Food security and sustainable resource use –
what are the resource challenges to food security?

Background paper for the conference

"Food Security Futures: Research Priorities for the 21st Century",

11-12 April 2013, Dublin, Ireland

Draft 25 March 2013

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Over the past 50 years, the agriculture sector, which is predominantly small-scale, consisting mostly of smallholder farmers (Deininger and Byerlee, 2011), has kept pace with global food demand and contributed to decreasing the proportion of people in the world that go hungry, despite a doubling of the total global population. This is an incredible achievement by any measure.

The demand for food is expected to increase by over 60 percent over the next 40 years, as the global population reaches over 9 billion and as increased income drives dietary pattern changes towards more livestock products. The agriculture sectors (including forestry and fisheries) are also required to produce more non-food products, especially for energy (liquid biofuels, wood) and feed.

At the same time, the resource base of the agriculture sector is threatened by environment degradation, climate change, loss of biodiversity and ecosystem services and, particularly in certain areas, urbanization and industrial use. Also, agriculture is and will be increasingly facing greater uncertainty and risks – both natural, including the various direct and indirect impacts of climate change, and economic, including price volatility of both inputs and outputs. Recently concerns have been voiced that agriculture might, in the not too distant future, no longer be able to produce the food needed to sustain a still growing world population at levels required to lead a healthy and active life ((Godfray *et al.,* 2010, Foresight, 2011; HLPE, 2011a; FAO, 2012a, UNEP, 2012).

While the importance of farmers and their production systems to overall global food security is understood, the ability of these systems to continue to perform this function, along with increasing output to meet future demand, is questioned. Yield stagnation, and in some cases the decline in several of our grain production systems, is a concern for those charged with ensuring future global food supplies. Human-induced land and water degradation and associated provisioning of ecosystem services (i.e. benefits from a multitude of resources and processes that are supplied by natural ecosystems) threaten the integrity of both small and large farming systems and their ability to meet future food demand. The underlying cause for such problems is perceived to be an ever increasing demand for agricultural products facing finite natural resources such as land, water and genetic potential (Foresight, 2011; HLPE, 2011a; FAO, 2012a; UNEP, 2012).

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Agriculture and food production are already among the leading causes of pressure on natural resources (FAO, 2006a; FAO, 2009a; UNEP, 2010). Currently, about half of the world's land is used for agricultural production. Agriculture is a major driver of deforestation and loss of biodiversity. 70 percent of the water used are being consumed by the agriculture sector (Kabat, 2013). Agrochemicals are also an important cause of water pollution. Eutrophication is clearly associated with agriculture, mostly owing to the excessive application of synthetic fertilizers and mismanagement of animal manure. Food production and consumption account for an important part of energy consumption in many countries. In 2009, about 29.9 percent of fishstocks were overexploited, producing lower yields than their biological and ecological potential (FAO, 2012a). The decline of biodiversity is also continuing at an alarming rate: genes, species and ecosystems are being lost or are degraded, with often a strong impact on agriculture and livelihood.

The scarcity of some resources confronts production with the frontiers of capacities. This translates into a divide between limited resource availability and productivity increase on the one side, and global demand rise on the other. The first impacts of this tension in food and agriculture are the recent price spikes. The age of cheap resources is over (Giljum and Polzin, 2009). Resource scarcity translates into higher input and production costs and into tighter markets as demand rises at a higher speed than capacities of production. Tensions in the markets translate into higher commodity prices, which are the first signals of emerging scarcities (HLPE, 2011a). This happens noticeably in a price system that currently integrates the main productive resource inputs (land, capital, work) but that fails to account for the cost of other resources (very often water) or to internalize key environmental damage resulting from the production system itself (externalities, such as biodiversity loss, deforestation, degradation of ecosystems, carbon release, climate change, and water sedimentation and pollution). Resource scarcity also translates into a land rush, as some key land-scarce countries seek to secure their food security by not relying on the food markets but rather through foreign direct land acquisition and investments (HLPE, 2011b).

Resource scarcities (in terms of quantity and quality) will therefore constitute increasing challenges to food security both globally and locally. Ensuring a more efficient and sustainable use of natural resources is, thus, key to ensuring food security, as testified by the current discussions towards supplementing and integrating the United Nations Millennium Development Goals (MDGs), adopted in 2000, with Sustainable Development Goals (SDGs).

Addressing these challenges requires first a better understanding of what are the available resources, both globally and locally and how they match current and future needs. It has to take into account the respective trends affecting availability of resources (with the increased competition from other activities) and population and consumption growth and their regional and local distribution. Such an approach can lead to the identification of "systems at risk" (FAO, 2011a).

Increasing scarcities, growing needs and competing demands call for optimizing the use of resources. Improving resource efficiency sustainably can be a leading way to do so, provided that it encompass all dimensions of food security; not only availability but also accessibility, utilization and stability, which also introduce a long-term perspective. This requires considering this broad principle not only from an economic perspective but in all its dimensions – environmental and social and at various scales.

Progressing towards a more sustainable use of natural resources requires an improved assessment and monitoring of resource use to inform decision-making at every level, from the farm to global and consumer levels. It is essential to better design practices and technologies aiming not only for more physical production or more income but also taking into account the sustainable use of resources. A shared understanding of the availability of

resources and trends affecting them is also a prerequisite to improve their governance, which, increasingly, involves more numerous and diversified actors. Public actors can play a fundamental role in triggering the needed changes, using appropriate tools and policies.

1.   Resources for food security

Resource availability is giving way to various estimations, often because of integrating different criteria in their definition of availability. This section focuses on global biophysical availability, recognizing the need for more research towards integrated approaches, particularly at local level. It considers these estimations with regard to present and future needs, accounting for potential evolutions of yields.

1.1   What is the global situation in terms of available resources and how can it be compared with current and future needs

The headline finding from FAO's report on *World agriculture towards 2030/2050: the 2012 revision* (FAO, 2012b) is that agricultural production would need to increase by some 60 percent between 2006 and 2050 to meet projected growth in demand. Population growth alone would account for 39 percentage points of the increase, with the remaining 21 percentage points due to income growth and structural changes in the diet that are linked to income growth. This translates into improving caloric intake – from some 2 772 kcal/day/person in 2006 to 3 070 in 2050 at the global level, and significant improvements in the poorest regions: 2 240 to 2 740 kcal/day/person in sub-Saharan Africa and 2 293 to 2 820 kcal/day/person in South Asia. Pockets of undernourishment would remain a high concern through 2050, but the incidence would be down to 4.1 percent in developing countries, from the estimated level of around 16 percent in 2006. This assumes no change in policies; if targeted policies are pushed more actively (particularly in the most vulnerable countries and subregions), a zero-hunger target should be achievable.

Yield growth accounts from some 80 percent of the overall production increase, with modest improvements in cropping intensity and land changes accounting for the residual. There is a great deal of variance in present-day yields across regions with very low yields on average in sub-Saharan Africa (around 1 100 kg/ha) to a high of over 4 000 kg/ha in East Asia – even somewhat higher than in developed countries. The FAO (2012b) report assumes growth in yields of some 1.8 percent per annum in sub-Saharan Africa, perhaps on the optimistic side, though consistent with yield gap analysis. South Asia would see a more modest growth of one percent, with slower growth in all other regions. At the world level, the implied yield growth is 0.64 percent per annum.

Note that in the FAO scenarios, there is no incremental demand for bio-energy beyond the demand implied by existing biofuel mandates. More aggressive use of bio-energy would be expected to have an impact on these projections. This is estimated to result in about a 0.10 percent annual growth in agricultural product, thus of the order of an additional 5 percent to 2050 (Tweeten and Thompson, 2009). A more modest improvement in yields – compared with the trends depicted above – could also lead to more pressure on land use. Finally, the FAO report is predicated to some extent on minimal changes in net trade. A more globalized world, where stable access to food would be assured, would enable some production shifts to regions that have a distinct comparative advantage (see section 2).

The conclusion drawn by the FAO report is that food security at a global level is achievable under reasonable assumptions about land expansion and productivity growth, based upon historical performance and trend. However, food production and security at national level are

much less certain in a number of countries. Available land for agricultural expansion is concentrated in a relatively few countries; in many countries there are critical land and water constraints that severely impede expansion. The ability to achieve needed productivity growth may also be beyond the reach of many countries. A significant proportion of existing agricultural land has been characterized as degrading (Bai *et al.*, 2008) and some land is particularly challenging, being in remote areas with high marketing costs. Finally, the attainment of food security in many countries will also require more efficient and reliable international trade, given that urban population growth increases demand for foods such as wheat, for which very few countries are self-sufficient.

1.2 **Land**

[Note: The following is drawn from FAO, 2012a]

The first question is: how much land is there with crop production potential today?

On average at the global level, 4 million hectares of arable land were added annually over the period 1961 to 2007. Expansion of arable land continued to be an important source of agricultural growth in sub-Saharan Africa, Latin America and East Asia. This includes countries with ample land resources with potential for crops facing fast demand growth, particularly for exports and for non-food uses, e.g. soybeans in South America and the oil palm in Southeast Asia. Indeed, oil crops have been responsible for a good part of the increases in total cultivated land in the developing countries and the world as a whole, albeit often at the expense of forest land and savannah.

Notwithstanding the predominance of yield increases in the growth of agricultural production, land expansion will continue to be a significant factor in many developing countries and regions. The second question is therefore: "How much land is there that could be used to produce food to meet the needs of a growing population"?

A new version of the Global Agro-Ecological Zones (GAEZ v3.0) analysis has recently been finished (Fischer, van Velthuizen and Nachtergaele, 2011). The GAEZ, combining soil, terrain and climate characteristics with crop production requirements, estimates the suitability (in terms of land extent and attainable yield level) for crop production of each land grid cell at the 5-arc-minute-level, at four technology and management levels (low, intermediate, high and mixed). The suitability assessments provide extents for a range of suitability classes. Prime land is characterized as very suitable land with attainable yields of over 80 percent of maximum constraint-free yields. Good land represents "suitable" and "moderately suitable" land as per a definition allowing attainable yield levels down to 40 percent of maximum constraint-free yields, and "marginal" and "not suitable land" as per definition including all land with estimated attainable yields that are less than 40 percent of maximum constraint-free yields.

Summing over all the crops covered in GAEZ and the technology levels considered, about one-third (34 percent) of the world's land surface, or 4.5 billion ha, is estimated to be of prime or good quality for rainfed agriculture. Of this area, some 1.6 billion ha are already under cultivation. It is interesting to note that of this 1.6 billion ha, some 300 million ha (or 19 percent) of agricultural land are on areas the GAEZ deems only marginally suitable or even not suitable, at least for rainfed agriculture. Such areas might have been made productive by applying irrigation (e.g. 32 million ha in desert areas), or terracing of land with steep slopes, or because some farmers might have no choice or maybe are prepared to accept relatively

low yields. The remainder of the discussion below is limited to areas of prime and good quality.

Developing countries as a whole have some 2.9 billion ha of prime and good quality land, of which a quarter (700 million ha or 24 percent) was in use for agriculture in 1999/2001. The gross land balance at world level of 3.2 billion ha (2.2 billion ha in developing countries) would therefore seem to provide significant scope for further expansion of agriculture. However, this favourable impression needs to be qualified by a number of considerations and constraints.

First, the gross balance includes land currently under forests or built-up areas or on strictly protected land: excluding those from agriculture would lead to a remaining net balance of 1.4 billion ha (960 million ha in developing countries).

Second, the net land balance is very unevenly distributed among regions and countries. Some 85 percent of the remaining 960 million ha in developing countries is in sub-Saharan Africa (450 million ha) and Latin America (360 million ha) with very little land remaining in other regions. And furthermore, most expansion in Africa and Latin America is centred on a few countries, for example, the Sudan, the Democratic Republic of the Congo, Mozambique and Madagascar in the case of Africa.

Third, the method used to derive the estimates assumes that it is enough for a piece of land to support a single crop at a minimum yield level (40 percent of the maximum constraint-free yield) for it to be classified as prime or good land. The notion of overall land suitability is therefore of limited meaning, and it is often more appropriate to discuss suitability for individual crops.

Fourth, much of the remaining land suffers from constraints such as ecological fragility, low fertility, toxicity, high incidence of disease or lack of infrastructure. These factors reduce its productivity, and require high input use and management skills to permit its sustainable use, or prohibitively high investments to make it accessible or disease-free. Natural causes and human intervention can also lead to deterioration of the land's productive potential, for example through soil nutrient mining, soil erosion or salinization of irrigated areas. These lands are also home to rich biological and cultural diversity – natural habitats and ecosystems, indigenous peoples and communities. Expansion of global food production to these areas is not without significant social and economic cost. Hence the evaluation of suitability contains elements of overestimation, and much of the land balance cannot be considered as a resource that is readily useable for "food production on demand".

Expansion of land in crop production

Scarcity of these resources would be compounded by competing demands for them originating in urbanization, industrial uses and use in bio-fuel production, by forces that would change their availability such as climate change and the need to preserve resources for future generations through environmentally responsible and sustainable use.

Recently concerns have been voiced that agriculture might, in the not too distant future, no longer be able to produce the food needed to sustain a still-growing world population at levels required to lead a healthy and active life. The underlying cause for such problems is perceived to be an ever-increasing demand for agricultural products facing finite natural resources such as land, water and genetic potential (HLPE, 2011b). To meet projected growth in production, arable land in developing countries is projected to increase by 107 million ha (from 968 in the base year to 1 075 in 2050), an increase of 11 percent. Not surprisingly, the bulk of this projected expansion is expected to take place in sub-Saharan

Africa (51 million) and Latin America (49 million), with almost no land expansion in South Asia, and a constant area in Near East/North Africa and East Asia.

The arable area in the world as a whole expanded between 1961/63 and 2005/2007 by 176 million ha, the result of two opposite trends: an increase of 230 million ha in the developing countries and a decline of 54 million ha in the developed countries. The arable land area in the latter group of countries peaked in the mid-1980s (at 684 million ha) and has declined ever since. This decline in the arable area has been accelerating over time. The longer-term forces determining such declines are sustained yield growth combined with a continuing slowdown in the growth of demand for their agricultural products. The projections of this study foresee a further slow decline in their arable area to 608 and 586 million ha in 2030 and 2050, respectively (it should be noted that this could change should a sustained growth in the demand for biofuels materialize).

The slowdown in the expansion of arable land (and its eventual decline) is, of course, a direct consequence of the projected slowdown in the growth of crop production and the assumed continuing (albeit slower than in the past) increase in crop yields. Measured from the base year 2005/2007, the net result for the world as a whole would, by 2050, be an increase in the arable land area of some 70 million ha, consisting of an increase by almost 110 million ha in the developing countries and a decline by nearly 40 million ha in the developed countries. An increasing number of developing countries would witness a decline in arable land area towards the end of the projection period and embark on a pattern already seen for most developed countries (with production only increasing very slowly and increases in yield permitting a reduction in harvested crop areas).

It should be emphasized that all the estimates for expansion of arable land presented above are estimates of net expansion of arable area, i.e. they do not take into account the development of additional hectares of arable land needed to compensate for land taken out of production owing, for example, to severe land degradation. Unfortunately there is only anecdotal evidence of the extent of this phenomenon and there are no reliable estimates of the extent of land that needs to be replaced annually on a global scale.

Expansion of irrigated land

The importance of irrigated agriculture cannot be overstated. At present it accounts, with 16 percent of the arable area, for 44 percent of total crop production. The area equipped for irrigation has been continuously expanding (mainly in developing countries and only slowly in developed countries), although more recently this expansion has slowed down. The projections of irrigation reflect scattered information on existing irrigation expansion plans in the different countries, potentials for expansion (including water availability) and the need to increase crop production. The projections include expansion in both formal and informal irrigation, the latter being important in particular in sub-Saharan Africa.

The aggregate projection shows that the area equipped for irrigation could expand by 20 million ha (or 6.6 percent) over the period from 2005/2007 to 2050, nearly all of it in the developing countries. This means that some 10 percent of the land with current irrigation potential in this group of countries could be brought under irrigation, and that by 2050 some 60 percent of all land with irrigation potential (417 million ha) would be in use.

The expansion of irrigation would be strongest (in absolute terms) in the more land-scarce regions hard-pressed to raise crop production through more intensive cultivation practices, such as East Asia (+8 million ha), South Asia (+3 million ha), and the Near East/North Africa (+3 million ha), although in the latter region further expansion will become increasingly difficult as water scarcity increases and competition for water from households and industry

will continue to reduce the share available to agriculture. China and India together account for more than half (54 percent) of the irrigated area in developing countries. Although the overall arable area in China is expected to decrease further, the irrigated area would continue to expand through conversion of rainfed land.

1.3 Soil fertility

The importance of soil fertility for food production is undeniably paramount. The key issues for this section are: (i) what is the status of soil fertility in relation to agricultural and food production needs; and (ii) are current trends in soil fertility adequate to produce and sustain the required yield increases in the future. What is meant by soil fertility? Soils provide multiple functions for agriculture and the environment and are therefore managed in different ways depending on the nature of land use. Within agriculture, it is observed that three main aspects of soils are important in terms of sustainable agricultural production: chemical content (e.g. of nitrogen (N), phosphorus (P) and other elements), physical structure (e.g. texture, depth, cation-exchange capacity) and biology (organic matter and presence of fauna). There have been ample studies linking various aspects of soil fertility to yields and a global analysis using country data showed a strong negative link between nutrient depletion and major crop yields (Tan, Lal and Wiebe, 2005).

Assessment of fertility of soils

There is a surprising lack of compilation and analysis of current soil fertility status across vast areas of the world. Soil maps are traditionally based on soil types rather than soil fertility parameters. Hence, there is now a concerted effort to redress this gap through a coordinated soil analysis and mapping exercise (see Globalsoilmap.net). However, there have been studies of soil constraints and degradation. The FAO (2000) global study identified critical soil constraints for countries and regions and characterized regions by the following major constraints:

- Sub-Saharan Africa – aluminium toxicity, low cation exchange capacity
- North Africa and Near East – salinity and sodicity
- Asia and the Pacific – aluminium toxicity, hydromorphy, salinity and sodicity
- North Asia, east of Urals – hydromorphy, salinity and sodicity
- South and Central America – aluminium toxicity, high phosphorus fixation,hydromorphy
- North America – hydromorphy, aluminium toxicity
- Europe – hydromorphy

In some regions, such as North America and Europe, such constraints have been largely overcome through investments. However, in other areas, such as in sub-Saharan Africa, soil constraints remain problematic. The assessment by Oldeman, Hakkeling and Sombroak (1991) estimated that 15 percent of all land was degraded. A recent study based on trends in net primary productivity suggests that 24 percent of areas were degrading between 1981 and 2003, including many areas that were not previously classified as degraded. Of the degrading area, about 20 percent is cropland, which occupies about 12 percent of surface area (Oldeman, Hakkeling and Sombroak, 1991; Bai *et al.*, 2008). FAO has developed a land degradation assessment methodology (LADA). This approach leads to 25 percent of land being classified as highly degraded or affected by a high degradation trend according to FAO (2011a). Degradation of land can occur in several ways; it can be soil erosion, physical degradation and loss of organic matter. Then, nutrient depletion and chemical degradation of the soil may occur. Globally, only half the nutrients that crops take from the soil are replaced,

with nutrient depletion in many Asian countries equivalent to 50 kg/ha annually. In some Eastern and Southern African countries, annual depletion is estimated at 47 kg/ha of N, 6 kg/ha of phosphorus, and 37 kg/ha of potassium (FAO 2011a). When farming systems do not include fertilization or nitrogen fixation, losses from nutrient mining and related erosion are even higher (Sheldrick, Syers and Lingard, 2002). Henao and Banaante (2006) estimate that 85 percent of African farmland had nutrient mining rates of more than 30 kg/ha of nutrients annually and 40 percent of land had mining rates of over 60 kg/ha per year. FAO data suggests that by 1996, 550 million ha of land were degraded through agricultural mismanagement.

Irrigation has played a key role in raising agricultural production worldwide, but it can bring significant side effects such as salinization and waterlogging. Salinization may come about when irrigation releases salts already in the soil, or when irrigation water or mineral fertilization brings new salts to the land. Waterlogging is a related problem. It curtails plant growth by eliminating air from the soil, effectively stifling the plant. Waterlogging also often leads to salinization of soils. Globally, 34 million ha are now impacted by salinity representing 11 percent of the total irrigated equipped area, with Pakistan, China and the United States of America with the largest areas affected (FAO, 2011a); it is estimated that 1.5 million ha of arable land are lost annually due to salinity.

