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Combating Land Degradation and Desertification and Enhancing Food Security: Towards Integrated Solutions

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Abstract: This paper seeks to provide an overview of the relationships between food insecurity, land degradation and desertification, and its antithesis, food security and sustainable land management. It places particular focus on the world's drylands (i.e. arid, semi-arid and dry sub-humid areas), but situates the review within the wider context of global food systems and the macro-processes that drive land degradation and desertification. It is revealed that food insecurity can be attributed to a range of demand-side and supply-side causes, which include political, economic, social and environmental factors. Land degradation and desertification are shown to be exogenous issues that can amplify and aggravate food insecurity. Addressing desertification, including land, soil, water and plant degradation, can facilitate or ease the food security dilemma, but may not completely solve it in the presence of other underlying causes.

Key words: Sustainable land management; UNCCD, sustainable development, poverty, drylands, productivity.

According to recent data, approximately 1.56 billion hectares of land is currently used to produce crops for human and livestock consumption, and 3.4 billion hectares are devoted to livestock production (12% and 26% of the Earth's total land surface respectively) (Bruinsma, 2009). Although theoretically the world produces enough food for everyone, approximately one billion people are estimated to be undernourished (GDPRD, 2012). Evidence further suggests that producing more food in an unsustainable way may place a much larger share of the population at risk of food insecurity. In the context of a growing world population and other important sustainability challenges (such as land degradation and desertification, biodiversity loss, a decline in the availability and quality of water, and a changing climate), ensuring that agricultural and food systems are sustainable is a particularly urgent issue, both at present and looking forward to the future. Indeed, a recent report commissioned by the British Government warns that the world is threatened by a major food crisis within 20 years unless action is taken urgently (GOS, 2011).

Despite the vast extent of the planet's land area used to grow food, much of that land is considered to be degraded to some extent, particularly in the dryland parts of the world (MA, 2005). More than two billion of the world's seven billion people inhabit drylands, of which, more than 90% live in developing countries (Middleton *et al*., 2011). Drylands cover approximately 41% of the world's land surface and are defined as those regions that are climatically arid, semi-arid or dry-subhumid (Safriel, 2007). Despite their

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limited rainfall and high evapotranspiration rates, the drylands contain more than 40% of the planet's cultivated land area (UNEP, 2006), thus making a significant contribution to global food production as well as being important for pastoralist and other livelihood activities. Indeed, many of our major food crops, such as wheat, barley, sorghum and millet originated in dryland areas, and today, wild varieties from these origins serve as source of genetic plant material for developing drought-resistant crop varieties (White and Nackoney, 2003).

Compared to other parts of the world, drylands are considered to suffer disproportionately from land degradation and desertification (UNCCD, 1994) and have lagged behind in terms of the benefits that have been made from technological advances elsewhere in the world linked to food production, food processing and food storage. They also face a number of other critical challenges linked to land rights, poverty, markets, globalisation and the broader political economy, all of which shape the way in which drylands are used and managed to produce food (Baro and Deubel, 2006). Tackling problems such as desertification and land degradation in the drylands thus becomes an issue that is important in the quest for attaining food security more widely (Stringer, 2009).

This paper seeks to provide a review of the relationships between food insecurity, land degradation and desertification, and the antithesis, food security and sustainable land management. It places particular focus on the world's drylands, but situates the review within the wider context of global food systems and the macro-processes that drive land degradation and desertification. It first sets out key definitions and conceptualises food insecurity according to supply or demand side issues and a range of natural and/or human causes. It looks at the role of different environmental and biophysical factors, then at the political, economic and social factors that contribute to desertification and food insecurity. It identifies that sustainable land management can be a useful route towards addressing both issues and provides a range of international examples to illustrate successful land management practices. It concludes that combating desertification and land degradation can significantly alleviate the food insecurity problem, although it may not completely solve it, given the presence and importance of other underlying causes.

Defining the debate: food security and land degradation

Ensuring enough food and a food secure situation extends beyond food production to also incorporate consideration of the nutritional value of available and accessible food, as well as broader links to human well-being. For the purpose of this paper, we therefore draw on the 1996 World Food Summit definition, in which food security is achieved when: "all people, at all times, have physical and economic access to sufficient, safe and nutritious food to meet their dietary needs and food preferences for an active and healthy life".

