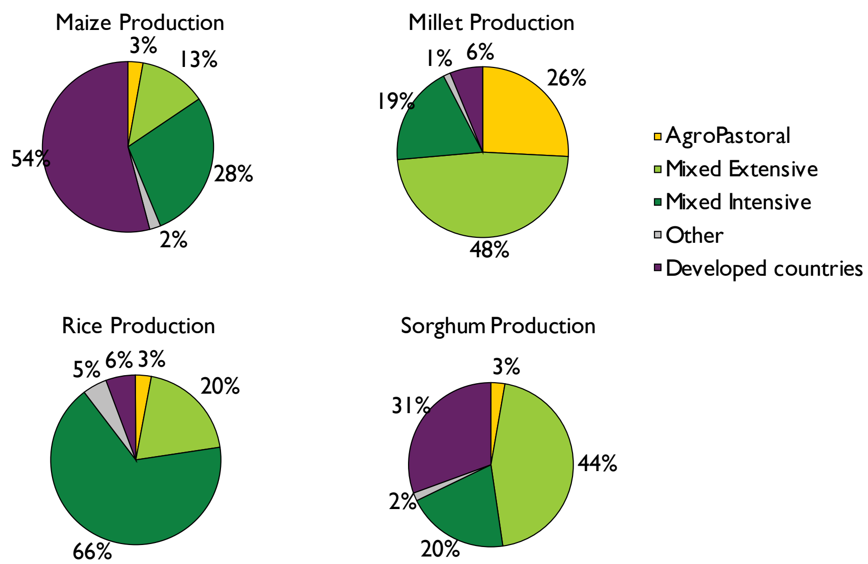
Mixed systems produce almost 50% of the cereals of the World

Most production coming from intensive systems (irrigation, high potential, relatively good market access)

More importantly, these systems produce the main staples consumed by the poor (see Figure 35).

Figure 35. Mixed systems in the developing world produce the food of the poor

Mixed systems in the developing World produce the food of the poor



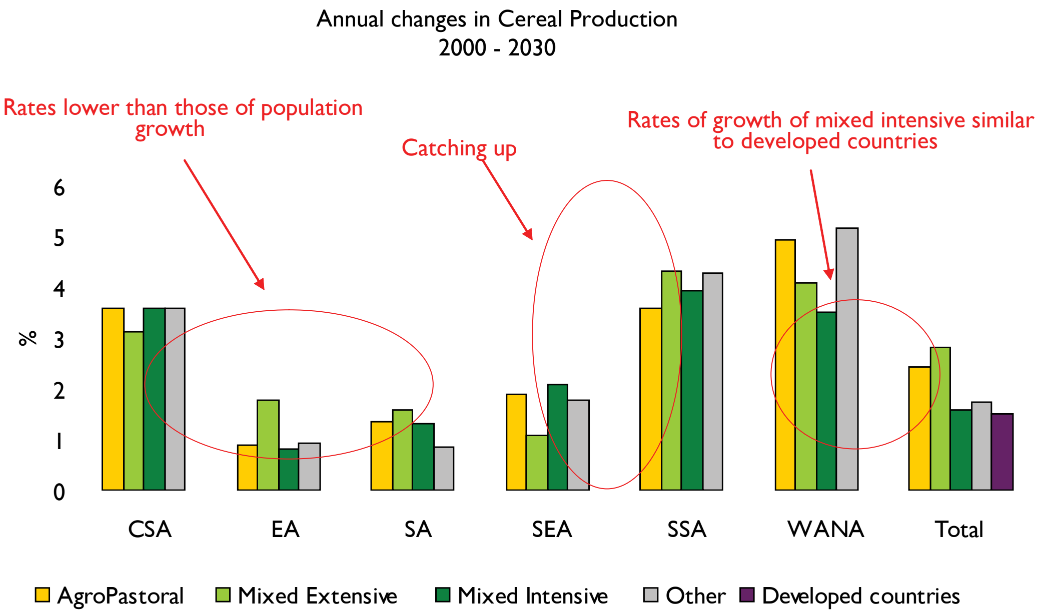
Apart from maize, which has multiple uses and large quantities are produced in the developed world (40% produced in the developing world), 86% of rice, 67% of millet and 64% of sorghum are produced in mixed systems of the developing world. The former mostly in mixed intensive irrigated systems in Asia, while millets and sorghums are grown largely in mixed extensive systems globally. This is a true case of 'poor producers feeding poor consumers' in the developing world.

The share of global cereal production in the developing world will increase even further due to faster rates of growth to 2030 than those in the developed world (Figure 36). However, by 2030, rates of growth of cereal will have stagnated in some places, notably in East and South Asia. Significant growth will be observed in SSA as a result of a combination of small area expansion and increased productivity due to increased use of inputs and technology.

Certainly yield gaps in SSA are higher than in East or South Asia. However, in the mixed intensive systems of SSA, like in the Kenyan highlands, land fragmentation is causing significant constraints to production, forcing farmers to diversify or to exit agriculture (Box 2).

Figure 36. Rates of cereal production to 2030 by farming system under the reference scenario

Rates of cereal production diminishing in places
due to water and other constraints



Rates of cereal production in the more extensive mixed systems are higher than in the more intensive systems which reflect higher potential for tapping existing yield gaps through technology and policy. In the mixed intensive systems, the green revolution increased yields significantly in Asia, to a point that rates of growth to 2030 will resemble those of developed countries.

Area and production of cereals and root crops under reference conditions

Maize is a key crop in the biomass competition throughout the world. It is used for human consumption, monogastric feeding and more recently for biofuel production. It is mostly produced in mixed intensive systems with good lengths of growing period. Nevertheless, it is increasingly grown in more extensive marginal environments like in mixed extensive systems and agropastoral areas. In all these systems, maize stover is a key feedstuff for ruminants. East Asia produces the largest amounts of maize. Due to its key role as food, feed and energy, and the increasing demands from these sectors, both area and but especially production will increase significantly by 2030 under the reference scenario. Area expansion will occur mostly in SSA and CSA, while productivity gains will occur, notably in East Asia, where more than 80% of the maize is produced in the mixed intensive systems.

Box 2. Falling farm sizes, diversification, and poverty in Kenya

There are many drivers of change in rural Kenya. Perhaps the strongest of them have been population growth and commercialization. While urban population growth outpaces that of the rural area, rural population continues to grow in absolute number (by 2.3% per year between 1990–2005) each year, leading to a doubling of population density over the past 31 years. New land is being cleared to accommodate some of the pressure, but in many agricultural areas, land holdings are subdivided and passed to multiple heirs. The implication of this reduction of farm size is the focus of this analysis.

A survey of over 900 households in 15 districts was used to explore relationships between farm size, diversification and income in Kenya.[1] In terms of farm size, the average among the households was about 1.6 with just a small difference across three major provinces: Nyanza 1.5 ha, Western 1.4 ha, Central 1.7 ha. The small land holdings provide strong incentives for intensification (following the Boserup hypothesis). Coupled with that, there have been improved opportunities for commercialized agriculture, emanating from growing urban markets and increased access to them, expanded international demand for selected commodities, and a re-orientation of extension and agricultural development projects towards income generation.

Conventional wisdom based on economies of scale in production or marketing would suggest that farmers might respond through specialization—growing best suited food crops and the most remunerative cash crops.

The data show, however, that diversification overwhelms specialization in terms of smallholder crop portfolios. Specialization is common in two key zones—the cereal belt of the Rift Valley where farming is on a larger scale and often mechanized and in the higher altitude tea zones where tea farming has been lucrative for years. Elsewhere, diversification is the norm, where on average, farmers harvest seven different crops. Among the sample, 36 different crops were commonly harvested (by a minimum of 40 farmers). Interestingly, diversification is commonplace even on the small farms. The correlation between number of crops grown and size of farm is slightly negative (–0.07).