Effects of soil fertility loss

A study by Eswaran, Lal and Reich (2001) estimated that the productivity of some lands had declined by 50 percent by 2000 owing to soil erosion and desertification. Yield reduction in Africa due to past soil erosion may range from 2 to 40 percent, with a mean loss of 8.2 percent for the continent. In South Asia, annual loss in productivity is estimated at 36 million tonnes of cereal equivalent valued at USD5 400 million by water erosion, and USD1 800 million owing to wind erosion. It is estimated that the total annual cost of erosion from agriculture in the USA is about USD44 billion per year, i.e. about USD247 per ha of cropland and pasture. On a global scale, the annual loss of 75 billion tonnes of soil costs the world about USD400 billion per year, or approximately USD70 per person per year. These losses are perhaps most pronounced in Africa. As much as 25 percent of land productivity has been lost to degradation in the second half of the twentieth century in Africa (Oldeman, 1998). Because of the importance of agriculture to African economies, this has cost between 1 percent and 9 percent of GDP, depending on the country (Dregne, Kassas and Rozanof, 1991; Dreschel *et al.*, 2001). Few African countries are self-sufficient in food production, resulting in massive annual food imports. At the household level, rural poverty rates in Africa remain high, with an increase of the number of rural poor between 1993 and 2002 (World Bank, 2007). In 2001, about 28 million Africans faced food emergencies due to catastrophic events (e.g. flooding) that were caused or exacerbated by land degradation (FAO, 2001). When soils become very degraded, the use of conventional inputs such as mineral fertilizer can become ineffective as demonstrated on maize in western Kenya (Marenya, 2008). Globally, Tan, Lal and Wiebe (2005) noted that the ratio of crop yield to NPK fertilizer application has fallen dramatically between 1961 to 2000, from 494 to 71, which in part reflects the negative effects that reduction of soil fertility is having. The production losses associated with salinity are estimated to be USD11 billion annually.

Towards improved soil fertility

While some agricultural systems show signs of stability and sustainability for future food production, there is concern that, on degraded or degrading soils, needed yield increases will be difficult to achieve. Causes of land degradation and loss of soil fertility may be broadly classified into two inter-linked systems: natural causes and anthropogenic causes. Natural causes include those due to extreme and persistent climatic events or changes, such as a

rise in temperature or reduction in rainfall which may lead to deterioration of all soil health components. Extreme weather events such as high winds and rains can also generate a significant amount of soil erosion. Human-induced changes to soil fertility are more important in the sense of having direct effects on fertility and exposing soils to greater risk of climate induced losses. Among often cited management practices that contribute to degradation are overgrazing, reduction in fallowing of crop land, inadequate soil conservation measures on sloping land, inadequate vegetative cover and lack of nutrient replacement. Human management of soil is in turn affected by a range of factors including access to factors of production, poverty, education/knowledge, market access and infrastructure, and government regulations and tax incentives.

The future scenario of soil fertility management will certainly be context-specific. There are areas currently receiving 400 kg of N/ha (double-cropped rice in Asia) and there are likely to be shifts to managing with less fertilizer. In other places, such as sub-Saharan Africa, efforts will need to be redoubled to increase both the effectiveness of fertilizer use and the amount of fertilizer from their current very low levels. There may be particular concern with the effective management of phosphorus, being a limited resource (see section on inputs). As natural fallowing will disappear in most places, more intensive integrated soil fertility management practices will need to become standard practice, with complementary investment in soil conservation, crop rotations and intercrops, organic nutrient management with crop residues, animal manure, green manures and agroforestry, and mineral fertilizers.

Figure 1. Status of the land (capacity of ecosystems to provide services)
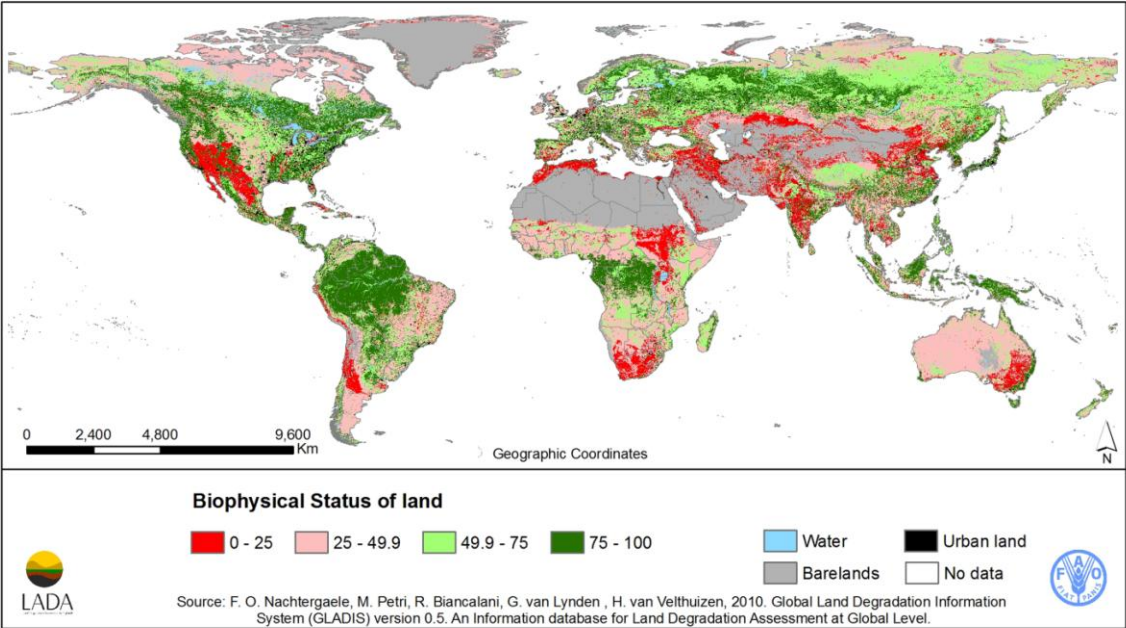
Source: Nachtergaele, Biancalani and Petri, 2011.

1.4 **Water (quality and quantity)**

The FAO projections indicate that the global demand for water withdrawals from agriculture will increase by 11 percent from a 2006 baseline to 2050 (Bruinsma, 2009). The threats to water security become even more pronounced when climate change, with its implications for

rainfall variability and scarcity, and the growing demand for biofuel crops, are factored into the equation. By 2050, more than half the world's population will live in countries with severe water constraints, including China, Egypt, Ethiopia, India, Iran, Jordan and Pakistan (Rockström *et al.*, 2009).

A starting point for the discussion on the pivotal role of water management in agricultural productivity is the trend in availability of arable land surface. Over the last 50 years, as average at global level, the number of hectares needed to feed one person has been reduced from 0.45 to 0.22 ha per capita, with the high-income countries cultivating 0.37 ha per capita against 0.17 ha per capita of the low-income countries (FAO, 2011a). Over the same period, the irrigated areas more than doubled (+117 percent), compensating for the loss of production as a result of the reduction of land surface availability per capita. Overall, with the demographic development expected in 2050, the arable land of the low-income countries (where most of the population growth will occur) will reduce worldwide to less than 0.13 ha per capita.

In the face of increased food demand expected in 2050, it is important to analyse the critical role of water management within the irrigated and rainfed farming systems.

With the mentioned doubling of the global irrigated area, withdrawals for agriculture have been rising significantly. While globally, total water withdrawals may appear to be limited (only 9 percent of internal renewable water resources), it varies greatly by country or region. Europe withdraws only 6 percent of its internal resources, and just 29 percent of this goes to agriculture. The intensive agricultural economies of Asia withdraw 20 percent of their internal renewable resources, of which more than 80 percent goes to irrigation. In many of the low rainfall regions of the Middle East, Northern Africa and Central Asia, most of the exploitable water is already withdrawn, with 80–90 percent of that going to agriculture, and thus rivers and aquifers are depleted beyond sustainable levels (FAO, 2011a). In fact, it is estimated that, on average, a withdrawal rate above 20 percent of renewable water resources represents substantial pressure on water resources – and more than 40 percent is "critical" (FAO, 2012c).

About 70 percent of the world area equipped for irrigation is in Asia, where it accounts for 39 percent of the cultivated area. South and East Asia account for over half of the world's area equipped for irrigation, and India and China together (each with about 62 million ha equipped for irrigation) account for 40 percent. The region with the least irrigation is sub-Saharan Africa, where only 3 percent of cultivated land is irrigated.

The irrigation water comes mostly from rivers, lakes and aquifers, while non-conventional sources of water, such as treated wastewater and desalinated water, provide a minor source of irrigation water (about 1 percent). Use of treated wastewater is on the increase as urban areas invest in treatment, and its use is popular for peri-urban cropping. Desalinated water is used for irrigation where high-value crops are grown and no alternative sources of water are available, but these tend to be exceptional cases (FAO, 2011a). Competition for water and the growing water scarcity are constraining both current availability of water for irrigation and further expansion of the irrigated area. Western, Central and South Asia are already in conditions of very severe water shortages, and these regions are undergoing significant increases of population, which will add greater stress on resources. In Northern Africa, withdrawals for irrigation exceed renewable resources. Furthermore, in many parts of the Middle East, North Africa, China and elsewhere, water tables are declining significantly. By contrast, Southern America barely uses 1 percent of its resources.

The substantive outcome of irrigation is in its large improvement of agricultural productivity and the stability of production. India and China tripled production in the 25 years after 1965,

mainly through investment in irrigation and widespread adoption of measures to enhance land and water productivity. At present, irrigated agriculture in developing countries covers about one-fifth of all arable land, but accounts for nearly half (47 percent) of all crop production and almost 60 percent of cereal production. In the least-developed countries, irrigation accounts for less than one-fifth (17 percent) of the harvested cereal area, but almost two-fifths (38 percent) of cereal production.

Relevant contrasts emerge when analysing rainfed agriculture, the predominant agricultural production system worldwide. Of the current world cultivated area of 1 600 million ha, about 1 300 million ha (80 percent) are rainfed, producing about 60 percent of global crop output.

Trends in rainfed areas differ by region. Sub-Saharan Africa, where 97 percent of staple production is rainfed, has doubled its cultivated cereal area since 1960. In Latin America and the Caribbean, rainfed cultivation has expanded by 25 percent in the last 40 years (FAO, 2010a).

Depending on temperature and soil conditions, rainfed cropping of some kind is possible where annual rainfall exceeds 300 mm. The distribution of rainfall during the growing season is also a key factor. Evidence from farms worldwide shows that less than 30 percent of rainfall is used by plants in the process of biomass production, the rest evaporates into the atmosphere, percolates to groundwater or contributes to river runoff (Molden, 2007). Soil nutrient availability in many rainfed lands tends to be low, and sloping terrain and variability and intensity of rainfall and runoff contribute to erosion and a high degree of risk associated with these systems. High temperatures and low and erratic precipitation often make soil moisture availability inadequate. All these factors reduce the chances of rainfed agriculture being highly productive and often preclude great investment. The most productive systems are concentrated in temperate zones of Europe, followed by North America, and rainfed systems in the subtropics and humid tropics. Rainfed cropping in highland areas and the dry tropics tends to be relatively low yielding. Clearly there are opportunities for reducing variability in these systems and being opportunistic in managing these systems has significant benefits.

It is argued, thus, that rainwater harvesting (RWH) offers great potential for improving the productivity and profitability of rainfed agriculture and for contributing to poverty reduction in Africa and Asia (Rockstrom, Karlberg and Wani, 2010). By collecting, conserving, storing and utilizing rainwater for multiple uses (e.g. domestic, livestock, agriculture, etc.), RWH can contribute significantly to the livelihood of rural people. Moreover, RWH has great potential to improve water use efficiency by storing and utilizing the water as supplemental irrigation at critical stages of the crop for an area that has been underutilized, thus reducing the risk associated with these systems. A wide selection of RWH technologies and practices to suit nearly every situation exists.

RWH interventions are also needed to respond adequately to climate change. There is broad agreement that one of the biggest impacts of climate change will be on rainfall, making it more variable and less reliable (Lenton and Muller, 2009). Therefore, the availability of water through harvesting, storage and its efficient use with improved water management practices remains a key strategy to cope with climate change, as it minimizes the risk of crop failure during droughts, intra-seasonal droughts and floods.

RWH for agriculture is therefore a means of making more water available from the same rainfall for different uses in agriculture, including irrigation.

When water is used in domestic and productive activities, and discharged again into the environment, water quality is changed which could compromise water use for human

consumption and in some cases for aquaculture and fisheries. In general, increasing population and economic growth combined with little or no water treatment have led to more negative impacts on water quality. Agriculture, as the largest water user, is a major contributor. Key non-point source pollution includes nutrient and pesticides derived from crop and livestock management. A further problem arises from salinization: many soil and water salinity problems have been reported in large irrigation schemes in Pakistan, China, India, Argentina, the Sudan and many countries in Central Asia, where more than 16 million ha of irrigated land are now salinized (FAO, 2010b).

Inland capture fisheries rely on adequate supplies of freshwater and functioning aquatic ecosystems. The world's inland fisheries provide food and nutritional security and livelihoods to many developing and least developed nations. Over 90 percent of inland fishery production is from developing countries with 65 percent produced from low-income food deficit countries (FAO, 2011a). Approximately half of the workforce is women.

Aquatic plants and animals provide high-quality protein and other nutritional components such as minerals and micronutrients that are not easily found in other food sources.

However, the supply of freshwater for fisheries is threatened by factors external to the sector, e.g. hydro-electric development, deforestation, agriculture, navigation, draining of wetlands and pollution. These activities can degrade water quality, disrupt water flow and fish migrations, make water unavailable when fish need it, and change aquatic habitats so that fish no longer survive. Freshwater fish are the most threatened group of vertebrates used by humans.

1.5 Forest and tree resources

Forests cover about 4 billion hectares, about 31 percent of the world's land area (FAO, 2012c, d). Globally, they are a source of livelihood for 1.6 billion people, including some 350 million of the world's poorest and most vulnerable people (World Bank, 2001; FAO, 2012d). Forests and agroforests provide crucial ecosystem services such as protecting soil from erosion, protecting against landslides, carbon sequestration, producing oxygen, delivering clean and reliable water supply, providing or enhancing the habitat of aquatic and terrestrial animals, and maintaining the habitats for biodiversity. Production of wood-based products, fibre and various non-wood products is critical for satisfying the needs for shelter, communication, packaging, food and many other uses of the global population (FAO, 2011b, c).

The increasing competition for land use (see section 1.1.1), including agriculture expansion, is a major driver of deforestation. Studies have shown that although the levels of deforestation are decreasing, they are still alarmingly high. Around 13 million ha of forest were converted to other uses – largely agriculture – or have been lost through natural causes each year in the last decade (FAO, 2011a; 2012d). Forest degradation is a serious environmental, social and economic problem, particularly in developing countries. On the other hand, afforestation and natural expansion of forests in some countries have significantly reduced the net loss of forest area at the global level. More than 12 million ha per year are afforested or reforested each year (FAO, 2010b). In the Mediterranean area, for instance, this is expected to continue towards 2050 as cropland and grassland decline under pressure from climate change (Skuras and Psaltopoulos, 2012). Forest ecosystems are also among the natural systems that will be severely affected by climate change (Pérez-García *et al.,* 2002; Walther *et al.,* 2002; IPCC, 2001a).

Forests contribute directly to food security through their contribution to more balanced and diverse diets, the intake of fruits and vegetables, the provision of bushmeat and fuelwood and their role in reducing malnutrition (FAO, 1996, 1997, 2009b, 2011c). However this crucial role of forests and trees for food security is not adequately documented, and thus less well understood and often overlooked (Colfer, 2008; Arnold *et al.,* 2011, Sunderland 2011). As a result forests and trees in agroforestry systems are often forgotten in the food security agenda. Too often food security is only measured in terms of food energy production, losing sight of the fact that by definition food security includes secure access to the foods needed for a nutritionally balanced diet. The focus on energy production has contributed to a dichotomization in which food production and forest conservation are portrayed as mutually exclusive endeavours. The contribution of forests and tree-based ecosystem services to food security is often overlooked when food security is operationalized as access to calories alone. The essential ecosystem goods and services provided by forests and trees needed for productive and sustainable food and agricultural systems are often overlooked in land sharing vs land sparing debates as well as in agricultural research, policy and practice in general.

While it is currently estimated that 868 million people do not have access to sufficient food energy (calories), estimates for the number of people who are micronutrient deficient are more than twice as high, at over 2 billion people (FAO, WFP and IFAD, 2012). Iron, vitamin A, iodine and zinc are the micronutrients most commonly deficient in diets around the world. Wild foods obtained from forested landscape mosaics are most often vegetables, fruit and animal source foods (Vinceti, Eyzaguirre and Johns, 2008; Powell, *et al.,* in press) – all very good sources of micronutrients. In the United Republic of Tanzania, wild foods obtained from a forest-farm landscape mosaic contributed 31 percent of vitamin A, 26 percent of iron and 23 percent of calcium intake of the local population (Powell *et al.*, in press). The same study found that wild food contributed 15 percent of the diversity in the diet and that tree cover was positively correlated with dietary diversity (Powell, 2012). In Gabon, Blaney, Beaudry and Latham (2009) found that use of natural resources (i.e. wild plant and animal foods) was positively associated with dietary nutrient adequacy in children (over two years of age) and adolescents. In the Democratic Republic of Congo, those individuals who had consumed wild plant foods had consumed more fruits, more fibre, more vitamin A and more calcium than those who had not (Termote *et al.*, 2012). There is emerging evidence of a link between tree cover and fruit and vegetable consumption. Ickowitz, Powell and Sunderland (forthcoming) found that across 21 African countries, there is a statistically significant and non-linear relationship between tree cover and fruit and vegetable consumption which peaks at about 53 percent tree cover. In the same study, the authors also showed that children's dietary diversity increases with tree cover for the majority of the population. Forests and areas with tree cover may enhance vegetable intake by providing vegetables in the form of leaves and fruit from trees, but possibly also through the ecosystem services provided by trees and forests within agricultural systems, which likely support the availability of wild and cultivated vegetables by providing the microclimates needed for vegetables to grow and other ecosystem services.

In many rural and urban settings wild meat from forests or agroforests provides much of the animal-source foods consumed (Fa, Currie and Meeuwig, 2003; Nasi *et al.*, 2008). This is particularly true in areas where livestock production is limited owing to tsetse fly and other environmental constraints. Nasi, Taber and Van Vliet (2011) show that approximately 4.5 million tonnes of bush meat is extracted annually from the Congo Basin forests alone. In Madagascar, the loss of access to wild bushmeat would result in a 29 percent increase in the number of children with anemia (Golden *et al.,* 2011). While the process of defaunation linked to unsustainable hunting is leading to a decline in the population of large game species, small resilient species are increasingly managed by Amazonian farmers in their fallows and forests. Small-game are mainly managed and hunted by women and children. Currently, small-game species constitute the main source of protein for rural families and the

relatively small amount of bushmeat from large-game species hunted by men is sold in the market.

Firewood or charcoal availability is an essential, but often overlooked component of local food systems (Kuhnlein, 2009). There are simply no affordable alternatives to fuelwood for cooking in many rural areas. Time spent collecting fuelwood is time not spent engaging in agriculture or other income-generating activities, not spent cooking and caring for children and not spent achieving full educational potential (education is strongly linked to household well-being, nutrition and food security). Even in areas with moderate fuelwood scarcity, women have been reported to travel over 10 km to collect wood (Wan, Colfer and Powell, 2011). Collection of fuel and water are energy demanding activities (possibly more so than most agricultural activities). In some areas with fuelwood scarcity, women have been reported to carry up to 70 kg of wood (Wan, Colfer and Powell, 2011). Wood energy scarcity can affect cooking practices and dietary choices including: skipping meals and avoidance of foods that are particularly fuel demanding (Brouwer *et al.*, 1996; Brouwer, Hoorweg and Van Liere, 1997; Wan, Colfer and Powell, 2011).

Agroforestry helps to tackle the challenge of securing food security, mitigating and reducing the vulnerability and increasing the adaptability of agricultural systems to climate change (FAO, 1995; 2013). It is estimated that 46 percent of agricultural land has more than 10 percent tree cover, affecting 30 percent of rural populations (Zomer *et al.,* 2009) and about 1.2 billion people rely on agroforestry farming systems (FAO, 2012f). Trees in the farming system can help to protect and sustain agricultural productive capacity, increase farm incomes, help to diversify production and thus spread risk against agricultural production or market failures (FAO, 2013). Tree-growing on farms is an increasing practice in many parts of the world not only to provide consumable products, but because it can diminish the effects of extreme weather events, such as heavy rains, droughts and wind storms, and prevent erosion, stabilize soils, raise infiltration rates and halt land degradation. In addition, forests can enrich biodiversity in the landscape and increase ecosystem stability (improving soil fertility is likely to increase the agricultural productivity and could allow for more flexibility in the types of crops that can be grown).