From a macro-economic perspective, one way of conceptualising food insecurity can be broadly to ascribe supply- or demand-side issues (Brown, 2011), linked to a range of natural and/or human causes. Supply-side issues refer to those factors that affect food availability in such a way that it becomes insufficient or inadequate to meet the demand as described above, and include:

- Biocapacity constraints, i.e. limitations to the production of output imposed by the utilization of natural resources at full capacity (e.g. plateauing of crop yields) and other biological thresholds, such as the finite amount of minerals, fossil fuels and other biophysical assets, natural regeneration rates, ecosystem regulating functions (e.g. water, nutrient, and purification cycles), etc.
- Production-related issues, such as the misuse of available resources, productivity losses due for example to the overexploitation, chemical pollution, depletion of aquifer and other natural resources, technological constraints, output substitution due to comparative disadvantages, inability to meet quality, food safety or health requirements or regulations, etc.
- Distribution-related issues, such as protectionist policies, poor infrastructure and market-related deficiencies that result in reduced availability or food wastage between the farm gate and the consumer. This includes transportation and storage losses, as well

as national and international trade-related barriers and constraints.

Conversely, demand-side issues refer to those factors that affect or distort the demand of food in such a way that it prevents some consumers from satisfying their primary food consumption needs. These include:

- Budget limitations due for example, to the lack or loss of purchasing power caused by increasing food prices, loss of employment or other sources of income, poverty, etc. (Rajiv, 2010).
- Competition in the appropriation of food supplies and resources on which food production relies by a group of consumers or countries, which prevents other consumers from accessing adequate food supplies to satisfy their demand. This is often spurred by asymmetries in per-capita consumption, information or purchasing power (Giovannucci *et al*., 2012).
- Changes in per capita consumption patterns determined by contingencies and other limitations imposed by geo-political, social, regional or ethical considerations.

Often, these factors are inherently interconnected – both with each other and with supply-side issues. Each disturbance factor described above can generate food insecurity for a small group of individuals or a large population (Nelleman *et al*., 2009). The severity of the phenomenon depends on the magnitude, scale and duration of the disturbance factor on the supply or the demand side, respectively.

Land degradation and desertification are both considered natural and human induced problems, that are largely, but not exclusively, driven by demand side causes. The terms ‘land degradation’ and ‘desertification’ are often used interchangeably in drylands. Land degradation refers to a reduction in the productive capacity of land resulting in a long-term failure to supply food, forage, fibers, wood and freshwater, carbon sequestration, biodiversity and cultural services, and can apply in any climatic zone. According to the United Nations Convention to Combat Desertification (UNCCD), desertification refers to “land degradation in arid, semi-arid and dry sub-humid areas resulting from various factors including climatic variations and human activities” (UNCCD, 1994: 4). Understanding land degradation and desertification thus requires an appreciation that the concepts apply to complex systems, with multiple interactions between the biophysical world that supplies natural resources, and the demands placed on it by social groups.

At the international level, combating desertification and land degradation is the focus of the UNCCD, which acts as the key international policy framework to guide signatories towards more sustainable land management by putting both human and ecological well-being at the centre of its intergovernmental portfolio. Food insecurity is addressed by several United Nations agencies and organisations, including the Food and Agriculture Organisation (FAO), the World Food Programme (WFP) and the International Fund for Agriculture and Development (IFAD). Although food was proclaimed and adopted as a universal human right in 1948 by the General Assembly of the UN, measures employed to date have not been able to ensure food security worldwide, particularly in the drylands. The outbreak of the recent famine in dryland East Africa in 2011 reveals once again the helplessness within societies worldwide to take suitable actions to implement long-term famine prevention strategies. This is despite the many real-time communication tools, global intergovernmental cooperation, agricultural surplus areas, reliable transport systems and observation systems that exist.