Although, economic theory would suggest that specialization is positively related to income, in this sample, the opposite is true. The more the number of crops grown (or number per hectare), the greater the income from crops (or crops per hectare). The correlation between the variables is 0.15. Diversification strategies differ across Kenyan regions, however. While the number of crops grown per farm is similar across region, in Central Province, there is much more focus on cash crop diversification than in Western Province. For example, cropping area under maize and other cereals is about 66% of smallholder cultivated area in Western Province, but only 46% in Central Province. This matters significantly in terms of poverty alleviation. Recent estimates of poverty rates show that districts in Central Province have the lowest poverty rates in rural areas. In contrast, those in Western Province are very high.

In conclusion, smallholder farmers in Kenya have opted for a diversification farming strategy (and this would also include an array of livestock and tree growing practices as well). In general, diversification is associated with greater agricultural income, but the degree of impact on poverty alleviation depends greatly on the market opportunities available and seized by farmers.

Frank Place (ICRAF).

Wheat is also produced in large quantities in the most intensive mixed systems of the developed and developing World. Under the reference scenario, its area reduces in intensive systems mainly at the expense of maize, notably in East Asia. Small area increases are observed in more marginal areas in the mixed extensive systems, notably in SSA and in East Asia.

1. The survey was conducted in 2004 in maize growing districts as part of the Research on Poverty, Environment, and Agricultural Technology (RePEAT) project.

In SSA and WANA areas are increasing across systems. Nevertheless, production of wheat will increase in most systems to 2030. Large increases are observed in developed countries (others category in all systems), WANA and SSA, while production in mixed intensive systems will increase much less than in the extensive systems; this is as a result of water shortage for irrigation.

Rice is also mostly produced in the mixed intensive, largely irrigated systems. The largest producers are EA, SA and SEA. In general terms areas will remain stable under the references scenario as a result of the low irrigation expansion, though small increases can be observed in SA and SEA. Rice areas in EA will tend to decrease also at the expense of other crops. Rice production is likely to increase much less than the other cereals as a result of water shortages due to competition for water from other sectors. The largest production increases are likely to be observed in the mixed extensive systems. The majority of rice production will, however, remain in the mixed intensive systems.

Sorghum and millet are dryland crops that grow predominantly in mixed extensive and agropastoral systems. SSA is the largest producer of both of these crops. Sorghum and millet stovers represent key feed resources in semi-arid tropical areas. For sorghum, substantial area and production increases will occur under the reference scenario to 2030, mostly in SSA. Across Asia, areas will decrease as competition with other crops, notably maize for food, monogastric feed production and biofuels increases. A similar pattern is observed in millet production, with significant increases in SSA and WANA and reductions in Asia, notably in the mixed intensive systems, where productivity and economic gains of growing other crops might be larger. In essence, these are key crops in arid tropical environments of Africa, but maize is replacing them in parts of Asia to satisfy the larger demands from multiple sources (humans, animal and the energy sector).

Cassava is an important crop, primarily in mixed extensive systems and agropastoral systems of SSA and in some mixed intensive systems of SEA. The largest increases in production under the reference run will be observed in SSA as a result of increased demands from the increasing human population and animal numbers and the steady trend of using cassava for ethanol production. Sweetpotato, on the other hand, is a key crop in mixed intensive systems of EA, where it is used as a dual purpose crop in smallholder pig systems and also in mixed extensive and intensive system of SSA. Sweetpotato areas under the baseline run are dynamic. SSA will likely increase the area under sweetpotato in all systems but the area under sweetpotato is expected to reduce in EA.

Area and production of cereals and root crops under alternative scenarios

Biofuels scenario: Increases in the demand of maize grain as a biofuel source will cause that area and production of maize will increase across systems and regions, with the largest gains observed in the mixed extensive (CSA, SSA and the developed world largest producers) and the mixed intensive systems (mainly the developed world 'others', EA and CSA) in comparison to the reference scenario. Note that maize production in the mixed intensive systems in the developed world, represented here by the 'others system' is twice the amount than in all the developing world combined. In comparison to the reference scenario almost 10% more maize is projected to be produced. Cassava and sweetpotato production, the other key biofuel crops will experience large increases in area and production, mostly in SSA where it is grown in large areas. The other crops will be relatively insensitive to the biofuels scenario, but will still constitute a key component in animal feedstuffs.

Irrigation scenario: Water shortages are a serious threat to increasing agricultural production. Under the irrigation scenario, only rice (especially in SA and SEA) and sorghum (SSA) in the mixed intensive system experience increases in production. The increases in production are a combination of moderate irrigation expansion and efficiency.

Box 3. The political economy of land cover and land use changes in Fogera and Lenche Dima, Ethiopia

Key message

Drivers of change in the Ethiopian highlands differ depending on the agro-ecologies and socio-economic arrangements. For instance, in the Fogera *woreda* (district) of Ethiopia, a water abundant case study area, introduction of rice in the formerly unproductive flooded plains and the implementation of irrigation schemes along the streams have allowed for multiple cropping and have markedly increased overall water productivity of the agricultural systems. Whilst there has been an increase of rice cropped area from 6 ha in the 1993/94 farming season to 6378 ha in the 2004/05 farming season as shown in Table 1, the livestock grazing area has markedly declined. As a result of expanding crop fields, livestock increasingly depend on low quality crop residues for most of the year. Agricultural intensification through introduction of rice and high value vegetables and increasing population pressure have been the drivers behind the land use/land cover changes. Given the huge grazing pressure on the remaining grasslands and the feed shortage problem, introducing high quality forages into the system while improving veterinary services and reducing the numbers of livestock seem to be promising interventions to improve water productivity in these crop–livestock systems.

Table 1. Trends in rice cultivation in Fogera **woreda**

Years	No. of peasant associations (PAs)	No. of households	Area (ha)	Yield (quintiles/ha)
1993–94	2	30	6	27
1994–95	5	256	65	25
1995–96	5	494	130	13
1996–97	5	1334	487	30
1997–98	11	2957	1113	15
1998–99	13	4450	1670	25
1999–2000	13	6158	1968	31
2000–2001	14	9453	2907	35
2001–02	14	9796	3037	35
2002–03	14	11,032	3340	35
2003–04	14	15,000	3480	35
2004–05	14	15,945	6378	45

Source: Ethiopia BMZ baseline report.

On the other hand, in the water scarce Lenche Dima case study, land degradation and drought are the main bottlenecks for agricultural intensification. Over the last decades, the increase in population has been the major driver behind increases in cropland, and corresponding decreases in forests and grasslands. The establishment of exclosures for land rehabilitation have on the one hand resulted in higher feed availability, and on the other hand have further put pressure on communal grazing areas, which have been declining over the years. Inter-community water access conflicts have escalated as most of the water upstream is now being used for irrigation and as water for livestock drinking is very scarce. Within the irrigation schemes themselves, conflicts have arisen due to inadequate water to meet the requirements of all the irrigators. The water scarcity in Lenche Dima enforces the need for improved water storage and regulations and their enforcement with respect to water distribution and the management of livestock drinking ponds. Past rehabilitation efforts have shown that revegetation can result in a more productive use of the water flows in a landscape.

Feeding resources for ruminants—A key pressure point?

Stover is a key feed resource for ruminants in mixed crop–livestock systems (Powell and Williams 1995). It comprises between 45–60% of the diets of ruminants in these systems (Blummel et al. 2006). Since the IMPACT model only includes grains in the calculations, we estimated the amounts of stover produced from cereals from the knowledge of crop production and generic harvest indexes by crop to ascertain whether there would be enough feed to feed ruminants in these systems.