Some of the better understood ecosystem services essential to agricultural productivity and sustainability that are dependent (to a greater or lesser degree) on forests and biodiversity include: ecological processes such as the maintenance of watershed services, soil fertility, pollination, seed dispersal, nutrient cycling, and natural pest and disease control (MA, 2005; Hajjar, Jarvis and Gemmill-Herren, 2008; Sunderland 2011). Wild relatives of today's crops grow in forested or uncultivated areas within an agricultural landscape mosaic, and provide valuable genetic material essential for future crop breeding and innovation (Toledo and Burlingame, 2006; Hajjar, Jarvis and Gemmill-Herren, 2008; Frison, Cherfas and Hodgkin, 2011). The majority of today's modern crop and livestock varieties are derived from their wild relatives and it is estimated that products derived from genetic resources (including agriculture, pharmaceuticals, etc.) are worth an estimated USD500 billion/annum (ten Kate and Laird, 1999). Pollination is perhaps one of the best measured ecosystem services from forests and biodiversity (Kevan and Phillips, 2001; Garibaldi, *et al.*, 2011). Gallai *et al.,* (2009) report that vegetables and fruits were the leading crop categories in value provided by insect pollination services, which may help to explain emerging relationships between tree cover and consumption of fruits and vegetables; the majority of the global vitamin C, vitamin A (RAEs), calcium and much of the folic acid are supplied by animal (and insect) pollination dependent crops (Eilers *et al.*, 2011). Agricultural systems with a diversity of cropping and land-use types are also more resilient to extreme weather events caused by climate change (Brookfield *et al.*, 2002).

Because food security is dependent on complex and intertwined issues of sustainability, availability, access, utilization and diet quality – and not production of food energy (calories) alone – it is evident that new approaches are needed to feed the world's population both efficiently and equitably (Vinceti, Eyzaguirre and Jones, 2008). Increases in food production over the past 50 years have been made largely at the cost of forest biodiversity and ecosystem service provision (Foley *et al.*, 2005), yet there is considerable evidence that diverse agro-ecological tree-based systems can be equally, if not more productive in terms of actual yield (Rosegrant and Cline, 2003; UN, 2011), notwithstanding the biodiversity benefits of such approaches (Brussaard *et al.,* 2010).

A clear programme of work on managing forest landscapes directly for food, but also indirectly for the biodiversity and ecosystem services that underpin sustainable food production, should be increasingly placed at the centre of future development initiatives.

1.6 Fisheries

Fisheries and food security

A recent analysis of wild capture fisheries drew two simple and related conclusions: (i). the countries that depend most on fish for food and nutrition security rely primarily on catches from the wild; and (ii). most of those countries are in the developing world (Hall *et al.,* submitted).

In many settings these fish represent the principal animal source food for the population, supplying both high quality protein and essential micro-nutrients for maintaining health and well-being (Kawarazuka and Bene, 2011). This dependency is likely to persist for the foreseeable future because, for most of these countries, aquaculture remains a relatively small contributor to total supply. This is particularly true for most of the African and small island developing states. Although recent aquaculture growth rates for some of these countries are among the fastest in the world, the low base from which they are starting makes a major contribution to national fish supplies unlikely in the next 10–15 years, even under ideal conditions. There is no immediate prospect, therefore, that aquaculture will replace any losses of local wild fish supplies or meet future demand growth unless it is through imports of farmed fish – currently an unaffordable prospect for these countries. Given this circumstance, a key question, therefore, is the ecological sustainability of wild fish production, particularly in the developing world, and the limits to supply.

The status and future of fisheries.

The most authoritative assessments of world fisheries status come from FAO. Covering 445 stocks, estimates of their status comprise about 80 percent of FAO estimated global catch. The most recent estimate states that 29.9 percent of stocks were over-exploited, depleted or recovering in 2009 (FAO, 2012a), a slight decrease from 2008.

These data also suggests a moderate increase in the proportion of over-exploited stocks over the past 20 years from around 25 percent in 1999 to about 30 percent in 2009 (FAO, 2012a). Using catch data, however, Pauly and Froese (2012) argue that this assessment is highly conservative and that decreases are much more dramatic, while Branch *et al.* (2011) argue that analyses based on catch are biased and provide a distorted picture of the status of world fisheries.

Although these disputes remain unresolved (Pauly, Hilborn and Branch, 2013), there remains considerable cause for concern. In particular, south, southeast, east Asia and west Africa are among several regions where the data to assess stock status have either not been collected or have yet to be adequately analysed and included in global syntheses.

Notwithstanding the inevitable uncertainties in the status and trends of both marine and freshwater fisheries, little doubt that we are at, or close to, the limits of what natural systems can provide (FAO, 2012a). Although improved fisheries and environmental management could increase yields to a some degree (Srinivanasan *et al.*, 2010, 2012; Ye *et al.*, 2012), and despite the considerable prospects for avoiding spoilage and waste of the landed catch in many fisheries (Kumolu-Johnson & Ndimele, 2011), any such increase in supply will be outstripped by increasing global demand (IFPRI/WFC, 2003).

While there may be relatively limited prospect for increasing wild fish catches, ensuring the long-term resource sustainability remains vital. Balanced against this, however, is the fact that hunting in the world's aquatic wildernesses generates societal concerns about the ecological effects of fishing – concerns that extend beyond issues of resource sustainability to encompass more fundamental nature conservation considerations.

Fishmeal

The most common use for fisheries resources is food. Over 75 percent of the global fish production is used for direct human consumption and the consumption of fresh fish is growing at the expense of other forms of fish products (e.g. canned fish). Fish landed that are not used for direct human consumption are reduced to fishmeal and oil (some 33 million tonnes per year) used as feed, mainly for pigs and chickens and, more recently, for raising carnivorous aquatic species (such as salmon, shrimp, sea bass, and sea bream).

Does using fish to feed fish deprive the poor of food? In some circumstances the answer is clearly yes, but overall no. On the contrary, a recent global estimate suggests that including fishmeal and fish oil in feeds for aquaculture products actually increases the effective supply of fish for human consumption by 7–8 million tonnes per year.

It is also worth noting that, since 2004, fishmeal and fish oil use has remained static while aquaculture has continued to grow. This decoupling of aquaculture growth from wild fish supply is comforting because efforts to increase catches to supply animal feeds could compromise the sustainability of these fisheries. In fact, recent modelling studies are showing just how important the fisheries that supply animal feeds are for also sustaining populations of larger predators; further efforts to limit or perhaps even reduce catches may be needed to ensure they continue to do so.

With little prospect that fishmeal and fish oil supplies can be increased, the limits to supply and price pressures will continue to drive efforts to further improve feed use efficiency and substitution both with crop-based alternatives and more innovative substitutes from algae and other sources.

1.7 Genetic resources

Genetic resources play a crucial role in making the best use of available natural resources and also in building resilience of natural and managed ecosystems to risks and changes. With the ongoing erosion of these resources, humankind loses the potential to adapt to new socio-economic and environmental conditions, such as population growth and climate change. A large portfolio of genetic resources of terrestrial and aquatic plants, animals and micro-organism species, obviously including fish, trees and invertebrates, will be needed to

increase agricultural production in a more sustainable way and meet future demands for food, despite the many challenges ahead.

This section considers genetic resources for food and agriculture, plants (including trees) and animals (including fish), and also biodiversity associated with agricultural sectors, such as pollinators, pest predators, soil microfauna and wild relatives of domestic species. Their sustainable use is closely linked to the management of associated ecosystems. Humans have used more than 7 000 species of plants and another 70 000 plants are known to have edible parts (Wilson, 1989) and have domesticated about 8 200 animal breeds. Different animal breeds and plant varieties provide different services, contain different nutrient elements and are adapted to survive and reproduce in different social and environmental conditions. Furthermore, Prescott-Allen and Prescott-Allen (1990) calculated that the world's food comes just from 103 plant species based on calories, protein and fat supply. However, only four crop species (maize, wheat, rice and sugar) supply almost 60 percent of the calories and proteins in the human diet (Palacios, 1998). In livestock, breeds of five main species provide the bulk of global food supply. Plant and animal species for food have been collected, used, domesticated and improved through traditional systems of selection over many generations. This has resulted in even more intraspecific diversity developed by early farmers in terms of crop varieties and local landraces and breeds. These form the basis on which modern high-yielding and disease-resistant varieties have been produced in the past (Plucknett *et al.*, 1987) and will continue to do so to feed the growing human population, expected to reach 9.1 billion by 2050 (FAO, 2010c).

Along with diversity still existant in farmer's cultivars/landraces, crop wild relatives (CWR) represent an important reservoir of genetic resources for breeders (Maxted and Kell, 2009). Many useful traits from CWR, such as pest and disease resistance, abiotic stress tolerance or quality improvements, have been introgressed in today's crops (Hajjar and Hodgkin, 2007). For example, genes from *Oryza nivara* S.D. Sharma & Shastry, a wild relative of rice, are providing strong and extensive resistance to grassy stunt virus on millions of hectares of rice fields in South and Southeast Asia (Barclay, 2004). There are between 50 000 to 60 000 crop wild relatives estimated globally (Maxted and Kell, 2009), of which 1 400 are considered as most important for global food security and require urgent conservation intervention (Vincent *et al.*, 2013).

Crop and livestock diversity continues to decline in most agricultural systems. The most important threats include changes in land use, replacement of traditional varieties by modern cultivars, agricultural intensification, increased population, poverty, land degradation and environmental change (including climate change) (FAO, 2010c; van de Wouw *et al.*, 2010). It is thought that over 900 cultivated plant species are thought to be threatened by extinction and 14 species have been reported to have already disappeared (Hammer and Khoshbakht, 2005). In terms of crop varieties, of the more than 100 000 rice varieties known to exist in the world, only very few are now utilized. The discontinued use of some varieties can lead these varieties to extinction. It is predicted that climate change will have a significant impact on agriculture with temperatures rising on average by 2–4 °C over the next 50 years, causing significant changes in regional and seasonal patterns of precipitation (IPCC, 2007; Burke, Lobell and Guarino, 2009). Model projections based on global distribution of suitable cultivated areas of 43 crops, highlight that more than 50 percent of these crops may decrease in extent (Lane and Jarvis, 2007). In the case of wild populations of peanut (*Arachis* spp.), potato (*Solanum* spp.) and cowpea (*Vigna* spp.), studies suggest that 16–22 percent of these species may become extinct by 2055, with most species losing as much as 50 percent of their range size (Jarvis, Lane and Hijmans, 2008).

Genetic resources have also an important role in socio-economic terms. About 70 percent of the world's rural poor rely on livestock as important components of their livelihoods and

presently about 22 percent of the 8,262 animal breeds around the globe are at risk of extinction, while 8 percent are already extinct.

Tree species are estimated to be 80 000–100 ,000 and many of these provide goods and services to countries and local communities, yet fewer than 500 of them have been studied. The immense potential of forest genetic resources, which could be used to improve wood supply as well as various non-wood forest products has been little explored, while many tree genetic resources are at risk of being lost forever before even being investigated and utilized.

Regarding aquatic genetic resources\, there are more than 31 000 species of finfish, 85 000 species of mollusc, 47 000 species of crustacean and 13 000 species of seaweed, with more than 5 000 species accessed in wild fisheries and about 400 species used in aquaculture. Aquatic genetic resources underpin the productivity and sustainability of world aquaculture and capture fisheries, and the essential services provided by aquatic ecosystems in marine, brackish and freshwaters.

Aquatic genetic resources can be utilized in aquaculture to improve marketability, disease resistance, body shape, colour, culturability and the conservation of natural resources. Traditional and modern genetic technologies are currently being used to develop new breeds, hybrids and other products that are efficient to farm and meet consumer demands – although the use of these, particularly in aquatic environments is still subject to considerable contention. In capture fisheries, aquatic genetic resources allow species to adapt, to colonize new areas and to evolve. Aquatic genetic resources are an insurance policy to help species survive climate change and other impacts on the environment. The genetic differences between stocks of fish can provide fishery managers with a powerful tool for management, traceability and product identification.

Natural habitats that provide ecosystem services essential to food production continue to decline in extent and integrity in most parts of the world, although there has been significant progress in slowing the rate of loss for tropical forests and mangroves in some regions. Fragmentation and degradation of forests, rivers and other ecosystems have also already led to loss of biodiversity and ecosystem services (Secretariat of the Convention on Biological Diversity, 2010).


1.8 Fertilizers and feed

[Note: The following is drawn from FAO, 2012b.]

Fertilizer consumption

The bulk of the projected increases in crop production will probably come from higher yields, with the remaining part coming from an expansion in harvested area. Both higher yields, which normally demand higher fertilizer application rates, and land expansion will lead to an increase in fertilizer use. Increases in biomass require additional uptake of nutrients, which may come from both organic and mineral sources. Fertilizer consumption is projected to increase from 166 million tonnes in 2005/2007 to 263 million tonnes in 2050. This would imply a continuing slowdown in the overall growth of fertilizer consumption, with particularly slow growth in the developed countries and East Asia.

The high returns to fertilizer use are well established. Smil (2002) estimates that N fertilizer has contributed an estimated 40 percent to the increases in *per capita* food production in the past 50 years, although there are local and regional differences and varying efficiencies.

One-third of the increase in cereal production worldwide and half of the increase in India's grain production during the 1970s and 1980s have been attributed to increased fertilizer consumption. The application of mineral fertilizers needed to obtain higher yields should complement nutrients available from other sources and match the needs of individual crop varieties.

FIGURE 3.3: TRENDS IN FERTILIZER USE
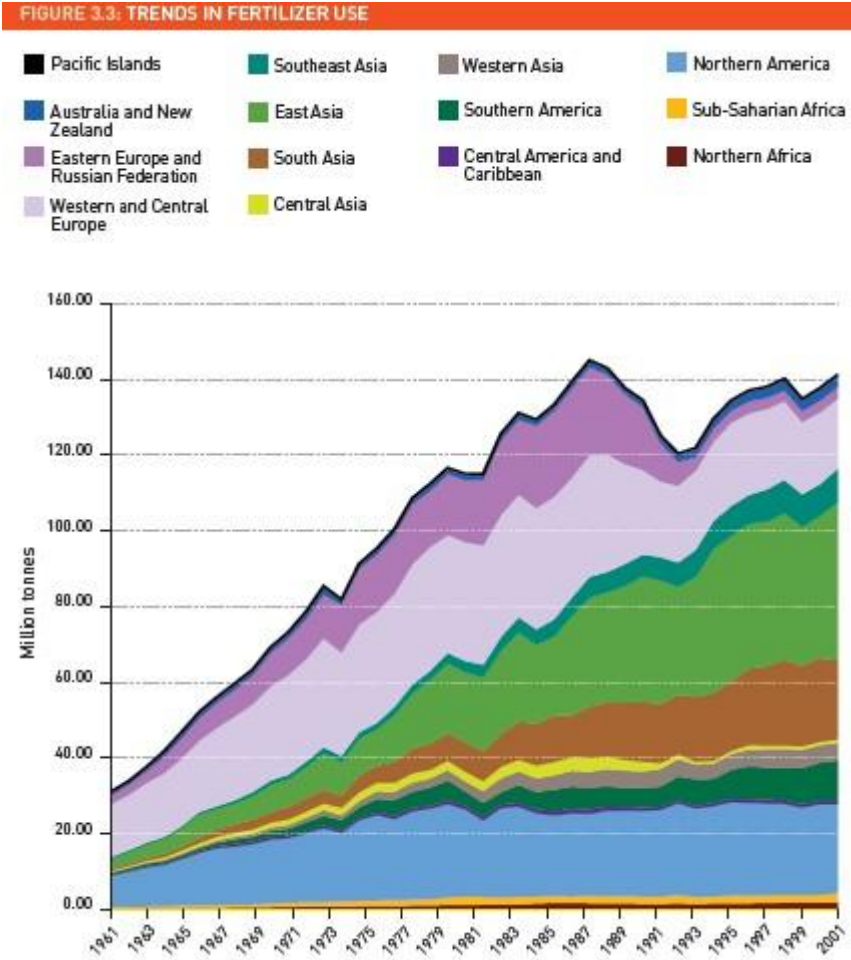
Source FAO, 2011a

Developing countries account at present for almost 70 percent of world fertilizer consumption and this share could increase further to over three-quarters of world consumption in 2050. China and India alone account for almost two-thirds of the developing countries' fertilizer consumption but this could decline to about half the consumption in 2050 as other regions will catch up. The decline in world fertilizer consumption in the 1990s was mainly caused by the decline in the transition countries following systemic reforms. Growth in fertilizer use in the industrial countries, especially in Western Europe, is expected to lag significantly behind growth in other regions of the world. The maturing of fertilizer markets during the 1980s in North America and Western Europe, two of the major fertilizer consuming regions of the world, account for much of the projected slowdown in fertilizer consumption growth. In the more recent past, changes in agricultural policies, in particular reductions in support measures, contributed to a slowdown or even decline in fertilizer use in this group of

countries. Increasing awareness of and concern about the environmental impacts of fertilizer use are also likely to hold back future growth in fertilizer use.

Cereals, in particular wheat, rice and maize, account at present for some 60 percent of global fertilizer use, and are expected to still account for just over half of fertilizer consumption by 2050. Fertilizer applications to oilseeds (in particular to soybeans and rapeseed) are expected to grow fastest so that oilseeds by 2050 could account for over one fifth of all fertilizer consumption.

Since the early 1960s, the use of mineral fertilizers has been growing rapidly in developing countries, admittedly starting from a very low base. This has been particularly so in East and South Asia following the introduction of high-yielding varieties. By now high application rates have been reached in East Asia and growth of fertilizer consumption in East Asia is expected to slowdown drastically; eventually fertilizer consumption is expected to decline. For sub-Saharan Africa, above average growth rates are foreseen, starting from a very low base, but fertilizer consumption per hectare is expected to remain at a relatively low level. The latter probably reflects large areas with no fertilizer use at all, combined with small areas of commercial farming with high levels of fertilizer use, and could be seen as a sign of nutrient mining (see also Henao and Baanante, 1999).

Average fertilizer productivity, as measured by kilogram of product obtained per kilogram of nutrient, shows considerable variation across countries. This reflects a host of factors such as differences in agro-ecological resources (soil, terrain and climate), in management practices and skills, and in economic incentives. Fertilizer productivity is also strongly related to soil moisture availability. Notwithstanding this variability, in many cases the scope for raising fertilizer productivity is substantial, but more so for N-fertilizer than for P- and potassium (K)-fertilizers (FAO, 2008). The degree to which such productivity gains will be pursued depends to a great extent on economic incentives. Farmers may increase fertilizer use only where remunerative market opportunities—inclusive of the soft and hard infrastructure required to make markets work—exist. Roads, storage facilities, price information systems, sophisticated supply chains, and competition are all part of ensuring that returns to fertilizer use are remunerative to farmers.

The projected slowdown in the growth of fertilizer consumption is in the first place due to the expected slowdown in crop production growth. Another factor is the continuing improvement in fertilizer use efficiency, partly driven by new techniques such as integrated nutrient management and precision agriculture, which will continue to reduce mineral fertilizer needs per unit of crop output (at a steady but uncertain pace). Then there is an increasing concern about the negative environmental impact of high rates of mineral fertilizer use. Finally there is the spread of organic agriculture, and the increasing availability of non-mineral nutrient sources such as manure, recycled human, industrial and agricultural waste and crop by-products. All these factors will tend to reduce growth in fertilizer consumption.

A key consideration is the continuous supply of fertilizers at affordable costs. The production of N is unlimited in the sense that it is derived from atmospheric N, which is abundant. However, the costs of converting atmospheric N into ammonia are tied to energy costs. Fortunately, the current practice of using methane for the conversion is expected to be affordable into the foreseeable future (Dawson and Hilton, 2001). In terms of N management, it is observed that the majority of N is lost either in production or in the post-harvest part of the cycle, including food waste (Smil, 2011). A good part of this is related to agronomic practices where leaching into water systems and nitrous oxide gas emissions have created environmental costs. There are some technological options to improve nitrogen use efficiency (e.g. through slow release products), but these all come with an additional cost.