Although there are links and common ground between land degradation, desertification and food security and the multiple agencies and institutions that address these challenges (both today and historically), there are few coordinated efforts that explicitly seek to address the problems in an integrated way. The Millennium Development Goals (MDGs) encompass both an aspiration to halve the number of people living in poverty and hunger (MDG1) and to ensure environmental sustainability (MDG7). However, they have not led to the development of a truly integrated programme approach. Within the realms of research a similar situation is apparent, with a severe shortage of research that investigates the links between food insecurity, land degradation and desertification, both in general and in the world’s arid, semi-arid and dry subhumid parts. Indeed, drylands have been studied by

Table 1. Drivers of food insecurity (both 'natural' and human-induced)

Food insecurity drivers	Natural (N) or Human-induced (H)	Primarily affecting Demand or Supply	Direct (D) or Indirect (I) impact
Civil unrest and conflicts	H	Demand	D
Demographic changes growth	H	Demand	D
Dietary changes due to economic growth	H	Demand	D
Pricing strategies hiding real economic costs, often linked to world trade regimes	H	Demand	I
Autarchy measures	H	Demand	D
Climate change	N+H	Supply	I
Land degradation/desertification	N+H	Supply	I
Natural disasters (e.g. floods and droughts)	N+H	Supply	D
Pollution or pest/disease outbreaks	N+H	Supply	D
Speculation in agricultural commodities	H	Supply	I
Export-driven agricultural support policies	H	Supply	I
Unsustainable renewable energy policies	H	Supply	I
Urbanisation	H	Supply	I

researchers from a range of different angles including climate variables such as rainfall (e.g. Williams and Albertson, 2006), river channels (e.g. Hooke, 2007), and carbon sequestration (e.g. Nosetto *et al.*, 2006). However, there is only a small body of interdisciplinary work that links knowledge about the natural biophysical environmental conditions and processes with the human, societal, economic and political aspects of environmental change (Gurib-Fakim and Smith, 2009; Abraham, 2009; Abraham *et al.*, 2006).

These challenges and the lack of integration suggest that nuanced assessments of land degradation, desertification and food insecurity are needed that take into account a range of different variables, scales, processes and contexts (see e.g. Antwi-Agyei *et al.*, 2012; Abson *et al.*, 2012 under review) and use an array of different assessment methods (qualitative and quantitative, and from a range of different disciplines), in order to measure the loss of potential productivity due to human activities, in drylands and other climatic zones. However, assessing the extent of land degradation in the drylands and globally, remains a difficult challenge. Estimates of degradation in drylands according to a wide search of the literature vary from as low as 10% and as high as 80%. One of the most commonly used figures is that published in the Millennium Ecosystem Assessment (MA, 2005), which identifies that 10-20% of drylands are degraded (with medium certainty). The variety of degradation figures available to policymakers, and the poor visibility of the problem in the initial phases of desertification, mean it is difficult for scientists to communicate the magnitude of the problem, and thus, for policymakers to appreciate how urgently action needs to be taken. Furthermore, data on land degradation are collected using a wide range of methods, measure different variables, and include different system boundaries (e.g. drylands, non-drylands), so are often not amenable to comparison. Some analysts have pointed out that findings on land degradation are highly context-dependent (spatially, temporally, economically and culturally): they vary greatly depending on the scale of assessment and the land-use system under consideration. Hence, they warn against reliance upon simplified (large-scale) approaches induced by global management processes (Warren, 2002). Even within the same production system, perceptions of degradation may change with the management strategy or, in the case of animal production, with regard to different species (Roba and Oba, 2009).

Drivers and impacts of land degradation, desertification and food insecurity

Aside from the difficulties associated with defining and measuring land degradation and desertification, it is challenging to unravel the many drivers of the problem. A plethora of environmental, political, economic and social factors act as drivers, which can in turn, reduce the productive ability of the land and impede attainment of food security. Land degradation and desertification can thus generate or aggravate food insecurity through negative impacts affecting the supply side of food production (Table 1). These drivers and "boosters" operate over scales from the global to the local and interact in a range of complex ways.

The remainder of this section looks in more detail at many of these drivers, placing a focus first on the role of environmental and biophysical factors and then on the political, economic and social factors linked to desertification and food insecurity. While we attempt to separate the natural and human drivers to some extent, there remain a number of overlaps, highlighting the truly interlinked nature of the issues. Similarly, many of our examples are dryland-specific, but we draw on the broader body of literature from other (non-dryland) climatic zones too because land degradation is a global phenomena and the production of food in drylands does not take place in isolation from that in other environments.