As expected, apart from the developed world which produced the largest quantities of cereals, the amounts of stover are largest in the mixed intensive and mixed extensive systems of the developing world. In intensive systems, the larger productivity of the crops determines the amounts of stover; while in the extensive regions it is mostly the larger is areas that produce the higher quantities of stover. In 2000, the largest stover production areas were the mixed systems of SA, CSA, the mixed intensive system in EA and the mixed extensive system in SSA.

Changes in stover production vary widely from region to region for the reference run to 2030. Large increases in stover production are likely to occur in Africa as a result of area and productivity increases mainly in maize, sorghum and millet. Other large increases will occur across systems in SSA and CSA and less so in the mixed extensive systems of East Asia. It is important to note that there are systems where stover production will stagnate, notably the mixed extensive and intensive systems of SA which together have the largest numbers of ruminants in any system in the world.

A proper assessment of the adequacy of the amount of stover in each system can only be made when comparing it to the numbers of animals present, by knowing the amounts of metabolizable energy the stover may contribute to, and by knowing the requirements of the animals. For the calculations that follow we assume that a 250 kg LU will require around 15 thousand megajoules of metabolizable energy per year to meet its maintenance requirement. This equates to 41 MJ ME/day per animal and includes small corrections for level of activity. Figure 38 presents the global availability of ME from stover per LU per day.

Table 50 presents the results for 2000 and for the reference run to 2030. As expected, apart from the developed world which produced the largest quantities of cereals, the amounts of stover are largest in the mixed intensive and mixed extensive systems of the developing world. In intensive systems, the larger productivity of the crops determines the amounts of stover; while in the extensive regions it is mostly the larger is areas that produce the higher quantities of stover. In 2000, the largest stover production areas were the mixed systems of SA, CSA, the mixed intensive system in EA and the mixed extensive system in SSA.

Table 51 presents the metabolizable energy amounts (total and per LU) by system, region and scenario. The key observations we can make are from these numbers are:

1. The increase in animal numbers has outpaced the rate of growth in availability of stover in many places. This means that either stover will become less important as a feed in these systems and it will be substituted by other feeds in the diet, or that there will be significant feed deficits in some places.

2. There are vast differences in the ME availability from stover by region and system. Several have surpluses but others (those with less than 15 thousand MJ/LU, see Table 51, Figure 38) will not be able to meet the maintenance requirements of ruminants from stover alone and will need to obtain all production from alternative feed resources.

3. This may not be a problem in many parts, like in some systems where land is not a constraint as other feed resources can be planted or will be available. However, of alarming concern are places like the mixed intensive systems of South Asia that depend on irrigation to a great extent and which are supposed to produce 113 million tonnes of milk and 4.5 million tonnes of beef to contribute to feeding the ever-increasing populations. All this production will have to come from alternative feed resources apart from stover (which only meet the maintenance requirements of the animals. Other systems face similar dilemmas although they have fewer animals to feed).

Table 50. Stover production in the developing world 2000–2030 under alternative development scenarios

Farming system	Region	Stover in 2000 (10^6 MT)	Baseline 2030 (10^6 MT)	Biofuels 2030 (10^6 MT)	Irrigation expansion 2030 (10^6 MT)	Low meat demand 2030 (10^6 MT)
(Agro-) pastoral	CSA	11.86	25.7	28.46	26.16	26.2
	EA	20.23	27.17	28.27	28.69	26.67
	SA	31.71	46.77	50.88	48.3	47.75
	SEA	0.84	1.37	1.41	1.39	1.38
	SSA	6.47	13.64	14.84	13.55	13.73
	WANA	15.62	38.29	38.27	38.49	37.15
Total		**86.73**	**152.95**	**162.14**	**156.57**	**152.88**
Mixed extensive	CSA	89.93	176.36	194.5	180.7	180.1
	EA	55.61	92.19	95.89	97.01	90.79
	SA	41.27	61.66	63.56	65.62	61.79
	SEA	30.74	42.93	45.72	44.07	43.56
	SSA	102.82	236.08	253.04	236.56	238.98
	WANA	31.27	69.58	71.63	70.74	69.28
Total		**351.63**	**678.79**	**724.33**	**694.7**	**684.5**
Mixed intensive	CSA	89.8	189.33	210.85	192.6	192.94
	EA	338.88	450.46	486.75	477.21	450.93
	SA	166.28	233.67	241.76	249.36	235.11
	SEA	91.31	156.91	164.66	159.82	158.76
	SSA	31.99	71.3	78.73	71.35	72.72
	WANA	39.41	79.5	80.29	78.68	77.34
Total		**757.67**	**1181.17**	**1263.05**	**1229.00**	**1187.80**
Other	CSA	10.6	22.61	25.34	23.36	23.18
	EA	16.34	22.41	23.43	23.19	21.9
	SA	14.69	19.47	20.99	19.69	19.83
	SEA	3.19	5.18	5.42	5.28	5.24
	SSA	3.26	7.68	8.44	7.68	7.8
	WANA	1.25	3.17	3.25	3.19	3.14
Total		**49.32**	**80.53**	**86.86**	**82.39**	**81.1**
Total—all systems	CSA	202.19	414	459.15	422.82	422.42
	EA	431.06	592.23	634.34	626.1	590.29
	SA	253.95	361.57	377.19	382.97	364.48
	SEA	126.08	206.39	217.21	210.56	208.94
	SSA	144.54	328.7	355.05	329.14	333.23
	WANA	87.55	190.54	193.44	191.1	186.91
	Others	1063.65	1568.16	1675.94	1586.13	1559.90

Table 51. Metabolizable energy from stover by system, region and scenario to 2030

Farming systems	Region	Stover ME/LU 2000 (10³ MJ/LU)	Baseline 2030 (10³ MJ/LU)	Biofuels 2030 (10³ MJ/LU)	Irrigation expansion 2030 (10³ MJ/LU)	Low meat demand 2030 (10³ MJ/LU)
(Agro-) pastoral	CSA	1.40	2.05	2.05	2.10	2.31
	EA	5.96	4.21	3.96	4.15	4.42
	SA	26.15	28.38	25.63	29.05	31.14
	SEA	3.69	3.98	3.25	4.03	4.16
	SSA	1.00	1.96	1.78	1.97	2.15
	WANA	6.04	10.66	10.29	10.36	10.79
Mixed extensive	CSA	10.49	12.74	12.94	13.09	14.36
	EA	17.50	13.14	12.17	12.97	13.79
	SA	3.96	5.55	4.76	5.61	5.90
	SEA	22.24	22.51	18.90	22.91	24.31
	SSA	11.19	19.56	17.98	19.88	21.27
	WANA	25.99	46.02	44.91	45.95	48.15
Mixed intensive	CSA	10.20	15.06	15.09	15.42	17.06
	EA	66.50	48.85	45.51	49.03	53.26
	SA	10.94	13.61	11.96	13.81	14.46
	SEA	45.19	44.77	37.54	45.46	47.66
	SSA	15.74	25.14	23.59	25.72	28.06
	WANA	34.61	53.90	52.01	52.50	55.10
Other	CSA	1.93	2.70	2.73	2.78	3.07
	EA	10.76	7.57	6.91	7.42	7.99
	SA	11.87	13.78	11.54	14.15	15.25
	SEA	3.25	3.43	2.83	3.48	3.65
	SSA	3.00	5.11	4.76	5.20	5.67
	WANA	5.25	11.63	11.25	11.58	12.13
Total—all regions	CSA	6.53	8.83	9.96	8.88	9.05
	EA	32.61	23.05	24.89	21.50	23.03
	SA	9.82	12.58	13.51	10.91	12.80
	SEA	26.93	28.26	30.19	23.57	28.71
	SSA	7.78	14.14	15.45	13.02	14.37
	WANA	17.17	27.94	28.77	26.99	27.46
	Others	27.36	39.73	43.02	40.96	39.63