In the case of P, the situation is different as phosphorus is derived from rock phosphate mines that have finite deposits, and the process of regeneration of P is measured in centuries. The current stock of rock phosphate deposits can only be estimated and two recent estimates differ considerably. The USGS (2010) estimated deposits at 16 000 million tonnes while the IFDC (2010) estimated a much higher amount of 60 000 million tonnes. In recent years, production has been around 160 million tonnes which means that the current production and use of P could be sustained for between 100 years (USGS estimate) and 400 years (IFDC estimate). In theory, therefore, there are sufficient stocks of rock phosphate to accommodate needed total fertilizer quantities for the additional 60 percent of food needed. However, because of the finiteness of the resource and the fact that the vast majority of stocks are found in a handful of countries, it is almost certain that prices could rise consistently or spike at various times. Countries with large rock phosphate mines could decide to conserve their resources for their own long-term use, for example. Given this scenario, there will be pressure to increase P use efficiency through technology (e.g. spread of precision farming) or through better use of complementary technologies (irrigation, N, organic nutrients and soil conservation practices) as well as to better recycle P from food waste and animal bones. All this may lead to increases in the cost of P and limit its expansion in certain areas, such as where transport costs remain high.

Organic nutrient sources

There has been increased attention given to the use of organic nutrient sources for crop production, not simply as a way of reducing reliance on mineral fertilizer, but because of their importance in increasing soil organic matter and thus potentially improving soil biology and physical structure. Thus there is increased advocacy for the use of integrated soil fertility management (ISFM) or integrated nutrient management (INM) – e.g. FAO, 2006b. Already, the use of some organic nutrients is very important, accounting for about half of all nitrogen used on crops (Smil, 2009). Animal manure contributes more than 50 percent of N in the Netherlands and Belgium and is an important source of nitrogen and organic matter in many other areas of the world, including sub-Saharan Africa. Crop residues are another widely available source of nutrients, though their concentration of key nutrients is low. The use of woody and herbaceous legumes, which can fix atmospheric N can generate significant amounts of nitrogen in addition to producing other products of their own. There are numerous examples where both are practised at scale, such as the tree parklands of the Sahel where farmers of Niger have regenerated trees on close to 5 million hectares of agriculture land (Reij, Tappan and Smale, 2009), many of which improve soil fertility and crop production (Place and Binam, 2013). Graham and Vance (2003) note that, at the turn of the millennium, grain and forage legumes were grown on some 180 million ha, or 12 percent to 15 percent of the earth's arable surface. Grain legumes alone contributed 33 percent of the dietary protein N needs of humans (Vance, Graham and Allan, 2000).

There is agreement on the importance of organic nutrient sources and the need to promote their use. However, despite proponents such as some organic farming advocates who argue that chemical inputs are not needed to increase food production at scale, there are many challenges to this view. First, the ability of organics alone to meet the various chemical requirements of crops, notably P is limited. Second, the required new area for producing organic courses would itself compete with food crops and the costs involved in growing, transporting and incorporating them would be significant. This is especially challenging in dryland areas. Third, the availability of animal manure and crop residue is varied across countries and regions (see Valbuena *et al.,* 2012).

Use of cereals and oilseed cakes for animal feed

Estimates put the world feed use of cereals at 742 million tonnes, or 36 percent of world total cereal use. Growth rates of total livestock production have generally been higher than those of cereal feed use, suggesting a *prima facie* case of productivity gains in livestock production in the limited sense of more meat per kilogram of cereal feed. No doubt, there have been such productivity gains reflecting in part the growing share of the poultry sector in total meat production (poultry requires much smaller quantities of cereal feed per kilogram of meat than beef). However, other forces have also been at work, leading to the reduced grain/meat ratios. Principal among them is the relative shift of world livestock production out of the regions that use grain-intensive feeding systems to the developing countries that have lower grain/meat ratios on average. The relative shift in the geographical distribution of world livestock production and cereal feed use towards the developing countries reflected not only their faster growth of consumption but also the drastic decline in the 1990s in the livestock production and feed use of the formerly centrally planned economies of Europe, which had high and often inefficient use of cereal feed per unit of output.

An additional factor that contributed to the slowdown in the use of cereals as feed has been the shift towards more balanced feed rations that favoured the use of protein-rich oilcakes. Indeed, such use has grown four times as fast as that of cereals from 1980–2007 or from 1990–2007. The process was very pronounced in China, fuelled by rapid expansion of its imports of soybeans: the country now accounts for some 50 percent of world imports of soybeans, up from 10 percent in the mid-1990s.

The growth rate of cereal feed use will likely continue to be lower than that of livestock production. Differences, however, will not be as pronounced as in the past: the depressing effect of the reforms in the formerly centrally planned economies of Europe has been exhausted and the increase of the share of poultry in total meat production will be less pronounced than in the past. The increase in developing countries' share of world livestock production will also contribute, as developing countries show lower cereals feed/livestock ratios. All these factors will reduce the gap in growth rates of cereals feed use and livestock production.

An additional factor working in the same direction will be the gradual shift of livestock production in the developing countries from grazing and "backyard" systems to industrial units and stall-fed systems using concentrate feedstuffs. Such a structural change in production systems will raise the average grain/meat ratios in developing countries and perhaps compensate partly for opposite trends resulting from the other factors mentioned above. A strong case for this prospect is made in an analysis by the Dutch Centre for World Food Studies (Keyzer, Merbis and Pavel, 2002).

At the same time, a significant increase of cereal-based biofuels may produce by-products that can substitute for cereals in feed rations; this, together with the rise in cereal prices caused by an eventual substantial diversion of supplies to biofuels, will tend to depress the growth rate of cereals use for feed. As explained elsewhere, in the present projections the biofuels factor plays a role, albeit a minor one.

In the opposite direction, i.e. continuing to depress the growth of cereal feed use, will be the further increase of the share of protein-rich oilcakes in feed rations, a process that will be supported by the continued expansion of the oilseeds sector faster than that of cereals. This effect may be reinforced if vegetable oils uses for biofuels were to continue expanding, as oil cakes are produced as joint products with oils, particularly in the case of soybean oil. World production of oilcakes (assumed to be used for feed) derived as joint products with the vegetable oils, rises by 80 percent to 2050, i.e. faster than the 50 percent increase in the cereal feed use.

1.9 Regional and local resource availability as regards resources/production capacities. Systems at risk?

Land and water resources are unequally distributed. Moreover, this maldistribution does not favour the countries that need them most to produce more in the future.

Country category	Global share of land (percent)	Share of global population (percent)
Low-income	22	38
Middle-income	53	47
High-income	25	15

The average per capita availability of cultivated land in low-income countries is less than half that of high-income countries. The suitability of land for cropping is also generally lower. There is generally a strong link between poverty and lack of access to land and water (FAO, 2011a).

This is likely to be exasperated by population growth. There are a handful of countries, most in Sub-Saharan Africa, that could see population increases of 200 percent or more. Examples include Niger, Zambia, Malawi, Tanzania, Angola, Burkina Faso, Somalia, Uganda and Mali. The need to cope with rapidly increasing populations will stress both natural and human resources.

Regions	Cultivated land (million ha)	Population (million)	Cultivated land per capita (ha)	Rainfed crops (percent)		
				Prime land	Good land	Marginal land
Low-income countries	441	2 651	0.17	28	50	22
Middle-income countries	735	3 223	0.23	27	55	18
High-income countries	380	1031	0.37	32	50	19
Total	1 556	6 905	0.23	29	52	19

Source: FAO, 2011a

Some countries with a rapidly growing population and a rapidly growing demand for food are also facing high levels of water scarcity. Certain regions already experience very severe water scarcity, such Western, Central and South Asia, which use half or more of their water resources in irrigation, and in Northern Africa, where withdrawals for irrigation exceed renewable resources as a result to groundwater use and recycling. Among the 40 percent of land irrigated partially or totally with non-renewable ground water figure key food production areas in China, India and the United States of America. On a regional basis demand for fresh water will be greatest in Asia where in 2020 annual water use will exceed 3 000 km^3/yr, which is in stark contrast to the second highest water use region (North America) with a mere

500 km^3/yr (Kabat, 2013). The greatest increase in water demand will come from China, the United States of America and India as a result of population growth, increasing irrigation for food production, and growth in GDP (Lux Research, 2008). By 2030, demand for water in India and China, the most populous nations on earth, will exceed their current supplies (2030 Water Resources Group, 2009). The strain on the world's agricultural and industrial sectors will be substantial, as these countries' populations move towards middle-class diets and consumption patterns. The lack of available water will be compounded by issues of water quality. Pollution in China is already so widespread that 21 percent of available surface water resources are unfit even for agriculture (2030 Water Resources Group, 2009).

Some systems are also particularly vulnerable to climate change. Among the most vulnerable systems are pastoralists and smallholder farmers systems in dry areas and coastal ecosystems, where about 40 percent of the world population live, and which are at risk from flooding and sea-level rise (HLPE, 2012).

Based on an analysis of resource availability and quality towards needs, FAO, (2011a) has identified nine "systems at risk" threatened by specific risks: densely populated highlands in poor areas; small holder rainfed farming in semi-arid tropics; densely populated and intensely cultivated areas in the Mediterranean basin; intensive rainfed cropping in temperate climate; irrigated rice-based systems; crops depending on irrigation by groundwater; rangelands on fragile soils; deltas and coastal areas; and periurban agriculture.

Figure 2: global distribution of risks associated with main agricultural production systems

A schematic overview
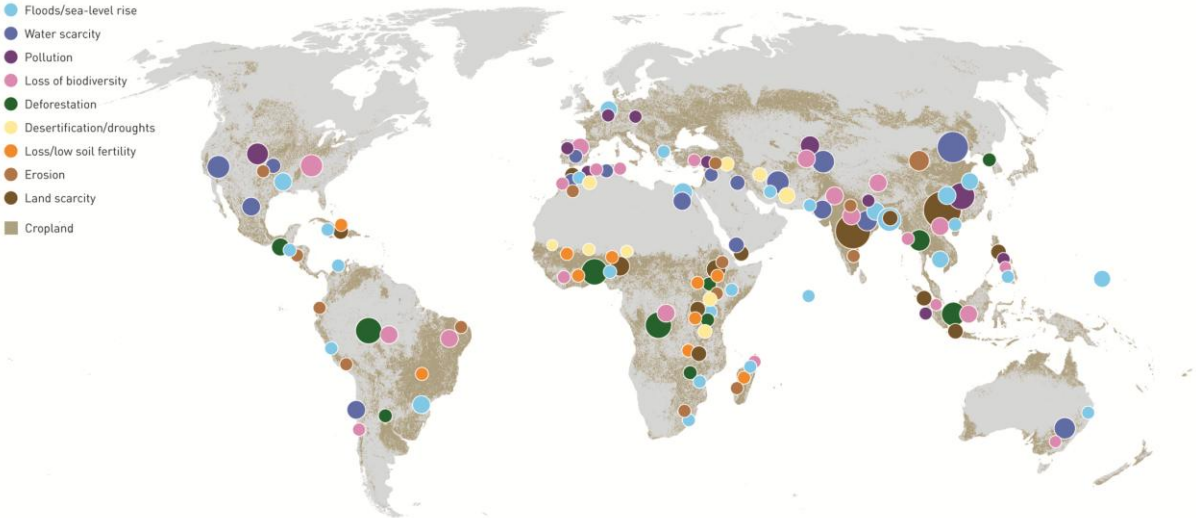
Source: FAO, 2011a

1.10 Main conclusions

According to FAO's data and projections, global land availability does not appear to be, per se, a limiting factor, as most of the production increase would result from yield increase. This, in turn, is very dependent on availability of other resources: water, fertile soils, nutrients,

genetic resources and ecosystem services, and also on management and practices. It shows how, even from a global perspective, resources are linked, how scarcity of one can impede best management of another. It calls for a better understanding of the interrelations of trends in availability and use between various resources, relative value and price, at global, regional and local levels, as farming systems can be put at risk by any type of imbalance.

It is particularly the case when resources are not only providing food but also the main source of income and livelihoods. Populations which are the most dependent on natural resources are also often the more vulnerable. They often are in areas where resources are scarcier, including by lack of investments, especially in regard of projected increases in population and demand. This calls for a close monitoring of these systems at risk to anticipate crisis and devise options for change.

The very notion of "availability" of a resource deserves closer consideration within a double perspective. First it has to account for all uses and functions, including non marketable. "available" land has already uses and functions, including as food provider for indigenous and vulnerable populations. It also provides various ecosystem services, most of which are not accounted for. It has then to account for the potential completion between uses in light of projected competing demands. This requires both closer field surveys and projections integrating various drivers of change.

2 Resource efficiency for food security

The issue of resource efficiency is a long-standing item on the agenda of the broader economy, in industry and energy. The Rio Conference in 1992 (Agenda 21) adopted a 90 percent reduction target for material and energy flows over a period of 50 years. This is based on the premise that the resource base to produce one dollar of GDP can be (more or less) easily delinked (and is increasingly decoupled) from the use of materials and inputs. The emergence of a worldwide economy of services, which is also a key engine of growth, contributes to mitigate partially the increase of resource use versus the accumulation of wealth. In that picture, some sectors still continue to be more problematic: the energy and transport sectors, and some segments of the manufacturing and other industries (such as steel). Nevertheless, progress in resource efficiency in these sectors can be obtained, as major technological shifts can lead to the same level of final service (e.g. passenger, kilometre and lighting intensity) with highly reduced energy or material input. This is because of the existence of major efficiency gains and potential savings at the end of the chain, owing, for instance, to energy-efficient equipment, or efficient modal organizations (in the case of transport). In addition, in non-agricultural sectors, resource efficiency gains can often be obtained by a change from short-life to long-life products and a reduction in the product range.

The case of resource efficiency in food and nutrition is more problematic, and the problem statement cannot be the same as for the other sectors for three main reasons.

1. First, some major sources of resource efficiency gains that can be reached in other sectors by shifting from short-lived to longer-lived products cannot, by definition, be applied to the problem of food and nutrition, except for the domains of wood and clothing.
2. Second, the final "service" provided by food depends directly on the amount of calories provided, as well as the nutritional quality of the diet. Ways to improve the "nutrition" efficiency of a given diet are therefore thin as one can assume that the "diet" is the final service impacting nutrition, though in some case other parameters are important for this, such as good health and good drinking water, to ensure the "diet" is efficiently metabolized and fully profits the organism. But in the end, with good health and good drinking water, good nutrition is first and foremost a matter of enough calories and nutrients being provided, which in the end comes back to the very concrete issue of physical quantities.
3. Finally, food and nutrition "goods" are basic needs and the most fundamental ones in the "consumption" basket. Therefore, fundamentally, it does not make sense to try to "trade" or substitute them against more resource efficient items in the consumption basket[1]. The only exception to this concerns the non-food items produced by agriculture, which could eventually be replaced by other raw materials, for clothing, for heating and construction (wood), and for transport (biofuels), which in some cases can effectively lead to substitutions with lower environmental footprints.

The above means that the contribution of food production and consumption to the resource question, and the ways to improve the resource efficiency of food, has to be found to a large extent in agriculture, in the food sector and its organization (worldwide) and, to a certain extent, in the diets themselves. Finally, it can be also found in the valorization of losses.

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[1] In the climate change debate, following works from Patchauri (2008), the idea that meat can be traded against kilometres by car has been widespread (Patchauri calculates that 1 kg of beef is responsible for the equivalent of the amount of CO_2 emitted by the average European car every 250 km, and burns enough energy to light a 100-watt bulb for 20 days" (Patchauri, 2008). It remains that proteins – in meat or in other forms – are vital to life, and kilometres in cars are not, or much less directly.

2.1 What does resource efficiency mean?

Before looking at how resource efficiency in food systems can be improved (by what means), we need to have a common understanding of what efficiency "means".

Resource efficiency can be measured by the quantity of a specific resource used to produce a specific output or outcome – number of litres of water to produce a kg of maize – or quantity of output or outcome per a specific quantity of resource – yield of maize per hectare. It can be measured in two ways. Likewise, the pursuit of increased resource efficiency can be approached from an output perspective: how to produce more efficiently a certain amount of product, or an input perspective: what is the more efficient way to use scarce resources?

The measurement of resource efficiency needs to confront the amount of resources mobilized (in the denominator, inputs) and the amount of services provided (in the numerator, outputs). There is also the time dimension to consider, as governments down through to farmers also consider efficiency not simply in a single year but in a longer-term perspective.

> Resource efficiency = (measure of outputs)/(measure of inputs) (Eq. N1)

Efficiency can also be pictured in terms of incremental environmental impacts or externalities with respect to incremental unit production. For instance, the measure GHG emissions/unit of product is a proxy to "climate change impact" efficiency of agricultural production.

A difficult point is the measure of biodiversity "used" (here meaning biodiversity lost). In a life-cycle analysis of non-agricultural products, the amount of land used is generally used as a proxy for biodiversity lost. For agriculture, this can be misleading, as the impact of agriculture on biodiversity is very dependent on practices and on associated agro-biodiversity. Extensive practices, using more land, can be more favourable to biodiversity than intensive ones. On the other hand, intensive practices that use less land can also "free-up" other areas for biodiversity.

To apply Eq. N1 to food and agriculture, three main elements must be considered:

(i)   first, the need to deal with multiple resources or inputs, including non-marketed inputs, when assessing resource efficiency is common for many activities;
(ii)   second, the fact that there are often **multiple outputs** in agriculture (what is often called "multifunctionality" (IAASTD, 2009);
(iii)   third, the fact that there are **different levels** at which resource efficiency can be computed (and, consequently, at which resource efficiency gains can be reached).

These three elements can then be integrated either in space (which adds a spatial dimension) – one can look at a very local scale, at national, regional or international scale – or in time. The time dimension is important as resource efficiency can be integrated over time and therefore measured over different timescales. The issue of resource efficiency in the future, or of trajectories of resource efficiency in time, is particularly relevant to sustainability discussions.

2.2 Dealing with multiple resources: synergies and trade-offs

There are different measures of efficiency as there are many different resources, but some measures exist that capture the effect of the combined use of resources, and therefore also the effect of substitution among such factors. For example, GHG emissions/unit of output is a measure of efficiency that is not only useful because of its relevance to climate change, but is also one of the few metrics that can integrate fossil energy use, fertilizer use and land-use change.

The definition of a metric to encompass a set of several resource uses is challenging, owing to the difficulty of attaching relative weights to the different inputs. In some rare cases, as in the carbon footprint metric, it is possible to do so on a purely physical basis. At the other end, inputs can be weighed against their relative price, which leads to the notion of strict economic efficiency. Ideally, if all externalities (including local ones) were factored in prices of each input, relative prices would reflect relative "environmental values" of inputs making the use of the "economic" metric meaningful in environmental terms.

The first element in the list refers to the complexity of gathering various resources or impacts into a single metric, which would encompass a set of several resource uses. This is challenging, for two reasons.

The first relates to the difficulty of attributing and summing up impacts even when considering one single dimension or specific resource or impact, be it land, water or carbon, etc.

The second reason reflects the difficulty, once this is done, in confronting the different resources and inputs and attaching relative weights to them (land, water, energy). One first approach would be to weigh each input against its relative price, which leads to the notion of strict economic efficiency. Ideally, if all externalities (including local ones) were factored in prices of each input, relative prices would reflect relative "environmental values" of inputs making the use of the "economic" metric meaningful in environmental terms. However, this is hardly the case, and calls for more subtle, multidimensional approaches to account for resources use at different levels (Gitz, Meybeck and Huang 2012). Gallia *et al.* (2012) argue that no single indicator per se is able comprehensively to monitor human impact on the environment, but rather indicators need to be used and interpreted jointly. They argue for the use of a family of indicators, the "Footprint Family", based on the ecological, carbon and water footprint. However, this family fails to account for soil quality and land degradation, ecosystems' eutrophication owing to nitrogen deposition, and accumulation of pollution by toxic compounds.

Box: Resource efficiency and other accounting metrics for resource intensity use

Life cycle assessment (LCA) (often used for carbon/GHG footprinting) is a suite of methods designed to assess the environmental impacts resulting from a product's entire lifetime (or specified portion thereof). This includes the impacts originating from the sources of the raw materials (breeding, harvesting, land use, etc.), processing, manufacturing, distribution (transportation and storage), use, and finally either disposal or recycling and reuse (Hendrickson, Lave and Matthews, 2005). The carbon footprint represents the total amount of GHG directly or indirectly caused by human activities or accumulated over the stages of products, using a LCA methodology. Unit: kg CO_2 equivalent for GHG.

The ecological footprint is a resource and emission accounting designed to track the amount of biosphere regenerative capacity that is directly or indirectly (i.e. embodied in trade) used by humans (including generation of wastes) compared with how much of it is available at both local and global scale, in a given year. Unit: global hectares of bioproductive land.

The water footprint is a consumption-based indicator of freshwater use, accounting for the appropriation of natural capital in terms of the water volumes required for human consumption (Hoekstra, 2009). The water footprint represents the human appropriation of the volume of fresh water required to support, directly or indirectly, human consumption. It looks at surface and groundwater (blue component), rainwater stored in the soil as soil moisture (green component) and pollution (grey component) – defined by the volume of fresh water required to assimilate the load of pollutants based on existing ambient water quality standards (Hoekstra, 2009). Units: water volume (m^3) per year, or water volume per kg of product.