Environmental drivers

Fischer *et al*. (2006) note that more than three-quarters of the global land surface, excluding Antarctica, suffers from severe constraints with regard to rainfed crop cultivation. Some 27% of the Earth's surface is considered too dry for agricultural use, 13% is too cold and 12% is too steep. Apart from these climatic and topographic constraints, if the 3 billion ha land suitable for cultivation is not managed in a sustainable way, productivity reductions can occur in the medium or long term. This suggests that there is a need to consider the extent of land that is available for food production globally, but also its quality and ability to remain productive, particularly in the drylands, and where drought, sloping lands, sparse land cover and highly erodible soils combine to impose both biocapacity and production constraints.

Drylands are fluctuating environments with large within- and between-year rainfall variability. Their natural ecosystems (deserts, rangelands, scrublands and forests) are endowed with feedback mechanisms that can reverse adverse conditions to allow them to recover to a certain steady state (Canziani *et al*. 1998). Nevertheless, the conversion of 'natural' dryland landscapes to 'anthropogenic' landscapes may increase the risk of desertification when disturbances go beyond the resilience of the land and surpass its ability to 'bounce back' (Puigdefábregas and Mendizabal, 2004). This can lead to the loss of its long term productivity potential (Brandt and Thornes, 1996). Short-term degradation or sporadic low productivity should not be confused with desertification, however. For example, the re-vegetation of the Negev-Sinai border area demonstrates that thousand-year-old nomadic grazing did not damage the ability of pastures to recover (Warren and Harrison, 1984).

Geist and Lambin (2004) synthesized the major underlying drivers of desertification including human impacts such as livestock and crop production; irrigation; deforestation and woodland degradation and human settlements in combination with direct and indirect impacts of climatic variability. Scarcity of vegetation caused by human impact leads to reduced shade and increased top-soil temperatures, coupled with a rapid decrease in soil moisture, affecting evapotranspiration rates that may reduce the overall water balance. The sum of these local-scale changes may cause large-scale impacts in water balance (Van Wilgen *et al*., 1998) and may even affect the local rainfall regime (Williams and Balling, 1995; Zeng *et al*., 1999), increasing the risk of desertification.

Land use and land cover: Land use and land cover are important considerations when assessing the availability of land upon which food can be grown. Land may be used for many purposes: urbanisation and infrastructure, landscape and biodiversity conservation, extraction of raw materials, pastures, recreational uses, and so on. Land used for food production will increasingly compete with these other uses, as well as competing with the production of biofuels and animal feed crops. The possibility of land scarcity must be considered as an environmental concern. According to data from the UN, in 1960 globally there were 0.4 ha of arable land in use per capita. This figure decreased to 0.25 ha in 2010 and is estimated to be <0.2 ha by 2050 (Bruinsma, 2009).

A considerable expanse of productive land suffers from land degradation, desertification, abandonment or pollution. Often, degradation can stem from an alteration to the distribution of vegetation linked to land use change. This can yield vegetative patches separated by bare soil, which is sometimes seen as an indicator of desertification (Kéfi *et al.*, 2007; Sun *et al.*, 2007; Danfeng *et al.*, 2008). The new vegetation distributions can alter the connecting pathways that serve as conduits for the movement of nutrients, soil or water, explaining how processes at local scales can influence broader scale dynamics (Oweis, 2000; Okin *et al.*, 2001; Peters *et al.*, 2008). They also affect the ability of natural vegetation to moderate water regulation services: water infiltration; ground storage of freshwater; flood regulation; water provisioning for vegetation in off-site areas; water purification and quality of freshwater ecosystems (Puigdefábregas, 1998; Mueller *et al.*, 2007). A paucity of water can lead to upstream-downstream conflicts. Runoff harvesting may e.g. reduce the risk of crop failure and increase livestock production, but at the same time, extracts the water needed by downstream ecosystems and resource users, and therefore affects the whole catchment area (Batchelor *et al.*, 2002; Kerr *et al.*, 2002; Ouessar *et al.* 2002), increasing the risk of desertification.