Figure 37. Composition of cereal stover availability by system and region 2000

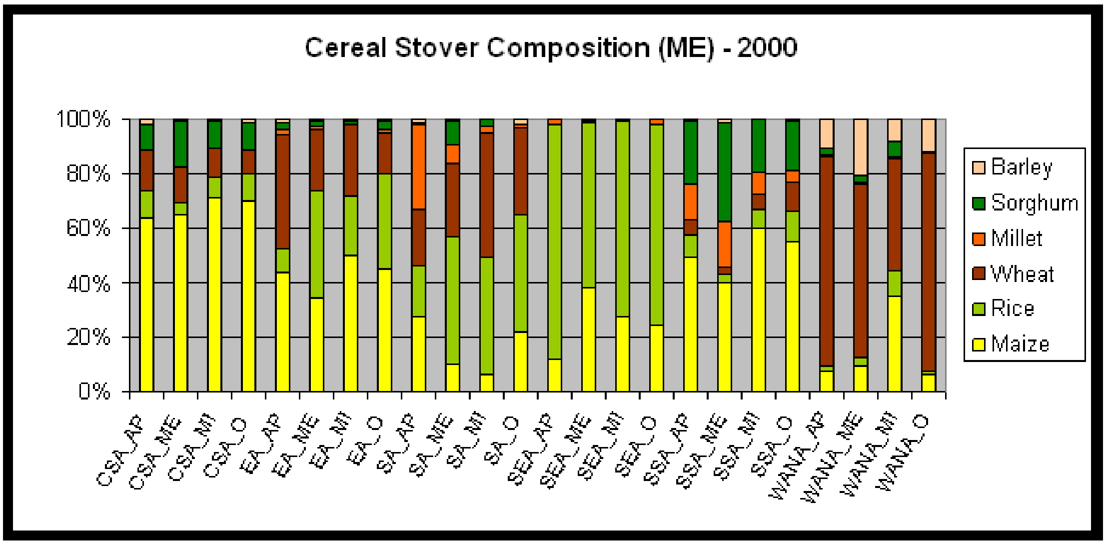
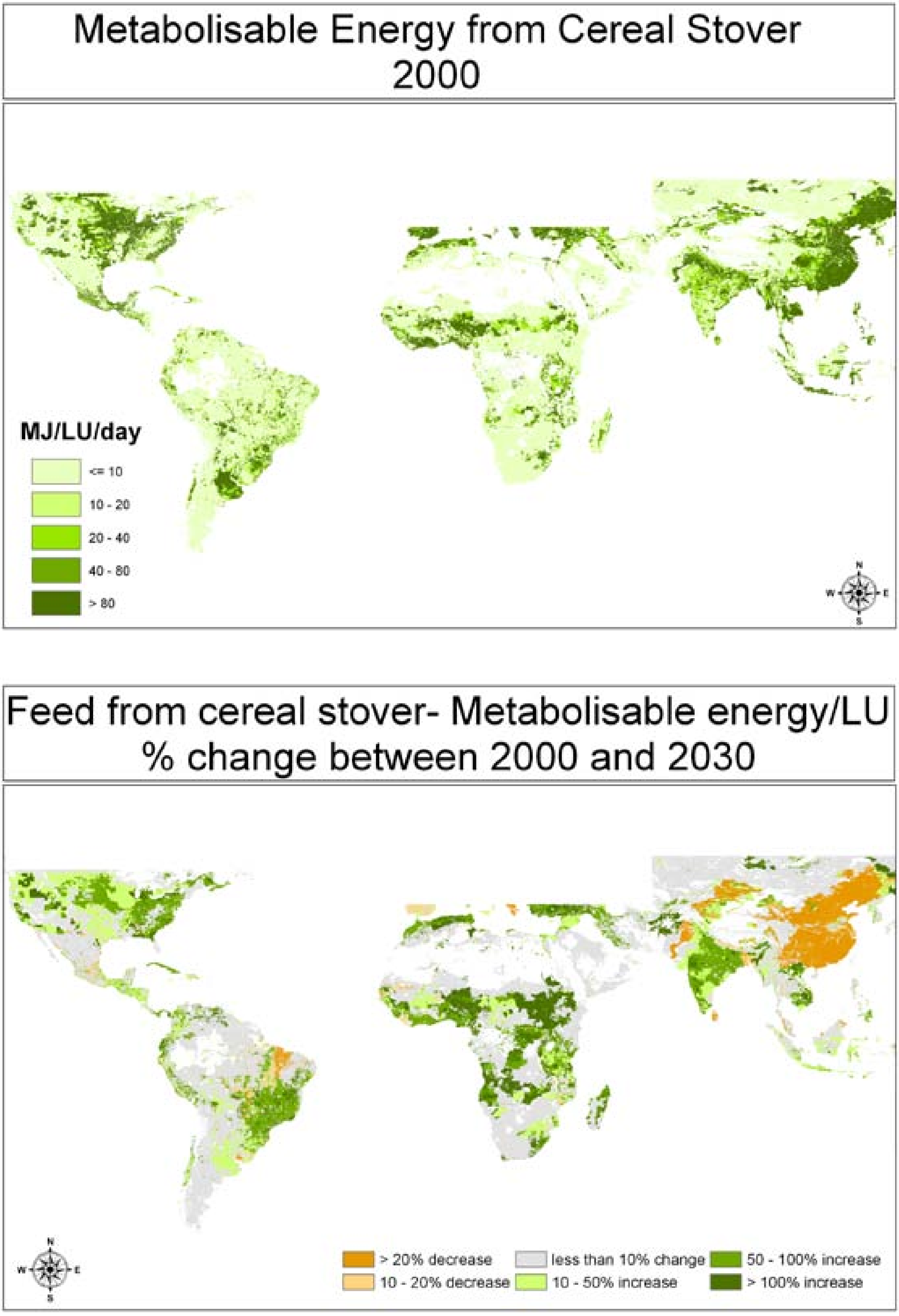


Figure 38. Global availability of metabolizable energy from stover for ruminants and its change to 2030



4. Land availability and water will be key constraints to the production of alternative feeds. If this production levels were to materialize, water demands from livestock would rise several fold (billions of litres) to produce fodders for animals and would compete directly with irrigation for the production of crops for multiple uses. On the other hand, if more grains were given to ruminant to match production this is likely to increase the prices of animal products further, thus bypassing the abilities of the poor to consume more milk and meat. In a sense—the livestock revolution—at least from ruminants, could potentially exclude the poor in terms of the benefits of consumption.

5. Another possible trend (and opportunity) would be a substantially increased trade of fodders and stovers in certain regions to move 'megajoules' from surplus to deficit areas (see Box 4). There is growing evidence that this is starting to happen at an accelerated pace in parts of South Asia (Michael Blummel, personal communication). Stovers are traded in India, they cover vast distances, their price is increasing and farmers are starting to pay for quality indicators.