Material flow analysis measures the material flows in a region, in a factory, in a production process, or an industry on the basis of *mass balances*. By measuring the economic processes and the associated material flows, material flow indicators can, for example, provide information on how much wood, biomass, grain, or feed is used within an industry or a region.

Nitrogen accounting: The calculation of a food nitrogen footprint consists of a bottom-up calculation with two essential parts: food consumption and food production. The N-calculator estimates the nitrogen footprint by using data on total food consumption and associated virtual N factors associated with the steps of production that lead to it (Leacha *et al.,* 2012).

"**Decoupling**" of resource use and economic growth: One typically distinguishes between resource decoupling and impact decoupling as well as between relative decoupling (where resource use and/or impacts grow at a slower rate than economic growth) and absolute decoupling (where resource use and/or impacts stagnate or decrease) (Hirschnitz-Garbers *et al.*, 2012).

The existence of many potential resources from which to measure resource efficiency in agriculture points to the necessity of either selecting one or of finding a method to integrate them. One idea could be to take the point of view of looking at efficiency from the perspective of the scarcest or most limiting resource in a particular context. For example, in the water-scarce regions of North Africa/West Asia, water efficiency is probably one key indicator and water efficiency measures would seem more important than others.

2.3 Assessing resource efficiency dealing with multiple outputs (new section)

Agriculture and food systems not only utilize a very diverse range of resources but also produce a very diverse range of outputs.

Agriculture provides physical products but also income and employment, for farmers and in agri-industry. From a food security perspective, these three outputs are equally important. Agriculture is also a producer of environmental services at the landscape level: for example, through improved soil management practices, agriculture can increase carbon stored in soils. Ultimately the output of agriculture can also be defined as human diets.

The scope of a comparison can be enlarged by broadening the definition of the output, from product, to comparable products, to diets. The difficulty is to find a common metric to measure more diverse outputs.

Hilborn and Tellier (2012) offer a comparative perspective by calculating environmental indicators per 40 g protein portion in New Zealand food production systems, comparing various fisheries and dairy and meat production. Fisheries had a lower impact in terms of

water use, fertilizer use, eutrophication potential and antibiotics. Most fisheries also had lower GHG production levels than the meat industry and some were lower than those for average dairy production. The dairy and meat industries were more efficient in energy inputs and production per unit but relatively good states of major fish stocks maintained relatively efficient fuel consumption scores. The New Zealand quota management system also discouraged excessive vessel capacity and largely eliminated competitive openaccess fishing, thereby supporting lower fuel consumption. Likewise, the New Zealand dairy and meat industries were more efficient in energy use and GHG production than comparable industries around the world. The authors argue that the high year-round productivity and the ability to raise both dairy and livestock on pasture for most of the year – which reduces the need to use feed crops – is a primary reason for this relative efficiency

To a certain extent, the broader the output or outcome the more possibilities there are to improve efficiency, including by substitution.

A Finnish project on the environmental consequences of consumers' daily food choices follows the idea that lunch is a "nutritional whole, in which interchangeability of components is restricted" (Kurppa *et al.,* 2009). In comparing lunch plates with half vegetables, a quarter protein and a quarter carbohydrates, the study found GHG emissions per lunch plate varied from 570 g CO_2 to 3.8 kg CO_2. The main impact was from livestock products, but also from greenhouse grown vegetables. Here it is the emissions efficiency of a complete meal that is measured.

Such comparisons can be attempted at a global level through the use of mathematical models. Another study (Erb *et al.,* 2009) compares various scenarios based on diets – "western high meat", "current trend", "less meat" and "fair less meat" – to estimate the land and practices (intensive or not) necessary to produce the needed food. It is the efficiency of a type of diet that is thus estimated.

Agriculture provides not only physical products but also income and employment – for farmers, in agro-industry and as a driver of the non-farm rural economy. From a food security perspective, these three outputs are equally as important. It implies a more complex conception of resource efficiency, by which employment, which is formally an input in pure economic terms, can be seen as a key output. This conception implies a shift from the classical economic targets of labour productivity towards resource efficiency with labour intensity being possibly an asset, as a system can be judged superior to another if it uses an equal amount of natural resources but provides more employment (and not less work related costs), everything else being equal.

The mere use of input–output ratios as efficiency measures can therefore be misleading: for example, especially outside the industrialized systems, livestock systems provide a range of other functions besides the production of protein-rich food for human consumption. In many regions, livestock is still a major source of power for agriculture and transport and indispensable for the management of nutrients. A crucial function of livestock is the ability of ruminants to convert biomass not digestible by humans into food for humans: for example, biomass from wastelands or semi-deserts. Thus, livestock systems that appear to be inefficient owing to their input–output or feed efficiency ratio may in fact represent well-adapted, highly efficient production systems in their respective local contexts (Bradford and Baldwin, 2003; Erb *et al.*, 2009).

2.4 Assessing resource efficiency at different levels.

Ultimately, the output of agriculture can also be defined as diets, which raises the issue **of the different levels** at which the measurement of resource efficiency can also be done. To simplify, with increasing degrees of integration, we can consider three levels: **the field (including farm and landscape), the food product chain and the diets**, addressed in the sections below.

2.4.1 How to improve it at the production level? (reduce yield gaps, optimize inputs use…)

Resource efficiency can be improved in every type of food system. Studies using the results of detailed on-farm energy audits realized in France have shown that energy consumption per kilogram of output can be extremely variable between farms. It has, for instance, been shown (Bochu, Bordet and Trevisiol, 2010) that the most efficient dairy farms consume half of the energy consumed by the less efficient farms. Results from more than 400 farms have been analysed and categorized according to the importance of maize silage in the system (1–10 percent, 10–20 percent, 20–30 percent, more than 30 percent of the feed). It appears that variability within each of these categories is more important than between categories, and that in every category the more efficient farms use less than half of the energy used by the less efficient ones. This is also true in organic farms. This means that, no matter what the system, there can be important improvements in management practices (FAO, 2012g).

Increase resource efficiency in plant production

Studies (Fischer, Byerlee and Edmeades, 2009) have shown the importance, in many developing countries, of the yield gap. The yield gap is the difference between actual farm yields, as represented by the average yield achieved by farmers in a defined region over several seasons, and the potential yields, which are the maximum achievable yield with latest varieties and by removing as much as possible all constraints, as achieved in highly controlled stations. Reducing this gap is essential to improve food security and reduce deforestation.

FAO has calculated a "yield gap" by comparing current productivity with what is potentially achievable assuming that inputs and management are optimized in relation to local soil and water conditions. Results show that the yield gap is greatest in sub-Saharan Africa (where yields are only 24 percent of what could be produced under higher levels of management). The gap is lowest in East Asia (actual yields are 89 percent of potential). This implies that, if all current land and water were managed optimally, output could more than double in the regions where the yield gap is less than 50 percent: Northern Africa, sub-Saharan Africa, Central America and the Caribbean, Southern America, Western Asia, Central Asia, South Asia, Eastern Europe, the Russian Federation and the Pacific Islands. By contrast, much of Asian farming is already using advanced management such as irrigation and high levels of mineral fertilizer (FAO, 2011a).

Nutrients are essential to increase yields. But production of synthetic fertilizers is energy-intensive, with a high cost in terms of CO_2 emissions and transport from factory to farms. In addition, when applied in the field, excess fertilizers have an impact on water quality. Improving fertilizer efficiency is thus essential. This can be done through a variety of techniques. One way is to match more precisely the nutrients with plant needs during the growing season, such as by fractioning the total amount in multiple doses. Other techniques include precision farming and placing nutrients closer to plants roots, such as deep placement of urea for rice and point placed micro-dosing on grains (Roy and Misra, 2003; Singh *et al.*, 2010; Ladha *et al.* 2000; IFDC, 2010).

The inclusion of legumes as intercrops or rotations exploits symbiotic microbes to fix nitrogen, which is harvested in the crop and partly transferred to concurrent or subsequent crops, increasing their yields. In forage legume/grass mixtures, nitrogen is also transferred from legume to grass, increasing pasture production. The protein content of legumes makes them important from a nutritional point of view. When included in livestock feed, legumes increase the food conversion ratio and decrease methane emissions from ruminants, thus increasing efficiency.

Sustainable crop production intensification can be summed up in the words "save and grow". Sustainable intensification means a productive agriculture that conserves and enhances natural resources. It uses an ecosystem approach that draws on nature's contribution to crop growth – soil organic matter, water flow regulation, pollination and natural predation of pests – and applies appropriate external inputs at the right time and in the right amount to improved crop varieties that best fit changing climates, and uses nutrients, water and external inputs more efficiently. Better maintenance of ecosystem services can be accomplished through agricultural practices that are based on crop rotations, use minimum tillage and maintain soil cover; build soil organic matter and reduce soil erosion; harvest and manage rainwater; rely on natural processes of predation or biocontrol for pest or weed problems; manage pollination services; select diverse and appropriate varieties; and through the carefully targeted the use of external inputs. These practices are knowledge-intensive and are often also interdependent. In the initial stages, encouraging these practices may require public support through targeted incentives and investment (FAO, 2011d).

Increase resource efficiency in livestock production

The livestock sector has expanded rapidly in recent decades and will continue to do so as demand for meat, eggs and dairy products is expected to continue to grow strongly, especially in developing countries. Already, livestock grazing occupies 26 percent of the earth's ice-free land surface, and the production of livestock feed uses 33 percent of agricultural cropland (FAO, 2006a). There is an urgent need to improve the resource use and production efficiency of livestock production systems, both to improve food security and to reduce the use of resources. These efforts need to take into account the growing dichotomy between livestock kept by large numbers of smallholders and pastoralists and those kept in intensive systems.[2] This increased efficiency should be pursued in all possible ways, from livestock selection and diet to manure management.

Selection to improve efficiency of livestock systems involves numerous parameters, including productivity per animal, early maturity, fertility, feed conversion ratio and longevity. In controlled environments, breeding for high performance has already resulted in significant reductions in the amount of feed per unit of product, especially for monogastrics and dairy cattle. The challenge is now to also improve productive parameters in more diverse environments (Hoffmann, 2010).

Improving animal health, including disease prevention and management, has a strong impact on the efficiency of livestock systems, food security and sustainable management of resources. Establishing strong veterinary institutions and policies is essential both to improve livestock efficiency and increase the preparedness against new risks, including those that result from climate change.

Nutrition plays a critical role in making a livestock production system more efficient. Proper nutrition is imperative for achieving high reproductive efficiency in animals, protecting them from diseases and making animal health interventions more effective. Imbalanced feeding

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[2] Types of systems and size not being necessarily associated.

leads to productivity losses. A balanced diet enhances animal performance. Efficient nutritional strategies for monogastrics (pigs and chickens) include matching nutrient contents in feeds (taking into consideration both their level and availability to the animal) to the physiological requirements of animals, selecting feeds with high nitrogen availability in the animal body, and optimizing proteins and amino acids in diets to improve the feed conversion to animal products. For intensive ruminant systems, techniques such as: (a) feeding of: diets balanced for nitrogen, energy and minerals – preferably as total mixed rations; chaffed forages, preferably of high quality; chaffed and water-soaked straws or urea-ammoniated straws; and grains; and (b) use of feed additives (e.g. ionophores, probiotics, enzymes, oils including essential oils, some tannins and saponins) either to improve the feed conversion ratio and/or to specifically reduce methane emission and nitrogen release into manure.

Improving pasture productivity and quality, either by improving the composition of forage, especially in artificial pastures, or by better pasture management, is an important means to improve the use of resources and food security. Supplementing poor-quality forages with fodder trees, as in silvopastoral systems, or with legumes, increases its digestibility, thereby improving the production efficiency of livestock and decreasing methane emissions. The introduction of legumes in pastures also increases forage production and reduces pressure on forests without a corresponding increased use of fertilizers. Improved grazing management could lead to greater forage production, more efficient use of land resources, enhanced profitability and rehabilitation of degraded lands, and the restoration of ecosystem services. Grazing practices, such as set asides, postponing grazing while forage species are growing, or ensuring equal grazing of various species, can be used to: stimulate diverse grasses; improve nutrient cycling and plant productivity and the development of healthy root systems; feed both livestock and soil biota; maintain plant cover at all times; and promote natural soil forming processes.

When manure is used as organic fertilizer it contributes to the productivity and fertility of the soil by adding organic matter and nutrients, such as nitrogen, that are trapped by bacteria in the soil. It improves productivity and allows for reductions in the use of synthetic fertilizers. The increasing geographic concentration of livestock production means that the manure produced by animals often exceeds the (nitrogen) absorptive capacity of the local area. Manure becomes a waste product rather than being the valuable resource it is in less concentrated, mixed production systems. Better integrating crop and livestock production can help make much better use of nutrients.

Integrated systems

Integrated crop and livestock systems, at various levels of scale (on-farm and area-wide) increase the efficiency and environmental sustainability of both production methods. When livestock and crops are produced together, the waste of one is a resource for the other. Manure increases crop production and crop residues and by-products feed animals, improving their productivity. In these systems, livestock is also a strategic element for adaptation. The animals provide an alternative to cropping in areas becoming marginal for cropping; in dairy systems, they provide regular income streams against the irregular payments for crops, offer a way to escape poverty and represent a coping mechanism in a variable environment. They also constitute capital that can be converted to cash when needed.

Rice–fish integrated systems are another example of very productive systems that also provide more balanced diets.

Agroforestry is the use of trees and shrubs as part of agricultural systems. It contributes to prevent soil erosion, facilitates water infiltration, recycles nutrients below crop rooting levels

and diminishes the impacts of extreme weather. Agroforestry also helps diversify income sources and provides energy and often fodder for livestock. Nitrogen-fixing leguminous trees, such as *Faidherbia albida*, increase soil fertility and yields (Bames and Fagg, 2003, Garrity *et al.*, 2010). Thanks to development and community-led projects and relaxed forestry measures that enable farmers to manage their trees, there has been a considerable regeneration of *Faidherbia* in the Niger through farmer-managed natural regeneration (Garrity *et al.,* 2010). Agroforestry systems are indeed a key source of nutrients for soils and livestock in dryland systems of the Sahel where use of mineral fertilizer and feed concentrates is very low. Since 2000, FAO has initiated special programmes for food security with the governments of Guatemala, Honduras, Nicaragua and El Salvador. These programmes work together, sharing practices, experiences and results to improve and develop agroforestry systems. Agroforestry systems are promoted in the subregion as a substitute for traditional slash-and-burn systems, particularly on slopes. Under these systems, productivity of land and labour increased. Yields are less variable, partly thanks to better retention of moisture in the soils. The soil is also protected from hydric erosion. Farm production, including wood products, is more diversified, which stabilizes incomes. As it is more efficient in the use of land, agroforestry reduces the pressure on forests. As wood is produced in the fields, these systems also contribute to preventing forest degradation.

Resource efficiency in fisheries and aquaculture

The definition of resource efficiency depends on the definition of the objectives for the sector. Over time, the industrial fishing fleet has improved in terms of fuel efficiency but productivity remains constrained by overcapacity and management failures. In addition, subsidies distort the sector's performance.

Concern for economic efficiency and sustainability is a long-standing issue in fisheries management and aquaculture development, while distributional issues are a matter of ongoing debate in both capture fisheries and aquaculture, and interest in low-carbon fisheries and aquaculture is a recent and rapidly evolving area of policy. Overcapacity in often subsidized fishing fleets and a decreasing resource base have reduced the profitability and economic contribution of the fisheries sector as a whole (Sumaila *et al.*, 2008). Approximately 32 percent of the global stocks are estimated to be overexploited, depleted or recovering from depletion, and a further 50 percent to be fully exploited (FAO, 2010d). It has been estimated that the world's fishing fleets are double the size they should be and the potential economic gain from reducing fishing capacity to a sustainable, economically optimal level and restoring overexploited and depleted fish stocks is of the order of USD50 billion per annum (World Bank/FAO, 2009). Considering solely the physical availability of fish in food supplies, Sirinivasan *et al.* (2010) have estimated that the undernourishment of about 20 million people could have been averted without overfishing. Overfishing also curbs the potential of small-scale fisheries to add to income and economic growth in coastal areas of developing countries, thereby worsening poverty (FAO, 2005; Béné, MacFadayen and Allison, 2007). Moreover, overcapacity and overexploitation threaten biodiversity (Pereira *et al.*, 2010), particularly of larger, longer-lived marine organisms that are more vulnerable to depletion (Norse *et al.*, 2012), and structurally complex habitats such as coral reefs, which are easily damaged by indiscriminate fishing methods. While the overcapacity of the large industrial fishing fleets has been well documented (World Bank/FAO, 2009), they are not the only sources of overexploitation. If connected to large enough markets, small-scale fisheries can also deplete high-value marine resources (Cinner and McClanahan, 2006). Weak governance, the high dependence of coastal communities on fishery resources and the lack of alternative livelihood options lead small-scale fisheries to overexploit inshore resources in many parts of the world (Pomeroy, 2011).

Small-scale fisheries generate income, provide food for local, national and international markets and make important contributions to nutrition. They employ over 90 percent of the world's capture fishers and fishworkers, about half of which are women. In addition to full- and part-time fishers and fishworkers, seasonal or occasional fishing and related activities often provide vital supplements to other livelihood activities, in times of difficulties or as a recurrent side-line activity. Small-scale fisheries contribute about half of global fish catches and, when considering catches destined for direct human consumption, the share contributed by the sector increases to two-thirds. Inland fisheries are particularly important in this respect, with small-scale fisheries' food fish production dominating the subsector.[3]

The economic and social importance of the capture fisheries value chain is frequently underappreciated, and the contribution of small-scale and inland fisheries to livelihoods and food security is often poorly recognized. Undervaluation of this sector is both a cause and a result of having weak data on how fisheries interact with the greater society and economy. These knowledge gaps may in part explain why policy-makers tend to neglect comprehensive efforts to manage this complex and politically sensitive sector.[4]

In response to the International Plan of Action for the Management of Fishing Capacity, several countries have tried establishing targets for the reduction of national overcapacity of fishing fleets. While the numbers of fishing vessels have been decreasing in some parts of the world in recent years, they have being increasing elsewhere.[5]

Aquaculture lags behind crops and livestock in domestication and genetic improvement of farmed species; most farmed aquatic species are very similar to their wild relatives. Projected seafood demands could be met by incorporating traditional animal breeding techniques into aquaculture production systems. Seafood production needs to increase by about 2 percent per year to meet demands – and although some of this increase can come from reductions in post-harvest losses, much of it will come from aquaculture. Traditional breeding programmes can give 5–10 percent gains per year in cases where the production environment can support these increases – more than enough to meet our needs. The main issue for aquaculture is feed conversion ratios. [6]

2.4.2 How to improve efficiency at landscape level?

As seen in some of the practices described above efficiency at field and farm levels are often determined and enhanced by what happens at broader, landscape level.

Water or nutrient management have to be considered at broader than plot level. Nutrient management changes shape when evaluated landscape scale with lateral flows (Van Noordwijk, 1999).

Water management offers numerous examples of collective approaches not only in sharing water for irrigation but also in organizing the landscape to better manage water, retaining it to enable it to get deeper in the soil instead of flowing away, thus avoiding floods and soil erosion.

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[3] Source: ftp://ftp.fao.org/FI/DOCUMENT/ssf/SSF_guidelines/ZeroDraftSSFGuidelines_MAY2012.pdf
[4] Source: WB/FAO/WFC, The Hidden Harvest - REPORT NO. 66469-GLB, 2012
[5] Source: ftp://ftp.fao.org/FI/DOCUMENT/ssf/SSF_guidelines/ZeroDraftSSFGuidelines_MAY2012.pdf
[6] See http://seafoodforthefuture.org/aquaculture-efficiency-and-feeds/

Management of pastoral and fodder resources, including fodder trees, to provide feed to livestock all along the year, thus increasing the productivity of the herd, offers another example.

The integration of crops and livestock for instance can be managed at farm level or at broader scale, by moving the herd in the fields to eat crop residues and fertilize the field. Such practices are key to preserving soil fertility in arid and semi arid areas and, at the same time for associated livestock systems. Where livestock systems are more specialized it can take the form of transporting manure to crop farms.

More broadly, landscapes provide numerous ecosystem services, from complementary and alternative sources of food to pollination and pest management which all contribute to increase the efficiency of the system (MA, 2005). Assessing and valorizing them is a first step often needed to ensure collective appropriation and sustainable management.