To address food insecurity in light of these challenges, there are two key 'supply side' solutions: (i) increase the area of cropland dedicated to growing food crops and/or (ii) increase crop productivity of current land used for food production[1]. According to FAO (2006) projections, growth in crop production for 2030-2050 will be achieved by higher cropping intensities and/or shortening fallow periods (8%), yield increases (71%) and arable land expansion (20%). The figures expected by 2050 should be close to those presented in Table 2.

Table 2. Land use area, scenarios of the future (modified from Braat and ten Brink 2008)

Land use	Area (billion ha)		
	2000	2010	2050
Natural areas	6.55	6.28	5.80
Bare natural	0.33	0.31	0.30
Forest managed	0.42	0.44	0.70
Extensive agriculture	0.50	0.45	0.30
Intensive agriculture	1.10	1.29	1.58
Woody biofuels	0.01	0.01	0.05
Cultivated grazing	1.91	2.03	2.08
Artificial surfaces	0.02	0.02	0.02
World Total	10.84	10.84	10.84

The first option (increasing the land area cultivated for food crops) would be at the expense of other land uses devoted to e.g. conservation, livestock or biofuels, or the loss of ecosystems such as tropical, temperate and mixed forests, savannas, shrublands and grasslands. Competition for land used for food production is thus an important demand-side factor.

Over 1.5 billion hectares of land are used for crop production at present and an additional 2.7 billion hectares have crop production potential (FAO, 2006). The Global Agro-Ecological Zone (GAEZ) study cites that the majority of this expansion is predicted to occur in Latin America and Sub-Saharan Africa, estimated at 120 million ha, while in developed countries, agricultural land in production is estimated to be reduced by 50 million ha. The result will be a global net increase of 70 million hectares (Fischer *et al.*, 2002). These figures should be revised as the suitability of land seems to be overestimated if it refers only to minor crops in some areas (Bruinsma, 2009). The GAEZ study did not take into account the conservation of natural areas or the predicted expansion of human settlements, which may take up some 60 million ha globally (Nachtergaele and George, 2009). Bruinsma (2009) reports different figures of extension of arable land to take place in sub-Saharan Africa (64 million ha) and Latin America (52 million ha), with virtually no land expansion in South and East Asia or Near East and North Africa.

Sometimes land that is unsuitable for food crop cultivation is made productive through intensive human intervention. Restoring and rehabilitating degraded agricultural land, while at the same time taking steps to reduce the rate of land degradation, can sometimes be a cost-effective intervention that can allow the cultivation of otherwise unusable land (Yitbarek *et al.*, 2012). Land loss rates due to degradation are variable worldwide, with estimates ranging from 5 to 12 million ha^{-1} y^{-1} (Faeth and Crosson, 1994; Scherr, 1999; WRI, 2001). Lal (1990) has

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[1] A third (this time, demand side) solution – decreasing waste-can reduce pressure on land, optimize land use (via enhancements in the food distribution ystem) and improve the nutritional intake of consumers. However, here we focus on the supply side solutions, discussing waste issues later.

suggested that since farming began, up to 2 billion hectares have already been degraded and abandoned by humans: this is more than the total area now under cultivation. Aside from rehabilitating degraded areas, there are several alternatives by which current productivity can be increased without land expansion, each of which faces its own challenges. Such alternatives include: increasing economic investment in irrigation; mechanization; fertilization; use of pesticides and chemical weed control; or the spread of genetically modified organisms. All these approaches could be grouped under the umbrella term 'industrial agriculture'.

Both land extension and industrial agriculture have nevertheless led to undesirable consequences (Tilman *et al*., 2001) with a high variability of results with regard to effects on biomass production and yield decreases as a consequence of different environmental changes. Supply-side response measures alone, such as agricultural intensification through the use of chemical fertilizers, can indeed be effective in increasing food outputs in the short run, but may generate enormous negative impacts on environmental resources that are key to agricultural production, which in turn aggravate the risk of food insecurity in the long run. For example, it is estimated that fertilizer has accounted for 30 to 60% of the rise in average yields since the 1960s. However, as the case of phosphorus suggests, this has happened at the expense of the health of aquatic ecosystems and livestock (ETH, 2011). This, in turn, poses huge socio-economic costs and other challenges.