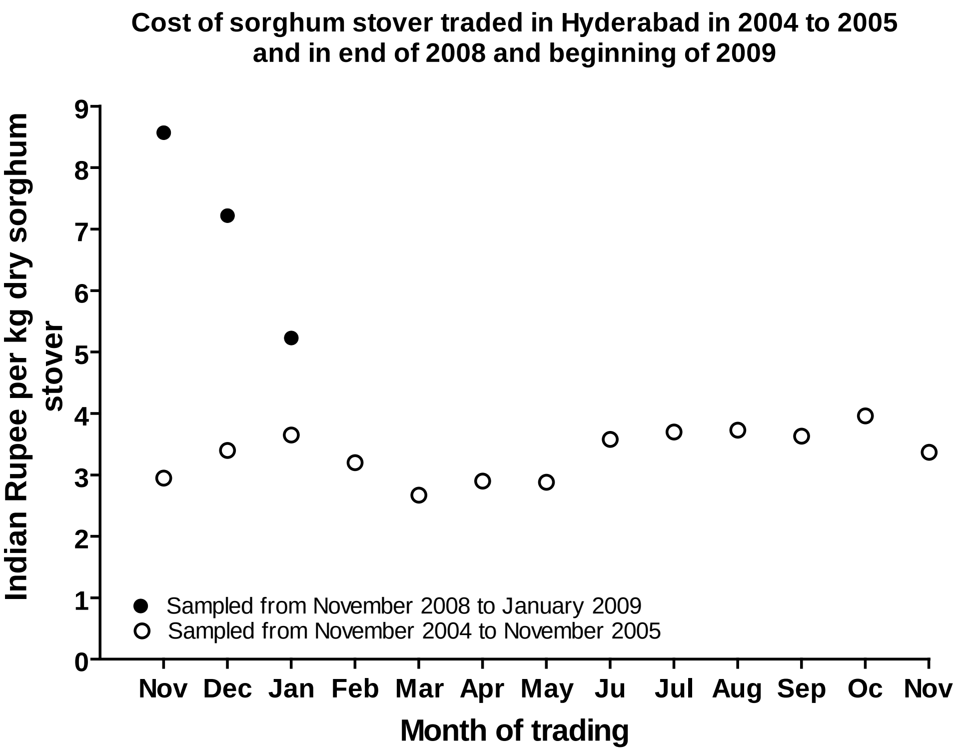
6. In these highly populated, land scarce systems competition or incentives for second generation biofuels from stovers may not happen, as there is not enough feed for ruminants. Prices of stover relative to efficiency and output prices of bio-energy and livestock production will determine the magnitude off this trade-off. Unless the residue after biofuel extraction was useable by ruminants then this could be an option to have both activities simultaneously, at least for a proportion of the farmers.

7. It is clear that the developed World has a surplus of stover that is not used as animal feed due to the poor quality of the material relative to the abundance of high quality, energy dense feed resources available and the needs of high producing animals to consume high quality feeds. Since stover is a surplus commodity that may only compete with conservation agriculture, these regions could invest in second generation biofuel technologies without detrimental trade-offs with their livestock industries.

Box 4. Economic value of sorghum stover traded as fodder for urban and peri-urban dairy production in Hyderabad, India

M. Blummel (ILRI) and P.P. Rao (ICRISAT)

Chopped sorghum stover is the major source of dry fodder for urban and peri-urban dairy production in Hyderabad, India (Tesfaye 1998). Blümmel and Rao (2006) sampled six major Hyderabadi traders of chopped sorghum stover monthly from November 2004 to November 2005 to better understand the value farmers and traders attribute to sorghum stover and to investigate the relationship between price of stover and stover fodder quality. Traditionally sorghum fodder was brought to Hyderabad market in cartloads from villages, a distance of 50 to 100 km away. During 2004 to 2005 the fodder shops traded sorghum stover from regions of Andhra Pradesh, Karnataka and Maharashtra up to 300 to 400 km away. The average stover price per kg dry stover was 3.5 Indian Rupees but the price was dependent on stover quality (digestibility) and season. Our survey during 2004 to 2005 indicated that the average price for sorghum grain in wholesale grain markets around Hyderabad (Tandur, Mahabubnagar, Jedcherla, Jogipet) was about Indian Rupees 6 to 7 per kg. Thus average sorghum stover price is now approximately half that of the average grain price. The price of sorghum stover in Hyderabad's fodder markets in the late 1970s was about one-fourth of the grain price. We recently revisited the stover trader and prices have further increased reaching an average of Indian Rupee 7 per kg dry stover during November 2008 to January 2009. Sorghum grain prices at the same time averaged Indian Rupee 10 per kg.



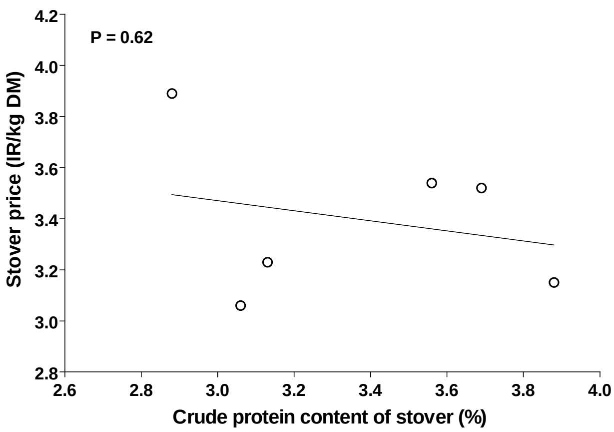


Figure 1: Relations between crude protein content of stover and price of stover

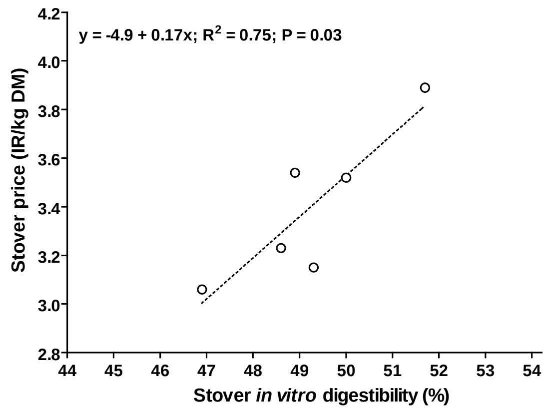


Figure 2: Relations between *in vitro* digestibility of stover an price of stover

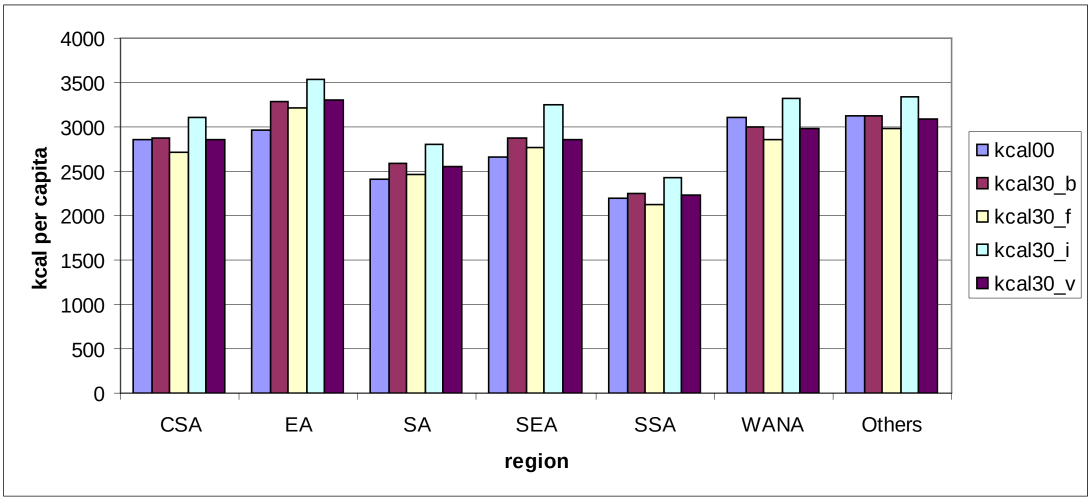
5.5 Impacts on human wellbeing

Human wellbeing

As discussed in the framework of the study described in section 1, agro-ecosystems responses to the pressures exerted by the drivers of change can be of many dimensions and can alter the condition of human wellbeing. As in IAASTD (2007), in this study human wellbeing is measured as food security (kilocalorie consumption) and the number and per cent of malnourished children under five which is a proxy for poverty.