Comparing efficiencies of systems at landscape level enable to better account for the contribution of its various elements through the provision of ecosystem services. A comparison of traditional slash-and-burn and agroforestry systems in Central America (FAO, 2010e) shows the latter to be more efficient on all parameters monitored. Less land needed per family, increased productivity of labour and capital, better use of fertilizers, reduced soil erosion. An analysis of the opportunity costs of irrigation in the Awash valley of Ethiopia (Behnke and Kerven, 2013) comparing the economic benefits of three alternative agricultural systems, pastoral livestock production versus cotton and sugar estates, concludes that pastoralism is consistently more profitable than either cotton or sugarcane farming while avoiding many environmental costs.

2.4.3 How to improve it in food chains?

The assessment of resource efficiency should not be limited at the farm but encompass whole food chains. For instance, it is estimated that half of the total energy used in the food system is used beyond the farm gate, mainly for transport, transformation and conservation. Moreover an estimated 30 percent of food is lost or wasted. Reducing food losses and waste is also a way to reduce the use of resources, as is also the valorization of "food" losses and "waste" (for example in energetic terms).

Energy is increasingly essential to the whole food system (Canning *et al.,* 2010; Woods, *et al.,* 2010), not only during crop, livestock and fish production, but also in processing and packaging, distribution, transportation, consumption and disposal (Martinez *et al.,* 2010). Modern food systems already consume a significant (considerable) amount of energy, and this tendency is expected to increase. In the United States of America, for example, between 1992 and 2002, the total energy use grew by 3.3 percent and food-related energy use by 22.4 percent (Canning *et al.,* 2010). An Economic Research Service analysis of food system energy use indicates that, while total per capita energy consumption fell by about 1 percent between 2002 and 2007, food-related per capita energy use grew nearly 8 percent.

Knowledge about energy use in agriculture and the food system is far from complete (Ziesemer, 2007; Bailey *et al.,* 2003), as there are no global studies on energy use in the food system accounting for energy use at all stages of food production and consumption. Only partial studies focusing more on developed countries or some stages of the food chain provide some insights.

In developed countries, the use of energy in the food system on average amounts to 12 to 20 percent of the total energy consumed (Carlsson-Kanyama, 2004). In the United States of America, in 2007, it was estimated that 15.7 percent of energy consumption was used to produce food (Canning *et al.,* 2010). In Sweden, energy use, in the food supply system is about 42 TWh or 13 percent of total energy use of which energy used for agriculture and fisheries is about 6.5 TWh or half of the total (Wallgren and Höjer, 2009).

Kaygusuz (2012) estimates that 1.4 billion people lack access to electricity and that 2.7 billion people rely on the traditional use of biomass for cooking. Cooking energy can represent a significant part of the income of poor families. For example, Sugure (2005) estimated that, in South Africa, the average poor home spends 25 percent of its income on energy compared with a figure of 2 percent for wealthier homes.

Recent figures from the developed world show that the consumption stage of the food chain is the least energy-efficient of all (FAO, 2012). Food consumption involves the storing, preparing, serving and eating of food, either at home or outside the home. A study (Canning *et al.,* 2010) found that food processing and consumption together accounted for about 60 percent of total 2002 food-related energy flows in the United States of America, up from 55 percent in 1997. This was partly because of the increasing use of technologies such as refrigeration, but also because households and restaurants have come to rely more heavily on processed foods, which use high energy consumption technologies for production. Similar results were shown by a 2000 Swedish study, which found that household energy use for cooking and storing food was 28 percent of the total energy used, and that processing contributed another 25 percent (Carlsson-Kanyama, 2004).

Transport at all stages of the food chain can play a significant role in the consumption of energy and energy performance. Food is traveling further from farmers to consumers, or from its place of production to the place of consumption (Hendrickson, 1996; Pretty *et al.,* 2005; Martinez *et al.,* 2010). However, this contribution depends much more on the means of transport than on the distance. Moreover, half of the energy consumption for global transport is caused by the individual consumer at the last stage. This last result mainly reflects the relative inefficiency of post-retail food transport compared to pre-retail. Globally, it has been estimated that as much energy is required to transport 5 kg of food by car for 1 km as is required to transport it for 43 km by plane, 740 km by truck, 2 400 km by train or 3 800 km by boat (Brodt, 2007).

There are options for achieving greater energy efficiency at every stage of food chains. Each link along the food chains, until consumption, has potential to improve energy efficiency – from production, transport, conservation, transformation and cooking (FAO, 2012g). For instance, transforming fresh products transported over long distances into less perishable products can reduce losses and emissions induced by conservation and transport as slower, more energy-efficient transportation means can be used.

Reducing food losses and waste is increasingly considered to be one of the most promising ways to improve the resource efficiency of the global food system (Foresight report; HLPE, 2011; 2012; FAO, 2012b, e, i; UNEP 2012; Moomaw *et al.,* 2012). FAO (2011d) estimates that roughly one-third of food produced for human consumption is lost or wasted globally during the entire process, from production to consumption, which amounts to about 1.3 billion tonnes per year. Kummu *et al.* (2012), who converted from FAO crop weight data to their nutritional value, have calculated that it represents a quarter of that in terms of calories and it would be enough to feed around 1.9 billion people assuming a 2 100 kcal/capita/day food supply level.

Food is lost or wasted throughout the entire food system with two stages, agricultural losses and consumption waste, accounting each for around 30 percent of the total losses and waste (Kummu *et al.,* 2012).
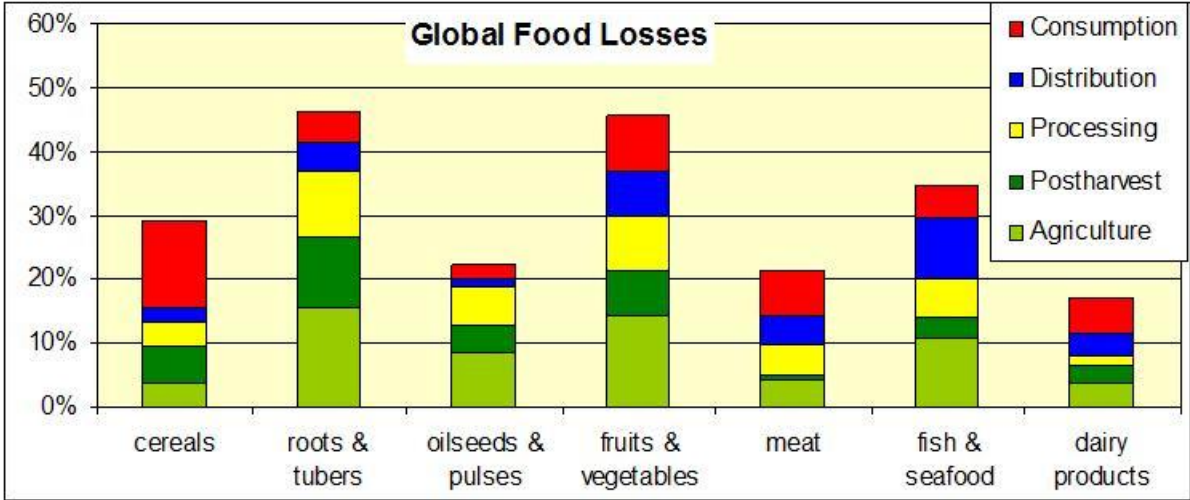
Source: FAO, 2012g

Estimations of food losses and waste differ widely between, regions, products and methodologies (FAO, 2011d; Kummu *et al.,* 2012). Considering regional differences, in low-income countries food is mainly lost during the early and middle stages of the food supply chain, owing to technological, logistical or organizational causes, while in medium- and high-income countries food is mostly wasted at the retail and consumption stage, meaning that the causes are mainly related to consumer and retailer behaviour (FAO, 2011d). For instance, in Europe, cereal losses and waste are twice as high as in sub-Saharan Africa, while in sub-Saharan Africa, milk losses and waste are twice as high as in Europe. In Africa, cereals are lost in the first stages of the food chain, while in Europe they are lost mostly at the consumer stage: 25 percent against 1 percent in Africa. For fruits and vegetables, the differences between regions are also striking. Overall, on a per capita basis, much more food is wasted in the industrialized countries (95–115 kg/year in Europe and North America) than in developing countries (6–11 kg/year in sub-Saharan Africa and South/Southeast Asia) (FAO, 2011d). Similar results come from Kummu *et al.* (2012), where results indicate that losses are proportionally larger in regions with intensive production systems and a large per capita food supply (e.g. North America and Oceania) and low in regions with a small per capita food supply (e.g. Sub-Saharan Africa or South and Southeast Asia). These global differences between products and regions indicate potential for improvement.

To make a global estimation of the potential of reduction of food losses and waste, Kummu *et al.* (2012) used a "minimum loss scenario", defined as an optimum situation where each step of the food chain would be everywhere as efficient as found in the more efficient regions in the world. The results showed that the largest potential for improvement is in production and in final consumption steps, with, respectively, an estimation of reduction potential of 47 percent and 86 percent. The potential for improvements is largest in regions where the food demand is not expected to grow in the future, and smallest in regions with the largest challenges in terms of malnutrition and population growth (sub-Saharan Africa and South and Southeast Asia). By region, the largest potential reductions in terms of food supply are in North America & Oceania (63 percent) and Europe (63 percent), and the smallest potential reduction is in sub-Saharan Africa (31 percent).

Addressing food losses and waste requires very different approaches depending on food chains and steps. It calls for better knowledge not only of food losses but of the economic and environmental impacts of reducing them. This often requires a multidisciplinary approach all along the food chain. Tools suchas the African Postharvest Losses Information System (APHLIS)[7] are essential in that regard. Food waste in developed countries is a more recent topic of interest. It needs to mobilize a different range of disciplines to better understand the drivers of economic and behavoural change. Studies have shown differences among different households of the same country, depending on household size and composition, income, demographics and culture (Parfitt, Barthel and Macnaughton, 2010). Drivers for retailers include improvement of corporate image (Stuart, 2009). The United Kingdom has promoted some successful actions at retail and consumer levels.

There is also a need to better know what share of those losses and waste is used for other purposes and not totally lost (Kummu *et al.,* 2012). Some food by-products or co-products, that are sometimes considered as waste, can be incorporated into other marketable products (Hodge, Buzby and Bennett, 2010). Some authors (Parfitt, Barthel and Macnaughton, 2010; Hodge, Buzby and Bennett, 2010) note that part of the food "lost" after the agricultural stage in developing countries is eaten by the poorest. The US Environmental Protection Agency (1999 ref) has designed a "food recovery hierarchy", prioritizing recovery of wholesome food to feed the hungry and poor, providing feed for livestock and zoo animals, recycling for industrial purpose and composting to improve soil fertility.

Importantly, reducing food losses, particularly for fragile fresh or frozen products, fruits, vegetables and animal products, often involves a higher energy consumption, for conservation and/or quicker transport. This is particularly important as the consumption of these fragile products is increasing particularly rapidly.

2.4.3 How to improve resource efficiency at broader levels (comparative advantages?)

We have seen, as mentioned above, that resource efficiency can be assessed at the upmost integrative level of diets. More "resource efficient diets" imply shifting consumption patterns towards the ones that rely on products produced from less resource intensive production and transformation systems, while keeping (or improving) levels of nutrition. This is, in fact, closely related to the notion of sustainable diets (FAO, 2011h).

In a first approach, the question of improving resource efficiency at the diet level can be posed independently of the two levels described above. There are feedback loops, however, because massive shifts in diets ultimately also trigger (in one direction or another) changes in production systems and in food chains, as we have seen in China in the last 40 years (ref Stanford).

The fact that the output of agriculture can also be defined as diets opens a margin of substitutions and trade-offs for resource efficiency improvements, as these can be found also through shifting diets (for the same level of nutrition service).

Essentially, economic welfare analysis is based on the maximization of utility, being very often an increasing function of consumption levels: by construction, economics do not prescribe individual levels of "over" consumption of goods per capita. However, in food and agriculture, "unnecessary" rich diets bring a whole range of problems, starting with health, as well as indirect impacts on the poor and too-rich diets of the wealthiest, linked to the fact that

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[7] Available at www.aphlis.net

excess consumption in rich countries aggravates the problem of hunger (HLPE, 2011a) for the poor. It results that a certain amount of calories and nutrients can be considered as excessive, and that its "redistribution" between individuals at world level can in fact lead to less resources being consumed for an improved level of world nutrition service.

Substitution of diets with high environmental footprint for those with higher resource efficiency constitutes an effective strategy. However, a key challenge lies in the difficulty to re-orient demand through public policies. Diets are difficult to change for a good reason: very often diets integrate very legitimate cultural dimensions that are not acceptable nor desirable to change. Public policies have little sway on diets as incentive systems; campaigns have recurrently failed to address issues of health and nutrition, for example. The issue of taxation of food products is also a very sensitive one. This comes with a huge challenge of finding ways to promote changes in consumption patterns towards less resource intensive diets.

Putting the question of improving resource efficiency at the level of diets (therefore at the consumer level) rather than at the level of the field or of the food chains (production level) might also be perceived as fairer accounting, especially for food or feed-exporting countries (Bruckner, Polzin and Giljum, 2010).

2.5 Resource efficiency, trade and exchanges

Trade and exchanges can play an essential role in optimizing the use of resources. This can be done at all the levels above.

1. The field level production of water-intensive products where water is easily available; of products needing heat where there is heat instead of artificial heating; better integration of crop and livestock at territorial level; avoidance of export of organic matter from areas where it is scarce; bulking of inputs and outputs in smallholder farming systems to reduce transport costs; generally removing input and credit market distortions so that complementary inputs are used and enhance resource efficiency.
2. The food chain level, with the issue of transformation *in situ* to avoid transport of bulky, low-value goods and over long distances, and to reduce transport of fragile products by plane. The issue of international fluxes of feed is a key issue of the improvement of livestock systems (Ciais *et al.,* 2007)
3. The diet level, with the issue of increasing globalization of diets, with many countries importing major quantities of staple food from overseas. Given the growing importance of trade, the issue of resource efficiency at the diet level requires an international perspective. This is not new to the world of industry, as the causal chains associated with our products and services typically involve worldwide material flows and energy inputs (Bringezu *et al.,* 1997). This is increasingly true for agriculture; with huge transfers of carbon and other footprints from the place of production to the place of transformation and consumption (Ciais *et al.,* 2007).

Shifting to more sustainable or resource-efficient diets raises, in fact, acute debates and a controversy between two rationales, the resolution cannot of which be solved through generalities. According to the first rationale "zero kilometres", sustainable diets have to be achieved by a movement towards the strengthening of local food systems and the consumption of local food – this would lead to bridging the "spatial" gap between the field and the fork, and to embed food systems in the local environment, to a certain extent allowing for a social internalization of positive and negative externalities: the consumer would

be more interested, as more directly aware and concerned, in sustainable and employment-rich approaches, such as slowfood (Andrews, 2008). It would also minimize transport costs.[8]

The second rationale assumes that a higher degree of international trade will optimize the food system at world level towards the minimization of global resource use, by producing food where it is more efficient to grow it, transforming it where it is more "efficient" to do so, and then shipping it worldwide according to the different diets and consumption patterns in different regions, themselves, ideally, optimized. It is notable that in our perception of efficiency, which does account for employment and jobs as an output, and therefore as a numerator to the metric, the contribution to more efficient diets worldwide entails a certain dimension of keeping people employed in agriculture, and not the reverse. This enlarged conception of what counts towards "output" in terms of metrics, allows the inclusion, in the same movement towards more resource efficiency, of initiatives such as fair trade.

The question of improving diets worldwide, to improve resource efficiency at the planet level, ultimately questions the sustainability of western consumption patterns, and the trends that would lead to their adoption (for legitimate reasons) by a growing share of the developing world.

2.6 Synergies and trade-offs efficiency/resilience.

To ensure and improve food security on the long run food systems have to be not only more efficient but also more resilient to shocks and changes. Biophysical, economic and social dimensions of food systems are linked; vulnerabilities in each of them add themselves (Gitz and Meybeck, 2012). Therefore, efficiency and resilience should be pursued together and at various scales in agricultural systems and food chains. In the pursuit of these two goals, there will be trade-offs, but there will also be synergies. Increasing efficiency could lead to greater sensitivity to certain shocks. For example, more productive livestock is more sensitive to heat waves (Hoffmann, 2010). Yield stability traits of species under variable conditions are particularly important areas where more understanding and research is needed (HLPE, 2012).

Specialized systems are often presented as being more efficient from an economic point of view, as they generate more income. These systems can benefit from the improved technologies and from economies of scale in the production and distribution of inputs, machines, and especially processing and trade.

Diversifying production can also improve efficiency in the use of land. as is the case in agroforestry systems for instance and of nutrients as by the introduction of legumes in the rotation or in integrated crop/livestock or rice/aquaculture systems. Studies show that they can also be more efficient in terms of income, especially if this is measured as an average over a period of several years. Some of the results of studies conducted in Finland have shown that diversity can increase income (project ADACAPA, Kahiluoto, 2012). Farms that both grow crops and exploit forest generate a higher and more stable income. Regions growing more diverse varieties of barley have a higher average yield than areas growing a single variety.

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[8] However, without necessarily implying substantial savings in GHG, as transport related emissions only represent a fraction of the emissions along the food chain, typically only 11 percent (Weber and Matthews, 2008).

2.7 Main conclusions

Optimizing the use of resources requires taking into account all inputs and expected outputs, not only physical products but also income and livelihoods, and externalities. It then requires prioritizing both input and expected output, which is often local specific. This can make challenging comparisons between different systems which would call for the use of metrics common to all the systems analyzed. It is often easier to compare the same system at different periods of time than different systems at a given time.

There is a need for better description and understanding of the various dimensions of resource efficiency, economic, social and environmental at each appropriate level: farm, landscape, food chain and global. It also has to integrate a time dimension, as often more sustainable practices generate benefits on a longer period.

Comparing practices has to be done taking into account all parameters needed for decision making. Especially, even if the aim is to improve the management of natural resources, it has to present also the relevant economic and social data, as these are often determinant in decision making.

This calls for more data gathering in order to provide bench marks and detailed analysis of specific practices in diverse situations.

3 Addressing resource challenges

The previous sections have identified some of the resource challenges to food security: increasing pressure and resource scarcities at global level and especially in certain regions or locations, leading to "systems at risk" and to the need to make better use of resources at every level, from farm to global. Key to such improvements is to give decision-makers, at every level, from farm to governments and consumers, the tools and means to act. First, they need a better knowledge of resource availability now and in the future. They also need tools and metrics to compare resource efficiency of practices and systems, identify potential improvements and monitor their impacts. This could contribute to shifting the primary focus of innovation in practices and technologies from producing more towards producing more efficiently. It is also essential to facilitate and improve the governance of natural resources which is becoming increasingly complex, involving more very diverse actors, with different objectives and points of view. A key issue here is that stakeholders are very different, sometimes have conflicting objectives and there is a need to work on a long-term perspective while most of them have to consider first a short-term outcome. Introducing this time dimension and, in some cases, compensating for it could be one of the core objectives of public actors. It is part of the broader key question of how to integrate and valorize the collective/public dimensions of individual/private actions, which requires adequate policies and tools.

3.1 Assessments, measurement

Better assessment and measurement are essential to inform decision-makers (governments, farmers, consumers etc.) and could lead to better economics of resource use and towards better pricing, as the quality of methods to eventually internalize externalities depends on the accuracy of their description.

As is obvious from the wealth of information shown above, there is a good foundation of assessments taking place with regard to natural resources of importance to food security. In particular, the regular inventories led by FAO on water, land, forests and fisheries have proven essential for planning and decision making. FAO's forward-looking analyses related to natural resources are also vital. Other organizations contribute complementary assessments, such as the CBD and UNEP World Conservation Monitoring Centre's work on biodiversity tracking and assessment.

Amidst this positive side, there are three areas that require more attention: (i) gaps in resource assessments; (ii) measures and assessments of resource efficiency and (iii) the *ex-ante* assessment of consequences of resource degradation and investments in natural resource management.

3.1.1 Resource assessments

A good knowledge of the status of the resources and their trend as a result of their uses and management are key steps towards sustainable management. Many development sectors that deal with natural resources management have put in place regular monitoring systems to provide decision-makers with sufficient and quality data to support their decisions. They also facilitate informed decision-making about sustainable biodiversity management at national level. On the contrary, a lack of agreed indicators or assessments of them often prevents this being adequately taken into account in management decisions.

Notwithstanding the investments already being made in resource assessments, there are some notable gaps. The first is related to the fertility status of soils, for which very poor information exists globally and in particular in certain regions. Existing global soil maps are based on parent material rather than on parameters associated with fertility and food production. Soil constraints and measures of land degradation are estimated in part by indirect methods and in part by expert opinion, and global libraries of soils have been incomplete. There are efforts underway to change this under the coordination of the Digital Soil Mapping Working Group of the International Union of Soil Science (see globalsoilmap.net), which combines strategic soil sampling, inexpensive techniques of analysis and high-resolution remote sensing data. Soil information will be available over wide scales and covering a range of important soil properties which can be used to inform management decisions. Although this effort is already underway, it remains to be seen how a more regular monitoring system can be designed and financed.

The loss of biodiversity including agricultural biodiversity is still recognized as a major concern by parties to the CBD after their failure to meet the 2010 targets of significantly reducing biodiversity loss by the year 2010 (Butchard *et al.*, 2010). A major reason for this failure has been the lack of appropriate observations and baseline data to measure the status and trends of biodiversity. It is also recognized that there is a lack of consensus about what to monitor and different organizations and projects adopt diverse measurements, with some important biodiversity dimensions, such as genetic diversity, often missing (Pereira *et al.*, 2013). Indeed there is no global routine scale of monitoring genetic diversity over time (Frankham, 2010; Dulloo, Hunter and Borelli, 2010). The Tenth Conference of Parties (COP-10) of the CBD held in Nagoya, Japan, in 2010 adopted a Strategic Plan for Biodiversity 2011–2020 including revised biodiversity targets, the so-called "Aichi Targets". Several of these targets address agricultural biodiversity (especially Targets 6, 7 and 13). To be able to assess and monitor biodiversity change, it is essential that metrics and indicators for the different components of biodiversity be developed. In this respect partners from the Group on Earth Observations Biodiversity Observation Network (GEO BON) are developing – and seeking consensus around – essential biodiversity variables (EBVs) that could form the basis of monitoring programmes worldwide. (Pereira *et al.*, 2013).

FAO undertakes regular assessment of genetic resources for food and agriculture and has developed indicators for monitoring the status and trends of agricultural biodiversity and other components of biodiversity in agricultural ecosystems within the context of the Global Plan of Action for the Conservation and Sustainable Utilization of Plant Genetic Resources for Food and Agriculture (GPA) and the Global Strategy for the Management of Farm Animal Genetic Resources (Collette, 2001; Diulgeheroff, 2004). A revised set of indicators and targets for monitoring the implementation of the Second GPA has been produced by FAO,[9] to be endorsed by the Fourteenth Regular Session of the Commission on Genetic Resources for Food and Agriculture. Such assessments allow for monitoring achievements towards reaching the CBD's Aichi targets. The first *State of World Forest Genetic Resources*, which is to be completed by the end of 2013, has already identified needs and priorities at national regional and international levels. These needs and priorities have been translated into strategic priorities (http://www.fao.org/docrep/meeting/027/mf815e.pdf) for implementation after adoption by the FAO Conference.

The System of Environmental-Economic Accounting (SEEA) – Central Framework[10], was adopted as an international standard by the United Nations Statistical Commission (UNSC) at its Forty-third Session in 2012. It is the first international statistical standard for environmental-economic accounting. The SEEA Central Framework is a multipurpose conceptual framework for understanding the interactions between the economy and the

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[9] CGRFA-14/13/4.1

[10] Accessible at http://unstats.un.org/unsd/envaccounting/White_cover.pdf

environment, and for describing stocks and changes in stocks of environmental assets. The SEEA brings statistics on the environment and its relationship to the economy into the core of official statistics. This version of the SEEA is an outcome of much path-breaking work on extending and refining concepts for the measurement of the interaction between the economy and the environment. Some important measurement challenges remain and are included in the research agenda. Regular compilation of environmental-economic accounts in countries as part of a programme of official statistics will foster international statistical comparability, provide policy-relevant information at national, regional and international levels, and improve the quality of the resulting statistics and understanding of the measurement concepts.

3.1.2 Resource efficiency measures and assessments

The assessment and measurement of resource efficiency comes with specific challenges.

First, as we have seen, there is a need to opt for appropriate metrics to measure resource efficiency, taking into account local scarcities and priorities (including in terms of outputs).

The best metrics to use depend on the question to be answered, and on the scope of the assessment or of the comparison (in time, across space, between systems) to perform. The broader the parameter and scales (spatial, temporal) of the system under scrutiny, the more different the metrics might be that cover different subsets of the system (products, inputs, outputs, parts of the food chain). But paradoxically, this does not necessarily mean that the options for a good metric of the "efficiency of the system" are more diverse, as to measure it we need an indicator that can capture the entirety of the system, including changes of internal pathways (systemic change).

There are now recognized standards to measure energy efficiency and the carbon footprint. There is however a risk of reducing the assessment of resource efficiency to these available tools. It is particularly tempting because as the impact they measure is globally relevant and compatible, they can be used for very broad comparisons. But it risks hiding all other impacts not related to carbon or energy, leading to a possible misrepresentation of environmental efficiencies and impacts in general.

Even for one particular resource, such as water, one specific tool might have antagonistic relevance in different contexts. For example, the water footprint of a product coming from an area where water is scarce is likely to be smaller, in absolute terms, than for the same product coming from an area where – or produced when – water is abundant. The environmental impact can, however go in the opposite direction, if the water footprint is measured against water availability (in time and space). Therefore, the choice of a "priority" metric has often to be made given local specificities. This in turn can make comparison between countries particularly difficult.

Second, there is a need for a broader and harmonized collection of data covering input availability and use (such as the one covered by FAOSTAT for land use), output production (such as the production data in FAOSTAT or in agronomic models such as GAEZ etc), data on emissions (FAOGHG), data on international trade, economic and social data (World Bank, OECD, UN). Yield estimates and inferences on contributions of inputs are based on few direct observations, instead of being calculated from aggregate data obtained through different processes. Even micro-datasets from farms rarely include direct measurement of both crops and area. This cannot be done on a large scale, but more groundtruthing to validate larger-scale estimates would be valuable.

Finally, there is also a need for coherent approaches to compute the various components of resource use. For instance, when one take the ecological, carbon and water footprint as in (Gallia *et al.*, 2012), each indicator has its own calculation methodology and accounting framework: carbon footprint accounts utilize a multi-regional input–output (MRIO) model to allocate emissions to consumption; conversely water and ecological footprint have been historically calculated using process-based LCA data and physical quantities of traded goods. When used jointly, the indicators have to bear on compatible and consistent methodologies and framework, which is not always the case. The nitrogen accounting indicator in turn uses a distinct methodology.[11]

For the monitoring and reporting of crop water productivity, the development of a water productivity score (WPS), which normalizes for crop type and climate, is under development (Bastiaanssen and Steduto, 2013). WPS can be measured by using satellites and used to benchmark the production efficiency of water utilization in agriculture.

3.1.3 *Ex ante* assessments of resource management

The ways and means to assess *ex ante* the impacts of changes in resource qualities or management, including potential long-term impacts, are critical to help inform policies and decisions.

Current foresight work is strong in terms of projecting food demand, food production needs and, consequently, productivity growth and changes in levels of resources such as land, water (irrigation) and inputs. What is less analysed is what current trends in resource quality will mean for productivity and food production. Thus, while studies are indicating degrading soil fertility at a significant scale, its implication on future food production is not well understood. Climate change brings a further element into the picture. The effects of temperature increase and rainfall decrease on crop yields and production have been estimated, but how these will also affect the long-term quality of the resource base is less understood, which may have further consequences on food production.

Likewise, the flipside of this, the potential for improved natural resource management (NRM) to increase yields and food production in the future is not well analysed. It is taken without debate that sustainable land and water management is critical to future food production, but surprisingly little quantification of this effect is made. Even our current knowledge of how integrated soil and water practices will alter yields in the short and long term is not well known. Much of our knowledge base is related to single components of soil and water management, which hold other technologies constant in their analyses. And to compound the issue, because there is poor information about soil constraints and needs in any particular location, there is a degree of uncertainty in designing best soil management practices for that location.

Foresight models within the CGIAR are regularly upgraded by IFPRI and partners and continue to take on greater breadth and resolution. They are built to estimate global impacts from technological change. However, as they rely on inputs from crop models, they are much better able to run scenarios based on crop variety innovations than natural resource management innovations. Complex management systems such as intercropping or agroforestry are not easily handled in such models and so there is a need to enhance such capability.

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[11] www.n-print.org

Studies comparing effects of systems managing resources very differently in the same type of environment, such as those mentioned in section 2.4.2, can be particularly useful here. For instance lessons drawn from the study in the Awash valley are relevant to better assess *ex ante* projects in the Omo valley (Behnke and Kerven, 2013).**3.2 Practices and technologies**

Addressing the resource challenge invites a reconsideration of innovation in practices and technologies.

Practices and technologies should not only aim for more physical production or more income but also aims to take into account the sustainable use of resources. This could imply radical changes of practices and thus of whole systems. It cannot be done without careful consideration of all their consequences, which requires more integrated and farmer-centred research, taking into consideration environmental, economic and social dimensions.

The need to reconcile ecological with economic sustainability thus leads to practices based on closer consideration of existing ecosystems. The aim is to make the best possible use of natural functionalities and interactions to develop robustness, productivity and rich variety in ecosystems. It therefore presupposes that agronomy-based knowledge and innovation are restored to the very heart of farming practice: by using, for example, associations of different varieties as a factor for enhancing resistance to parasites, or by making better economic use of local resources, notably as animal feedstuffs.

Principles of sustainable management of soil and water are well known. There are also many practices and techniques to implement them that are available and being used by farmers and landscape managers (see for example, Liniger *et al.,* 2011 for Africa). Some practices will have more immediate effects than others, while some other practices may have longer-lasting effects. For example, the application of nitrogen fertilizer has mainly a single seasonal effect while application of phosphorus can be much longer-lasting. Organic nutrients also have effects that last multiple seasons. The quality of the investment is obviously important. Terracing can be done to be long lasting or done poorly, requiring frequent maintenance. Many of the soil and water practices used for sustainable mangement have also been identified as useful for climate change adaptation and mitigation (Woodfine, 2009).

Numerous studies have shown the benefits of combining different management practices for boosting productivity in the short run (e.g. irrigation with mineral fertilizers) and maintaining yields over the longer term (e.g. organic nutrients with soil conservation) on cultivated plots. Studies from the Sahel for example, have shown that both water-use efficiency increases when nutrients are applied and long-term yields are higher in Kenya when organic and mineral fertilizers are combined as compared with when fertilizers are used alone (Bationo *et al.,* 2012). Farmers do understand these benefits and farm surveys from all parts of the world reveal the widespread adoption of multiple practices at the farm level. However, there are constraints preventing farmers from investing in practices at their optimal levels, e.g. cash costs of fertilizer or irrigation equipment, lack of labour for using compost, or lack of land for using improved fallows. The importance of these constraints is context-specific, across broad regions in some cases (e.g. overall lack of land for fallowing) but varying across households in other cases (e.g. some households can afford fertilizers while others in the same village cannot).

Similarly, moving from plot to farm, there are further benefits from integration of livestock and cropping systems, from integrating water harvesting systems with high-value food production and integrating trees into various niches on the farm to provide soil services, livestock feed and other direct food products. And at the landscape level, there is the importance of integration of forests and other habitats and biodiversity for provision of alternative food and

energy sources and critical environmental services to agriculture (notably pollination, pest control and water services).

Appropriateness of practices and of their combination is very context-specific. Therefore, the development of integrated practises that are used widely generally comes about from collaborative efforts with strong local input. Many practices have been developed by farmers themselves and may have been practiced over many generations. Science has become much better in understanding these contexts and building upon existing practices. There is still more progress to be made, such as understanding synergies and trade-offs from different integrated natural resource management practices and reducing constraints to practices whether that relate to reduced labour or solving credit constraints. This is not just a task for researchers, but for collaborations among research, development organizations and farmers. Designing the appropriate combination thus requires the establishment of an open dialogue among research, extension and farmers to foster exchanges between traditional knowledge and experience and science.

It also entails restoring and developing the professional skills of farmers. Integrated NRM practices are knowledge-intensive: they are not easily disseminated through media or short interactions with extension agents but require more sustained learning and interaction. This is one stumbling block towards wider use of integrated practices. The Farmer Field School approach which is based on experiential learning, has been shown to be an effective way to promote learning (e.g. in Bangladesh – Ministry of Foreign Affairs, Denmark, 2011), but this does not always lead to measureable outcomes (e.g. in Indonesia – Feder, Murgai and Quizon, 2003). However, ways to involve farmers in experiential learning at reasonable cost will be necessary to promote wider adoption of integrated NRM practices, especially in developing countries. The emergence of farmer groups and associations in sub-Saharan Africa may provide a new vehicle for dissemination of information in cost-effective ways.

Environmental issues vary between geographical areas, as do the relationships between farming practices and the environment.

For example, in areas where grass acts as the vehicle for agricultural systems, the goal must be to maintain ecosystems in order to retain the environmental services they render (preventing brush encroachment, protecting water quality, preventing fire, protecting biodiversity, storing carbon in the soil). Conversely, in those areas where the intensification and specialization of farming has led to high levels of pressure on habitats the goal must be to restore the ecological functions of agrosystems.

In order to extract value sustainably from resources while at the same time preserving natural balances and, in order to assess the nature of the impact of farming practices on the environment and to provide a coherent response to environmental challenges, we need to think out policy and practice on the scale of whole areas, addressing the diversity of their potential and their issues. What needs to be done is to develop collective, concerted strategies that are more positive for the environment than the simple accumulation of individual programmes. Indeed, the preservation and enrichment of the agro-ecosystem calls for coherent spatial organization acting as a vehicle for positive interactions.

Based often on "supply chain" – therefore vertical – approaches, agricultural development needs to give more effective consideration to the "horizontality" of problems in a given area. There is no single model for agriculture and more than one supply chain. Supply chains and models need to be organized at the level of a whole landscape. It is necessary to design collective strategies that maximize the diversity of the systems and their economic, agronomic and environmental effectiveness across a given area, notably by means of the coordination of activities within the area concerned (crop and livestock farming systems,

landscape structure, ecological infrastructures such as forest "islands", hedgerows, embankments).

The complexity of agricultural development stems entirely from this reality: standardized technical solutions are even less applicable in agriculture than in other sectors. In agriculture even more than other sectors, innovation is not simply a top-down process handed down from the laboratory to the enterprise via the technical institutes. On the contrary, the joint building of solutions is part and parcel of agricultural development.

The generalization of productive and sustainable agriculture depends on bringing research to bear on ecologically intensive systems and development including:

— Capitalization on technical knowledge relating to agro-ecology fed back from field trials, associated with standardized databases, for the construction of reference criteria for the implementation of ecologically intensive farming both in terms of the technical routes (management of plots of land) and complete production systems, plus their interaction across whole regions, beyond the confines of individual farms.

— Development of engineering methods for the design of agricultural production as part of its overall environment (decision aids, provision of methods for designing technical routes, computer-assisted design software, management and decision-making optimized for situations where certainty is lacking).

— Promotion of innovative approaches to assist the farming community across a whole region, notably providing for a role for scientific expertise and learning processes in order to make innovation more easily acceptable.

— The consolidation, in the defined domain of agro-ecosystems, of public research in designing agricultural systems and of the link with experience on the ground (a bottom-up approach, technical innovations by local actors). The specific skills of the many CG research centres are a major asset.

Taking into account and disseminating more effectively innovations that come from farmers themselves should be strengthened. It requires assessment of the impacts of innovation on agricultural practice, monitoring and dissemination. Initiatives such as the platform on tropical agriculture can go a long way towards bringing together national and international research.

3.3 Governance of natural resources.

Resources are often shared or competed for, either for the same type of use or for different uses. Their sustainable management requires a shared understanding of their scarcity and value and proper tools to distribute and/or manage them collectively. This requires the involvement of all concerned stakeholders in decision-making. It can be particularly challenging when local and global impacts have to be taken into consideration or when different resources, differently managed, do interact, at the same or different scales. Often resource efficiency has to be considered in whole food chains or food systems which also requires adequate information and governance mechanisms. It also requires ways to accommodate short term concerns of most of private actors within a long-term perspective.

Collective management of a resource covers various issues. It first needs to acknowledge the resource, the need to have a collective approach in its management, and the scale at which it should be done. It always considers, at least by default, the distribution of the

resource, between uses, between categories of users and between users. Increasingly it implies the recognition of the need to determine a certain maximum global level of use, lower than the actual possible maximum use, to protect the resource for future use. It can also include more complex management issues, particularly when a resource is used for various purposes, by different categories of stakeholders (water for its different uses, from irrigation to industrial and urban uses, and conservation of aquatic biodiversity) or shared, as forest for instance, where different interests, time scales and visions interfere.

An important literature, from Hardin (1968) to Ostrom (1990, 2010) has considered the question of the governance of shared resources, or "pooled resources". There is now a wide consensus to recognize the value of local governance, provided it respects the eight "design principles" of stable local common pool resource management identified by Ostrom (1990):

- clearly defined boundaries (effective exclusion of external un-entitled parties);
- rules regarding the appropriation and provision of common resources that are adapted to local conditions;
- collective-choice arrangements that allow most resource appropriators to participate in the decision-making process;
- effective monitoring by monitors who are part of or accountable to the appropriators;
- a scale of graduated sanctions for resource appropriators who violate community rules;
- mechanisms of conflict resolution that are cheap and of easy access;
- self-determination of the community recognized by higher-level authorities;
- in the case of larger common-pool resources, organization in the form of multiple layers of nested enterprises, with small local common pool resources at the base level.

These models are now facing broad challenges such as transnational resource management or the need to manage resources for more diverse stakeholders with more diverse interests and time scale and, often, with increased pressure.

In many areas of the world water management is transnational. About 40 percent of the world's population lives in transboundary river basins, and more than 90 percent live in countries with basins that cross international borders (Sadoff and Grey, 2005). These more than 263 international water basins account for about 50 percent of global land area and 40 percent of freshwater resources (Giordano and Wolf, 2002). Many of these transboundary rivers are among the largest flows of water globally.

It is known that food security of many countries also depends on the continuous transfer of genetic resources for food and agriculture. This interdependence of countries, which is also recognized in the Nagoya Protocol on access and benefit sharing, is also expected to increase with the challenges ahead such as climate change (FAO, 2011f). It also calls for the increased collaboration among countries to fully support, participate and implement the conventions, treaties and agreements that aim at the effective conservation and sustainable use of the biological diversity essential for food and agriculture (Dulloo, 2013). Many breeds are shared among countries: out of the global total 8 262 reported breeds, 1 060 are transboundary breeds (reported by more than one country) (FAO, 2012j).

Rights to access and use of fisheries resources are often poorly defined, ineffectively enforced, or unfairly distributed. The variability and diversity of small-scale fisheries and their close links with communities make them unsuited to traditional top-down command and control resource management approaches. Moreover, poverty in fishery-dependent communities is not necessarily linked directly to resource overexploitation, but rather reflects the lack of wider institutional, political and economic advantages in rural (and in some cases

urban) poverty (Béné, 2003; Béné *et al.*, 2007). Marginalization and violation of the rights of fish workers and fishing-dependent people sometimes results in a lack of access to public services, including health and education, a lack of participation and representation in the policy-making process and, in many cases, a lack of access to efficient markets or trade. There is hence a need to combine resource management with addressing social and economic development (ICSF, 2007; FAO, 2009e; Allison *et al.*, 2011).

An enabling policy framework for environmentally, socially and economically sustainable resource use needs to integrate fisheries into broader development plans and strategies and ensure that the sector is not socially, economically and politically marginalized. For a sustainable exploitation of capture fisheries resources the direct users need to become responsible stewards of the resources. The main elements to achieve this include the empowerment of stakeholders to actively engage in decision-making processes, appropriate management mechanisms and secure rights. In the capture fisheries sector, there is a broad spectrum of existing access, use and management rights systems that are applied and that can lead towards more economically efficient outcomes, ranging from very weakly to very strongly and explicitly defined rights The recently adopted Voluntary Guidelines on the responsible Governance of Tenure of Land, Fisheries and Forests in the context of national food security provide guidance on how to secure these rights, in particular for those who directly depend on the resources for their livelihoods.

In the aquaculture sector, the issues of rights are linked to the location of the activity itself. For land-based aquaculture, many of the rights issues are essentially land tenure issues. However, in the fresh- and salt-water environments, aquaculture rights are part of the more complex coastal spatial planning environment as well as the challenge of competing uses with the capture sector.

Sustainable management of resources has often to deal simultaneously with multiple resources and multiple purposes.