Figure 39 shows the consumption of kilocalories per capita for different regions under different scenarios (IAASTD 2007). There are important differences in consumption between different regions and scenarios. In general terms, SSA has a lower average consumption than all other regions irrespective of the scenario, while EA has the highest. Not all regions increase the calorie consumption per capita under the reference scenario (i.e. WANA, others, very small increases in CSA). Rate of growth in consumption in Asia happens across regions and is the product of overall economic growth.

Figure 39. *Per capita kilocalorie consumption by scenario*



There are important trends in the scenarios and how they affect consumption. In general terms, the drastic biofuels scenario presented here has detrimental effects on consumption, especially in CSA, SSA, WANA, and others. These effects are mediated via the increased prices in commodities caused by the extra demand for biomass for energy production. At the same time, there is a general trend that irrigation increases will positively affect consumption by increasing the provision of relatively cheaper food for human, at a potential environmental cost of depleting water sources, aquaculture etc. This is a key trade-off that will become more acute in the future as demand for water for domestic and other uses increase.

Child malnutrition

Figure 40 presents the number of malnourished children under five for 2000 and 2030, while Tables 52 and 53 present the total numbers of malnourished children and the per cent of malnourished children relative to the human population for different systems, region and scenarios 2000–2030.

In general terms, the highest numbers of malnourished children are in the highly populated mixed intensive systems, with a disproportionate majority being in South Asia.

Under the reference scenario, most regions, especially Asia make significant inroads in reducing the numbers of malnourished children by 2030. This is in contrast to SSA which has the highest numbers of malnourished children in the agropastoral and mixed extensive systems, and increasing to 2030.

Table 52. Predicted number of malnourished children under five by system, region and scenario 2000–2030

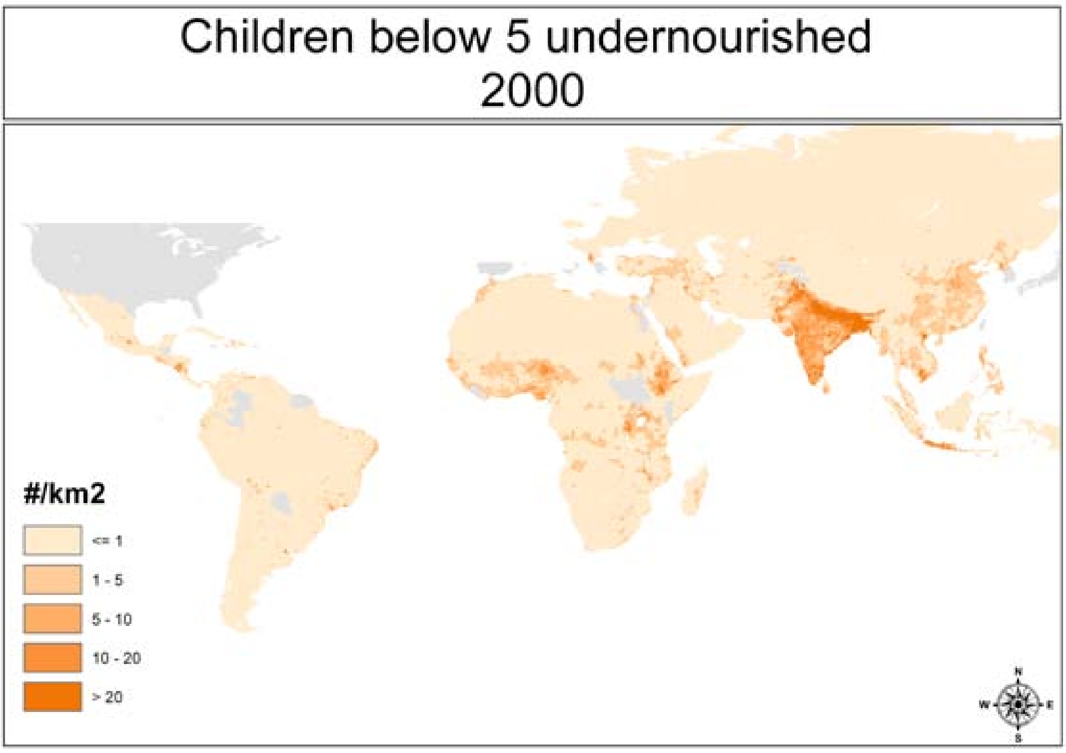
Farming system	Region	Malnutrition 2000 (10^3 children below 5)	Reference run 2030 (10^3 children below 5)	Biofuels 2030 (10^3 children below 5)	Irrigation expansion 2030 (10^3 children below 5)	Low meat demand 2030 (10^3 children below 5)
(Agro-) pastoral	CSA	2017	2062	2218	1654	2091
	EA	320	94	109	5	90
	SA	1168	1112	1156	844	1121
	SEA	54	46	48	33	46
	SSA	4861	5808	6177	4499	5888
	WANA	3763	4084	4413	2753	4150
Total		**12,183**	**13,206**	**14,121**	**9788**	**13,385**
Mixed extensive	CSA	1918	1953	2188	1474	1998
	EA	1999	608	705	17	576
	SA	20,998	16,298	16,750	13,636	16,403
	SEA	1768	1169	1219	871	1179
	SSA	15,621	20,099	21,343	15,361	20,363
	WANA	1802	1810	1966	1151	1844
Total		**44,105**	**41,937**	**44,172**	**32,510**	**42,365**
Mixed intensive	CSA	3999	3370	3712	2623	3435
	EA	6596	1829	2093	206	1745
	SA	47,475	38,424	39,457	32,595	38,662
	SEA	9380	7948	8281	6457	8016
	SSA	7380	10,942	11,609	8019	11,060
	WANA	1852	2069	2317	1094	2128
Total		**76,683**	**64,583**	**67,469**	**50,994**	**65,046**
Other	CSA	2348	2050	2285	1549	2096
	EA	1003	348	388	99	337
	SA	3370	2668	2750	2190	2687
	SEA	1094	864	908	607	873
	SSA	4455	6950	7458	5471	7050
	WANA	377	363	399	227	371
Total		**12,648**	**13,243**	**14,188**	**10,144**	**13,413**
Total—all regions	CSA	10,282	9435	10,403	7300	9620
	EA	9918	2879	3295	327	2748
	SA	73,011	58,502	60,113	49,265	58,873
	SEA	12,296	10,027	10,456	7968	10,114
	SSA	32,317	43,799	46,587	33,350	44,361
	WANA	7794	8326	9095	5225	8493

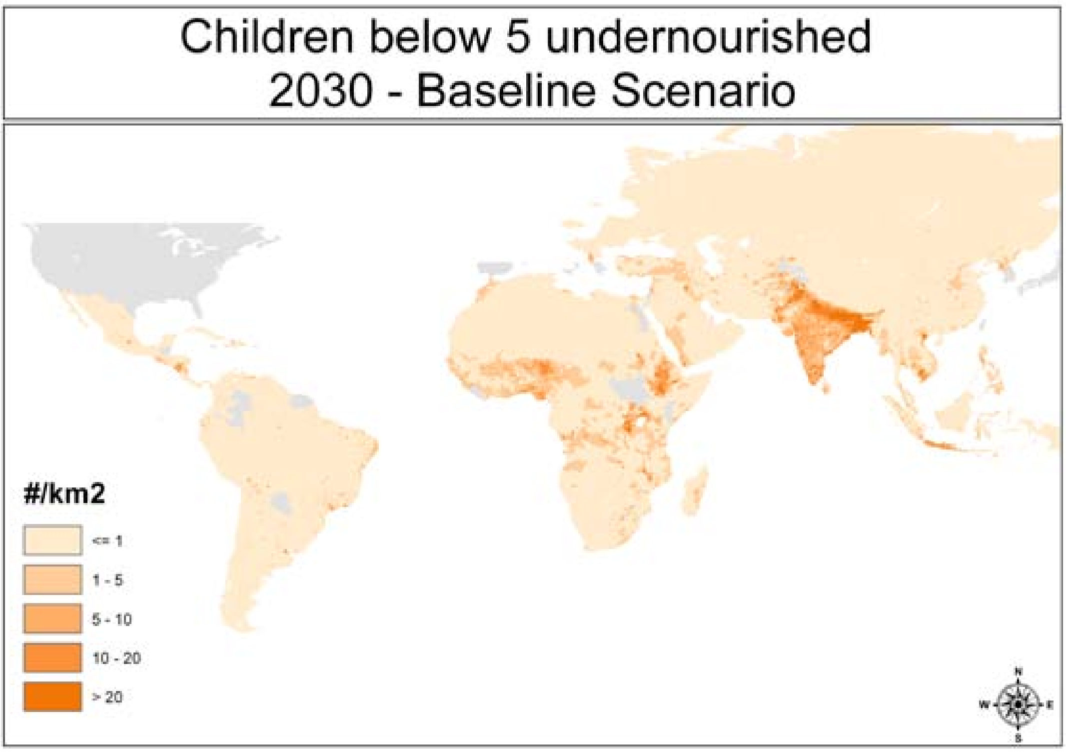
Distributions are large. Policy instrument change this distribution.

Table 53. Percentage of malnourished children under five relative to human population numbers by system, region and scenario 2000–2030

Farming system	Region	% malnourished as proportion of total population 2000	% malnourished as proportion of total population 2030 base	% malnourished as proportion of total population 2030 biofuels	% malnourished as proportion of total population 2030 irrigation	% malnourished as proportion of total population 2030 veggie
(Agro-) pastoral	CSA	2.6	1.8	2.0	1.4	1.8
	EA	0.9	0.2	0.2	0.0	0.2
	SA	5.5	3.0	3.1	2.4	3.0
	SEA	2.6	1.6	1.7	1.3	1.6
	SSA	5.3	3.8	4.1	2.9	3.9
	WANA	3.1	1.9	2.0	1.3	1.9
	Others	2.1	1.8	1.9	1.6	1.9
Total		**3.4**	**2.4**	**2.6**	**1.8**	**2.5**
Mixed extensive	CSA	1.9	1.2	1.4	0.9	1.3
	EA	1.0	0.2	0.2	0.0	0.2
	SA	5.7	3.0	3.1	2.5	3.1
	SEA	2.0	1.3	1.3	0.9	1.3
	SSA	6.6	4.4	4.6	3.4	4.4
	WANA	2.4	1.9	2.0	1.1	1.9
	Others	0.0	0.0	0.0	0.0	0.0
Total		**2.1**	**1.3**	**1.4**	**1.0**	**1.3**
Mixed potentially intensify	CSA	2.3	1.5	1.7	1.2	1.6
	EA	0.7	0.2	0.2	0.0	0.1
	SA	5.7	3.1	3.2	2.6	3.1
	SEA	2.7	1.6	1.6	1.3	1.6
	SSA	4.6	3.4	3.6	2.5	3.4
	WANA	1.2	0.8	0.9	0.4	0.8
	Others	0.4	0.3	0.3	0.2	0.3
Total		**2.8**	**1.7**	**1.8**	**1.4**	**1.7**
Other	CSA	1.9	1.2	1.4	0.9	1.2
	EA	0.8	0.2	0.2	0.0	0.2
	SA	5.2	2.8	2.8	2.3	2.8
	SEA	2.7	1.6	1.7	1.2	1.6
	SSA	4.0	3.5	3.8	2.7	3.5
	WANA	2.4	1.6	1.7	1.2	1.6
	Others	0.1	0.1	0.1	0.0	0.1
Total		**2.1**	**1.5**	**1.6**	**1.1**	**1.5**

Figure 40. Density of malnourished children under five, 2000–2030





The highest rates of malnutrition relative to population increases are in agropastoral systems followed by the mixed intensive systems. In one hand it may be the case of increased vulnerability, lack of primary productivity, poor market access and lack of economic growth but large land holdings (agropastoralists, Thornton et al. 2006) while on the other hand it may be simply too many people, specially poor, relative to the amount of resources available (i.e. mixed intensive systems). South Asia and SSA exhibit particularly large rates of malnutrition across these systems.

In terms of alternative scenarios, numbers and proportion of malnourished children are higher in the biofuels scenario when compared to the reference scenario. This is caused mostly by the increased competition for grains for bio-energy vs. food and feed, therefore increasing dramatically the prices of the basic staples and some livestock products. The ultimate result is that the poor are denied access to cheap food due to its high cost. The irrigation scenario reduces further the rates and numbers of malnourished children as more food can be supplied to meet demand, though at a potentially high environmental cost as explained before. The low meat consumption scenario releases some of the demand pressures for grains, thus lowering the prices of staple commodities. This increases the accessibility of basic staples for poor people.

6 Conclusions

A range of integrated assessments have studied the state and future of global ecosystems and their capacity to provide key services for humans (food, fibre, energy and others) while maintaining ecosystems functions (MA 2005). A recent study also highlighted the future pressures on global food production and the need for additional investments in science and technology as a prerequisite to meet increasing human demands in a sustainable way. This study used those results to further differentiate the impacts of different drivers of change on specific production systems in terms of what this meant for the sustainable intensification of food production and maintenance of ecosystems services for the developing world. There is a significant need for further differentiation of data from global assessments at the production systems level to be able to design technology, policy and investment options with more focus, that are of greater relevance to the social groups in question.

The role of population density, agro-ecological potential, length of growing period and market access as good proxies for describing change, development differences and investment opportunities in production systems in the developing world has been widely demonstrated. The CGIAR study describes three basic land-based production systems and one landless system:

- Agropastoral systems with low population densities, low agricultural potential and poor market access. These areas are characterized by livelihood systems depending mostly on ruminant livestock.

- Extensive crop–livestock systems with medium population densities, where there is crop cultivation but low yields, extensive livestock production mainly for meat production, low input use, and poor connectedness to markets.

- Intensive crop–livestock systems with high population densities, high agricultural potential including the use of irrigation sometimes, high input use, intensive livestock rearing predominantly for dairying, and good market access.

- Industrial systems: as developing countries industrialize, large-scale monogastric production systems spring up and tend to be located close to urban centres to minimize the problems associated with product conservation and transportation (Steinfeld et al. 2006). These are essentially landless systems.

Mixed crop–livestock systems are and will continue to be the backbone of sustainable pro-poor agricultural growth in the developing world to 2030. Their significance cannot be ignored in the global development agenda. Two-thirds of the global population live in these systems. They produce 50% of the world's cereals and more importantly, produce most of the staples consumed by poor people: 41% of maize, 86% of rice, 66% of sorghum and 74% of millet production. They also produce the bulk of livestock products in the developing world—75% of the milk and 60% of the meat—and employ many millions of people in long value chains. Rates of growth in production and consumption of agricultural products are significantly higher in these systems than in others, with livestock production and consumption rates doubling those of crops (Delgado et al. 1999).