A good example of such multipurposes resource management is "sustainable forest management". It is an overarching goal for the forestry sector, applicable at international, national and subnational levels (Braatz, 2012). It is a dynamic and evolving concept that aims to maintain and enhance the economic, social and environmental value of all types of forests, for the benefit of present and future generations (FAO, 2010b). It aims to ensure that the goods and services derived from the forest meet today's needs, while at the same time ensuring their continued availability and contribution to long-term development. Forest management encompasses the administrative, legal, technical, economic, social and environmental aspects of the conservation and use of forests. It implies different degrees of human intervention, ranging from actions aimed at safeguarding and preserving the forest ecosystem and its functions to supporting specific socially or economically valuable species or groups of species for the improved production of goods and services.

Pastoral systems offer a good example of how issues interact in complex ways at landscape level, which could also be of a transnational nature. Rangelands account for more than 85 percent of land use (MA, 2005) in arid and semiarid regions, which represent 40 percent of the emerged land mass. Pastoral systems exploit, and manage, these areas effectively, by moving according to pasture and water availability. It is expected that they will constitute a form of adaptation to climate change, for instance in sub-Saharan Africa (Jones and Thornton, 2009), as they are able to cope with shorter growing vegetation periods than crop systems. In most dry zones the annual production of biomass has been slowly decreasing (Steinfeld, *et al.,* 2010). This is often attributed to inefficient management, overgrazing and insufficient land use rules.

Pastoral systems are also threatened by changes in land use and land tenure that reduce the available area, reduce mobility, and subtract some of the areas that are indispensable for the viability of the system during the dry season. During the first half of the century, 15 percent of dryland rangelands were converted to agriculture and the process continues (MA, 2005). Often, arable farming is extending on land formerly used for grazing during the dry season (Steinfeld, *et al.,* 2010). Ex Arbinda. This removes land, and associated water access, which is of critical importance for the pastoral extensive grazing system, undermining its viability. These changes in resource availability are often leading to either higher seasonal mobility or long-term migration (Petit, 2000).

Pastoral systems and crop/livestock systems are essential to sustainable management of resources for food security in arid and semiarid zones. Key to their resilience is their adaptive capacity (Ickowitz *et al.,* 2012), funded on complex economic, social and environmental interactions to best use scarce and changing resources. Understanding and monitoring them, by tools such as the information system on the pastoralism in the Sahel (FAO/CIRAD, 2012), is essential to ground national and regional policies.

There is an obvious need for collective management of resources as one moves from specific land uses to a larger landscape perspective which often encompasses a combination of farms, forests or woodlands, wetlands, rangelands and water bodies. Collective action is required at such scales to ensure that managers of individual resources do take into consideration other resources on the landscape. There needs to be rewards built in for providing services to other resources just as there must be penalties or other disincentives for negative externalities.

3.4 Transfer of resources

Natural resources are unequally distributed across and within countries. Agriculture is a classical example that illustrates the role of trade to increase global economic efficiency by exploiting local comparative advantages.

Fish and fishery products are among the most traded food commodities worldwide. In 2010, fishery trade represented about 10 percent of total agricultural exports (excluding forest products) and 1 percent of world merchandise trade in value terms (FAO, 2012a). Trade plays a major role in the fishery industry as a creator of employment, food supplier, income generator, and contributor to economic growth and development. For many countries and for numerous coastal, riverine, insular and inland regions, fishery exports are essential to the economy. For example, in 2010 they accounted for more than half of the total value of traded commodities in Greenland, Seychelles, Faeroe Islands and Vanuatu.

The European Union is by far the largest single market for imported fish and fishery products owing to its growing domestic consumption. This makes the European Union the largest market in the world, with about 26 percent of world imports (excluding intra-European Union trade). In 2011, imports rose further to USD50.0 billion including intra-European Union trade (USD26.5 billion if excluded). The dependence of the European Union on imports for its fish consumption is growing. This is a result of the positive underlying trend in consumption, but also evidences the constraints within the European Union on further expansion of its own supply. In this respect, the current reform of its Common Fisheries Policy aims to rebuild its fish stocks, as well as boosting its aquaculture production. The results of the reform and the effects on supply and trade will only be felt in the medium to long term.

Owing to stagnating domestic fishery production, developed countries have to rely on imports and/or on domestic aquaculture to cover their increasing domestic consumption of fish and fishery products. In 2010, developed countries were responsible for 58 percent of the total import in volume (live weight equivalent) of fish and fishery products, and 76 percent in value, reflecting the higher unit value of products imported by developed countries. In 2010, 48 percent of the import value of developed countries originated from developing countries. In addition to the major importing countries, a number of emerging markets have become of growing importance to the world's exporters. Prominent among these there are Brazil, Mexico, the Russian Federation, Egypt, Asia and the Near East in general. In Asia, Africa and South and Central America, regional trade continues to be of importance even though it is not always adequately reflected in official statistics.

The volume of virtual water "hidden" or "embodied" in a particular product is defined as the volume of water used in the production process of that product (Allan, 1997; Hoekstra, 1998).

It is estimated that to produce one kilogram of grain, grown under rainfed and favourable climatic conditions, there is a consumption of about 1–2 m^3 of water. For the same amount of grain, but growing in an arid country, with high temperature and high evapotranspiration, there may be a consumption of up to 3–5 m^3 of water. For a kilogram of beef meat, the virtual water can go up to 15 m^3.

The concept has been used to describe how water scarce countries can preserve their water resources by importing water intensive products (Allan 2001, Hoekstra 2003). International trade in agricultural and industrial commodities, therefore, influences the fate of countries' national water resources management and consumption, and international water dependencies are likely to increase with continued global trade liberalization. Consequently, a water-scarce country would aim at importing products requiring a lot of water in their production (water-intensive products) and exporting products or services that require less water (water-extensive products). On the contrary, water rich countries could profit from their abundance of water resources by producing water-intensive products for export.

For instance, Mexico imports wheat, maize and sorghum from the United States of America, which requires 7.1 billion m^3 of water per year in the United States of America . If Mexico would produce the imported crops domestically, it would require 15.6 billion m^3 of water/year. Thus, from a global perspective, the trade in cereals from the United States of America to Mexico saves 8.5 billion m^3/year (Hoekstra and Hung, 2005).

However, as noted by Hoekstra (2008) the potential water saving from global trade is sustainable only if the price of the export commodities truly reflect the opportunity costs of the exporting country. As water is often subsidised, it is generally not the case. Moreover international trade in agricultural commodities depends on a lot more factors than water (e.g., availability of land, labour, knowledge and capital, competitiveness, etc.).

Thus trade does not always compensate relative scarcities. Export of water intensive foods from a water scarce area could contribute to increase scarcity. Trade of feed for intensive livestock contributes also to concentrate organic matter in certain areas, depriving other. Nevertheless, knowledge on the virtual water flows entering and leaving a country can put a completely new light on the actual water scarcity of a country, on its foot print and on the possible water-saving opportunities.

Transnational appropriation

The transfer of resources can take other forms than trade, such as direct investment in land in other countries or, fishery agreements. Increasingly, some economically rich but resource

scarce countries acquire land (and associated water rights) in economically poorer countries to produce for themselves. The phenomenon is either presented as "investment" thus good or as "land grabbing", thus bad. The study requested by CFS to its HLPE (2011b) notes that in most cases foreign investment in land have not yet been accompanied by increased productivity and/or incomes benefiting food security. Rather there are numerous examples of vulnerable populations having lost access to the resources on which their livelihoods were depending. The implementation in such cases of the voluntary guidelines for the responsible governance of land, fisheries and forests, adopted by CFS in 2012, is expected to enable better protection of the rights of local and indigenous populations.

3.5 Policies, tools (payment of environmental services, extension services)

Critical policy areas include overall attention to agriculture and natural resources, support for agricultural research, supporting investment in infrastructure and markets and attention to specific agriculture and natural resource sectors. Much of the section below draws from Alexandratos and Bruinsma (2012).

Invest in agriculture and natural resources

National, international and private sector investment in agriculture must remain strong in countries where it currently is emphasized and must increase in many other countries. In order to increase food production by 70%, the FAO estimates that investment in developing country agriculture has to increase by at least 60 percent over current levels through a combination of higher public investment and better incentives for farmers and the private sector to invest their own resources (Alexandratos and Bruinsma, 2012). For all this to happen, strong political leadership needs to forge collaboration and commitment because sustainable results will not be achieved with quick fixes but with longer term incremental advances that may not coincide with political targets. Sustained improvements will also not occur if different ministries work in isolation. There is need for much greater synergy between agriculture, water, environment, land and forest ministries. Public investment in agriculture should help to catalyze private sector investment at farm, landscape and value chain (e.g. agribusiness) levels.

Investing in research and development for agriculture and natural resources

There is great variation in public investment in agricultural R&D, with Asian countries in general increasing investment, leading to a doubling between 1980 and 2000. On the other hand, increases were small in sub-Saharan Africa, rising at less than 1 percent per year over the same period. Certain countries such as Brazil, China and India dominate in terms of growth in investment and thus there is a call to action for a large number of others lagging behind. Research on crop and livestock breeding and basic agronomy will need to continue, but increased attention should be given to resource management, including managing soil constraints, integrated soil fertility management, improving fertilizer use efficiency, expanding water harvesting and management techniques, and landscape scale research on provision of key pollination, watershed, feed, energy and food services from non-farm niches. A key lesson learned is that although there are widely accepted principles of NRM, local context dictates the specific practices that are appropriate. These practices are knowledge intensive and therefore one priority area for investment will surely be for extension mechanisms and systems to better integrate these natural resource management aspects.

Markets

National and international food and input markets need to be more efficient for food security to be achieved in 2050. At the international scale, trade in food will likely need to increase to

reflect growing imbalances in food demand and supply, as well as shifts in food preferences from growing urban populations and incomes. The needed increase in mineral fertilizers will also need to move across international borders and efforts are needed to facilitate transport of fertilizers to reach landlocked countries at reasonable costs. The same can be said for national markets for both food and inputs especially given that national markets offer most smallholders the best opportunities to sell their products. It is not just an issue of facilitating trade in raw products but also investing in development of agribusiness. There are many opportunities for more national value adding of food products, examples being the use of local fruits for juice processing and processing of local milk for dairy products. Improving markets will have a positive impact on natural resource management as well. If farmgate output prices rise (relative to input costs) through improved market and infrastructure development, there is greater incentive to invest labour and capital in a range of soil and water management practices and for agricultural credit markets to emerge.

Where the farming sector is characterized by smallholders, there will be need for strengthening of farmer groups and associations. As developing countries continue on their high growth rates, private capital markets will view investing in small, costly, and risky enterprises such as smallholders as increasingly unattractive compared to other options. In groups, farmers can become a more attractive option for private investment and can also gain efficiencies in accessing inputs and selling outputs. Technology – especially the use of mobile phones -- is now making it easier for farmers to access information on markets and is recently being tested as a mechanism to lend and monitor micro-finance.

Sector policies

In agriculture, in addition to increased overall investment in the sector, there needs to be more attention given to natural resources management as an essential element to sustainable food security. Agricultural programmes are often designed around delivery of various components such as new varieties, animal vaccines, irrigation, or terracing whereas what is required is an integrated and holistic approach to improving land management. Furthermore, more attention needs to be paid to the landscape as a whole, for foods that are provided from forests and grazing lands and for other environmental provisioning services such as water regulation and pollination. Agricultural extension has normally not devoted much attention to off-farm areas whereas other ministries, with far fewer field agents, implement programmes which are not necessarily well aligned with farmer needs.

Land is critical for food security, in terms of the quantity and quality of the resources available and in the ownership and rights to the land. In developed countries, farming is almost entirely commercial oriented, but in many developing countries, it remains largely semi-subsistence. Small semi-subsistence farms may not contribute much towards urban cereal consumption as their produce remains in the rural area. So policy makers must weigh the tradeoffs of retaining and supporting a small scale farm sector as a livelihood for the high rural population versus feeding the urban populations. Countries such as Kenya have followed a dual farming sector of both smallholders and larger commercial farmers to balance these needs. A key consideration for countries is how much new land should be brought under agriculture. Much forest land, where fertile soils may exist, has already been lost across many countries, threatening key ecosystem services. Moreover, experience has shown that in many cases the fertility of converted forest soils is quickly lost after a few years of cultivation. Other natural habitats, such as dry bushland, are only marginally suitable for agriculture. There are also increased land acquisition proposals from externally based private companies and public institutions. Governments must rationally weight the potential food, revenue and employment benefits from such investments against alternatives. A particular policy issue of global significance is the potential competition within agricultural land for food and biofuel

production. There are trade-offs between private (e.g. farmer income) and societal (e.g. food versus energy) desires to negotiate.

The agriculture ministry is key to promoting quality of agricultural land, but tools such as credits, taxes and subsidies based on development of land can also be used by land ministries. In terms of rights, numerous studies have shown that although the adoption of improved varieties and use of fertilizer is not dependent on the degree of tenure security or ownership of land, medium to long term investments are very much affected by the security and duration of rights to land. So the promotion of soil conservation, animal manuring and planting of trees, for example, will require secure property rights. This does not require full land demarcation and registration which is costly, but can also be accomplished through simpler means, as through the certification system employed in Ethiopia.

Improved agricultural water management is critical to achieving higher food production. This includes increasing the area under formal irrigation schemes and there are opportunities to do this, especially in sub-Saharan Africa. Water management also includes other investments in water harvesting on farms and fields. In the dry lands, these are particularly important to reduce evapotranspiration and to accumulate water to areas where it is most needed.

Environment ministries, including forestry, need to work more closely with agriculture on the planning and support for landscape management that can provide food and other ecosystem services in a sustainable manner. At present, there are cross-sectoral inconsistencies that need to be reconciled, for example the promotion of strict conservation versus local resource use, the expansion of irrigation versus protection of waterways, and the protection of trees versus the promotion of planting and harvesting on farms. Current trends towards decentralization of government should in principle help to forge stronger collaboration in design and implementation of programmes of different ministries.

To improve resource efficiency various tools can be used, from better information for producers and buyers (both businesses and consumers) to better pricing of resources (real price of water, carbon taxes, reduced subsidies or tax exemptions on inputs…).

Transition and change, even towards a more economically sound system, often requires farmers to be supported, both technically (extension), and financially (subsidies for investment or to cover income foregone or increased risk during the transition period). Here payments for environmental services could play an essential role. It also requires the establishment of the proper legal frameworks (land tenure and water rights)

Improving resource efficiency often requires collective change, either at spatial (at various scales from local to global) or food chain level. Public policies, which play a fundamental role to trigger such changes, will most of the time require the active involvement of all stakeholders.

3.6 Main conclusions

Addressing resource challenges requires first of all adequate assessment and measurement to inform decision makers (governments, farmers, consumers etc.). Three areas require particular attention: (i) gaps in resource assessments, (ii) measures and assessments of resource efficiency and (iii) the ex-ante assessment of consequences of resource degradation and investments in natural resource management.

It invites to reconsider innovation in practices and technologies to aim not only for more physical production or more income but also to take into account the sustainable use of resources. This requires more integrated and farmer centred research, taking into consideration environmental, economic and social dimensions.

As resources are often shared or competed for, their sustainable management requires a shared understanding of their scarcity and value and proper tools to distribute and/or manage them collectively. The forms of collective governance which have proved their effectiveness are now facing broad challenges such as transnational resource management or the need to manage resources for more diverse stakeholders with more diverse interests and time scale, and often, under increased pressure.

Trade does not always compensate relative scarcities as potential resource saving depend on the integration of the opportunity of the exporting country, area.

Critical policy areas include overall attention to agriculture and natural resources, support for agricultural research, supporting investment in infrastructure and markets and attention to specific agriculture and natural resource sectors.

Conclusion

Current and future resource challenges to food security call for research and knowledge to better characterise availability of resources, at global and local levels and to provide ways and means to optimize sustainable resource management for food security in its four dimensions. It also requires more inclusive and participatory ways of building knowledge.

First of all there is a need to have a clearer picture of resource "availability' (land, water, biomass,…) and of how it can respond to growing and competing demands. Of particular importance is to have a better understanding of land use, land use changes and of their drivers. This includes better global data, but also better understanding of the reality of land use and particularly of the various informal uses of it. It also requires the capacity to model together the competing demands for food and bioenergy (including from forests) and the impacts of climate change on land use. The increased demand for biomass, especially as feed for livestock, but also for bioenergy, calls for a better knowledge of grassland production, including rangelands. Reduced land availability and increasing nutrient scarcities (or/and imbalances) point to the need to reinvest on soil understanding and knowledge. Biodiversity in all its forms, from intraspecific diversity to ecosystems is both a resource in itself and a way to better use other resources. Better knowledge of its potential, of how to protect and sustainably manage it, is crucial for the future.

Research and data on resource use and efficiency often focus on one type of resources and/or one dimension of efficiency, either economic or environmental, much less often on social issues. There is an urgent need to develop approaches and data banks that consider at the same time all aspects and impacts of resource management. This requires developing adequate metrics, protocols to describe resource management, adapted to each scale from farm (or consumer) to global, all along food chains; to assess economic, social and environmental impacts of various practices. In other words we need the tools to adopt systemic approaches, at every level.

This also requires to develop a knowledge base which is not restricted to the management of a single resource but embraces the relationship between them and with agricultural production and its various outcomes in an ecosystem approach, integrating landscapes and farming systems, forestry and fisheries.

It is also the way to build knowledge and do research which has to be reconsidered, with farmers, fishermen and foresters and local communities being the focus and active actors, in order to devise changes which are adapted to their needs and possibilities.

Such an approach is of particular importance for shared resources, requiring collective management.

There is growing understanding of the complexity of global issues, which includes and are interlinked with the aims of improving food security, reducing poverty while ensuring sustainable management of natural resources, including the increasing interdependency between various policies and scales of implementation, in often unexpected ways. The progressive enlargement of the very notion of food security is a very good example of it.

To address such complex issues requires new modes of governance, at every level. It implies more evidence based processes of decision, including transdisciplinary thinking and consideration of emerging issues. It also requires the involvement of broader set of actors,

including civil society and the private sector; both in the decision making process and in the implementation of the orientations decided in common.

These two trends, towards more inclusiveness and more evidence based decision processes are very linked. Taking action on global, complex issues requires the construction of shared values, public goods or common aims which go beyond national or sectoral interests. Discussion between very diverse stakeholders and interests requires shared evidence to build decision upon. It requires data to be shared, definitions to agree upon, examples to be shared. This evidence has to be provided by scientific, transparent and open processes, including diverse forms of knowledge. This is a why there has been a progressive development of science/policy interfaces at national and international levels. This trend has been especially significant on environmental issues such as climate change (IPCC), ecosystems (Ecomilennium assessment) and also in agriculture (IAASTD) and now in food security with the creation of the High Level Panel of Experts for food security and nutrition. It goes often with a broader role of civil society and the private sector in the decision making process. Such evolutions, of which the reform of the CFS is a good example, also take place at local levels. To manage sustainably collectively resources, to manage a common landscape, there is a need to have first a common understanding of it.

This double evolution emphasize the importance of public research. Most of the efforts on genetic selection, vegetal and animal, have been oriented towards increasing production and productivity, often taking for granted stable conditions (climate, water, nutrients,..). There is an increasing need to better account for yield stability traits of species and varieties under variable conditions (HLPE, 2012).

As private sector investment is targeting mainly rich countries or a small number of developing countries where input markets are growing and becoming more cost effective to serve (Pardey *et al.,* 2006), the divide between regional have and have-nots in agricultural R&D has a tendency to grow, in particular between rich and emerging countries (OECD, Brazil, China, India) with respect to less advanced countries. The rich/poor disparity in the intensity of agricultural research (dollar spend on agricultural R&D for 100$ of agricultural GDP) is increasing.

Investments by the private sector in the developing world accounted for only 2 percent of the total world agricultural R&D in 2000 (Beintema and Elliott, 2009; Pardey *et al.,* 2006). In sub-Saharan Africa, the majority of the tiny amount of private R&D is oriented to export crop improvement research such as cotton and sugarcane. (Pardey *et al.,* 2006)

Agricultural science and technology spillovers might become more constrained, both because of the reorientation of R&D away from the type of technologies that are most easily adapted (Pardey, Alston and Piggott, 2006), and because intellectual property rights increasingly influence the extent to which such spillovers are feasible or economically sound to adopt (Pardey *et al.,* 2006).

At the same time there is also a trend towards more systemic and local based approaches to valorize local potentials. The employment of agronomists by private companies is a pattern that is bound to be followed in the developing world as industry grow in competitiveness.

Another important trend is the reduction of public extension services and the growing role of the private sector in the dissemination of technologies and practices.

The necessity to green the agriculture will however require a larger role of public actors both in research and development. This is even more the case that private-owned technologies are keen to focus on major markets, without a guarantee for isolated or non-lucrative markets to benefit from them. This will reinforce the need for public research and the CGIAR to be strengthened as public good producer in technology and natural resource management related fields.

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