Traditionally, governments in developing countries have often targeted public investments to the mixed intensive systems as they have been seen as the engines of agricultural growth in these regions, typified by the green revolution in South Asia in the 1970s. At the same time, public investment has historically been significantly higher in crops than in the livestock sector, often by a factor of ten or more.

Intensive crop–livestock systems in the developing world are under significant pressures and the substantial growth rates in productivity observed in the past may be attainable no longer. These pressures are larger in some systems than in others but are all caused by the rising demands of the human population, income shifts, and high rates of urbanization. Globally, population in these systems will increase from 2.5 billion people to 3.4 billion by 2030, predominantly in Asia. Intensive crop–livestock systems in South Asia are reaching a point where production factors are seriously limiting production as land per capita decreases. Rice and wheat production in the future may not grow fast enough to meet human demands due to water constraints. At the same time, livestock numbers will increase significantly: cattle and buffalo will increase from 150 to 200 million animals by 2030 while pigs and poultry will increase by up to 40% over the same period. The pressures on biomass to feed these animals are already high and significant trade-offs in the use of resources (land, water, nutrients) exist in these systems, especially as the demands for biomass for food, feed and energy increase. In the high-potential areas of Africa, such as the East African highlands, these phenomena can also be observed. They are manifested in significant reductions in soil fertility, loss of carbon, environmental degradation, reduced production and shrinking farm sizes.

Systems with high degrees of intensification will require options with high efficiency gains without using any more land and water. While crop production is reaching its yield increase limits in these systems, there is considerable scope for increasing the efficiency gains in resource use to produce more meat from intensive crop–livestock systems. Monogastrics such as chickens and pigs have doubled the efficiency of conversion of grain into meat in the last 30 years (Steinfeld et al. 2006). This has led to increased use of grains to feed livestock, at the same time producing more meat per unit of grain fed. Growth in this sector has reduced global poultry prices significantly at the expense of increased cereal demands that not only compete with food for humans but may fuel deforestation (Steinfeld et al. 2006). In some regions, livestock species shifts will be required to use resources more efficiently and policies to promote specialization of production will need to be implemented. Specialization and intensive industrial livestock production will also require environmental and trade regulations, as they may lead to concentration of animals and potential environmental problems such as large nutrient loadings in peri-urban areas (Steinfeld et al. 2006). This may affect water quality for human populations and increase the risk of epidemics of emerging diseases that could affect both livestock and humans. Evidence from South Asia suggests that species shifts are already occurring in intensive crop–livestock systems, and these will continue. For example, rates of growth in poultry production to 2030 are projected to be higher than 7% per year, two to three times higher than rates of growth in ruminant or crop production.

Not putting our money where our mouth is: a necessary paradigm for sustainable global food production, ecosystems maintenance and poverty reduction? Resource constraints in some land-based mixed intensive systems are reaching a point where crop–livestock production could decrease and where environmental degradation may have deleterious impacts on humans. In more extensive systems, with less pressure on the land, the yield gap for crops and livestock is still large. For example, yields of dryland crops such as sorghum, millet and cowpea could be increased by a factor of three with appropriate use of inputs. Important productivity gains could be made in these more extensive mixed rainfed areas. Pro-poor policies and public investments in infrastructure will be essential to create systems of incentives, reduce transaction costs, and improve risk management in these systems. Integration of production in these systems to supply agro-ecosystems services (feeds, food etc.) to the more intensive systems will also be needed to ensure the viability of the more intensive systems in the future.

Considerable changes in public and bilateral resource allocation may thus be required. Governments will need to prioritize investments in a non-traditional way. Instead of allocating most resources to areas that are highly populated or that have high agricultural potential, investing in infrastructure and services in the more extensive areas may be the key for the food security of the future. Early actions in this area are essential to combat increasing risks of food insecurity, especially considering the likely impacts of climate change in some regions (IPCC 2007).

Rural-to-urban migration rates in extensive crop–livestock systems are high but with the right sets of incentives, such as roads and market creation, infrastructure, health facilities and other services, these could decrease. Nurturing the next generation of food producers in the developing world is of key importance for the food security and poverty reduction of large areas of the globe. At the same time, with these incentives, some pastoralists will grow marginal crops, changing their systems from pastoral to crop–livestock systems. This additional food production, although small, is crucial to the livelihoods of poor people who are largely dependent on livestock.

Defining the limits to intensification is crucial for developing regulatory frameworks for sustainable food production and for maintaining ecosystems functions. Intensification of production through science and technology investments (increased input use, changes in crop varieties or animal breeds etc.) has been enormously successful in increasing global food production over the last 200 years. With this has come increased understanding that there can be serious consequences for the environment associated with intensifying systems without limits. Particularly in the developing world, there is a need for understanding and developing a set of criteria to define the thresholds of intensification before irreversible environmental degradation occurs. The limits and criteria will differ depending on location and production system but they should lead to a regulatory framework for systems' intensification that can be applied at the local level. This framework needs to be accompanied by a robust and practical monitoring and evaluation framework. Within this framework, it may well be that some systems will need to de-intensify or stop growing to ensure the sustainability of agro-ecosystems or to protect key resources for the future of specific regions. This will need to be accompanied by the development of options for diversification of income sources for users of key resources through smart schemes for payments for ecosystems services in these regions. Successful examples are starting to appear in the literature (FAO 2007).

The viability of global food production, the maintenance of ecosystems services, and the reduction of poverty, involve an increasingly complex and subtle balancing act of promoting well-regulated, differential growth in crop–livestock production, and in investing in food producing systems that traditionally have not received as much attention in the past. These strategies can only be implemented with new, more dynamic policies that weight carefully the trade-offs between agro-ecosystems services and human wellbeing. The rules of the game have changed, as protecting global goods becomes ever-more critical to the survival of the planet.

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Appendix A: Definition of the regions

Region	Country
CSA	Argentina
	Barbados
	Belize
	Bolivia
	Brazil
	Chile
	Colombia
	Costa Rica
	Cuba
	Dominican Republic
	Ecuador
	El Salvador
	French Guiana
	Guatemala
	Guyana
	Haiti
	Honduras
	Jamaica
	Mexico
	Nicaragua
	Panama
	Paraguay
	Peru
	Puerto Rico
	Suriname
	Trinidad and Tobago
	Uruguay
	Venezuela
EA	China
	Mongolia
	North Korea

Region	Country
SA	Bangladesh
	Bhutan
	India
	Nepal
	Pakistan
	Sri Lanka
SEA	Brunei
	Cambodia
	Indonesia
	Laos
	Malaysia
	Myanmar
	Papua New Guinea
	Philippines
	Thailand
	Vietnam
SSA	Angola
	Benin
	Botswana
	Burkina Faso
	Burundi
	Cameroon
	Chad
	Congo
	Congo, Democratic
	Côte d'Ivoire
	Djibouti
	Equatorial Guinea
	Eritrea
	Ethiopia
	Gabon

Region	Country
	Gambia
	Ghana
	Guinea
	Guinea-Bissau
	Kenya
	Lesotho
	Liberia
	Madagascar
	Malawi
	Mali
	Mauritania
	Mozambique
	Namibia
	Niger
	Nigeria
	Rwanda
	Senegal
	Sierra Leone
	Somalia
	South Africa
	Sudan
	Swaziland
	Tanzania

Region	Country
	Togo
	Uganda
	Zambia
	Zimbabwe
WANA	Afghanistan
	Algeria
	Egypt
	Iran
	Iraq
	Israel
	Jordan
	Kuwait
	Lebanon
	Libya
	Morocco
	Oman
	Qatar
	Saudi Arabia
	Syria
	Tunisia
	Turkey
	United Arab Emirates
	Yemen

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