Important negative effects of industrial agriculture in the drylands include erosion, nutrient depletion, compaction and salinity – processes that can lead to desertification and indeed, which are often considered indicators or symptoms of degradation. Intensive agriculture is frequently based on monocultures, fragmentation of natural habitats, use of pesticides, fertilizers and abuse of heavy machinery and land clearance, having a profound effect on biodiversity (Plieninger and Gaertner, 2011) both above and below ground. When traditional dryland land uses are, for example, replaced by mono-cultural production of cash crops for international markets, a whole range of valuable ecosystems goods and services may be irreversibly lost. For example, the expansion of soy production in Argentina was achieved through cropping new areas, but also by the substitution of other crops and activities; indeed, the area devoted to cotton decreased by 83%. The increased presence of soy is based on natural advantages, but also investment. Transgenic soy is easily grown and Argentina has become the third largest soy producer worldwide, with soy now occupying half the total cropped land area. Coupled with this, a rise in soy prices saw the expansion of the agricultural frontier. This affected great expanses of native woodland, which, besides supporting unique animals and plants, produced oxygen, prevented river flows and reduced erosion. Recent studies suggest that these kinds of changes happen because the total economic value of natural resources is often unknown and the discount rate to assess the present value of future ecosystem functions and services is too high, thereby steering the interest of decision makers away from optimal decisions that would maximise their benefits in the long run (OSLO, 2011).

Tilman and Dowing (1994) found that grassland became more vulnerable to drought if the richness of plant species decreased (in this case, from 25 to 5 species). This also has a severe impact on animal husbandry especially during the dry season as studies from the eastern Sahel indicate (Akhtar-Schuster, 1995; Akhtar-Schuster *et al*., 2000). This is a clear example of how biodiversity loss decreases ecosystem resilience. Evidence shows that the protection of biodiversity has become increasingly important and must be a priority at all levels (genes, species and ecosystems). In particular, natural crop wild relatives are at risk, and should be seen as important sources of useful genes through contribution to resistance to diseases and pests. Crops in degraded and desertified lands are often weak and prone to invasion by parasites (see Stringer *et al*., 2007). Some authors consider that these biotic constraints are underestimated (Hengsdijk and Langeveld, 2009) and can even be considered extremely severe threats to sustainable production of wheat and rice in South Asia (Li *et al*., 2011).

Soils and topography: There are different biomes within the various dryland subtypes (dry sub-humid, semi-arid, arid or hyper-arid) demonstrating that ecosystems respond not only to moisture deficits, but also to other variables such as soil type and conditions and geomorphological features (Safriel and Adeel, 2005). The dry climatic conditions, poor soil development and high susceptibility to soil erosion can combine to maintain low plant productivity.

Some soil types are more erodible than others, meaning they have a higher propensity to degrade, particularly when they are situated on sloping land. Natural erosion ranges from 0.001-2.0 t ha^{-1} y^{-1} on flat vegetated grasslands or forests, to 1-5 t ha^{-1} y^{-1} on sloping lands with other vegetation cover. Pimentel *et al.* (1995) cited estimated rates of erosion of 17 t ha^{-1} y^{-1} in North America and Europe and up to 40 t ha^{-1} y^{-1} in Asia, Africa and South America. Under arid conditions Gupta and Raina (1996) reported 5600 t ha^{-1} y^{-1} soil losses due to wind erosion. In this scenario, approximately 75 billion tons of fertile soil is lost annually from agricultural lands worldwide (Myers, 1993). As a result, during recent decades, some 30% of world arable land has become unproductive and therefore has been abandoned. If accelerated erosion continues, yield reductions could reach a magnitude of 16.5% in Africa by 2020 (Eswaran *et al.*, 2001) and around 20% in Asia (Dregne, 1992).

When soil is eroded, organic matter and basic nutrients such as nitrogen, phosphorus, potassium and calcium are lost, with knock-on implications for soil fertility. Eroded soil usually contains about 2-3 times more nutrients than the soil left behind on the eroded land (Lal and Stewart, 1990). Intensive agriculture may lead to reductions in organic matter of up to 50% after several decades of cropping (Lal *et al.*, 1997; Woomer *et al.*, 2001; Zingore *et al.*, 2007). Even small changes in total carbon content can have large impacts on key soil physical properties (Powlson *et al.*, 2011). Soil fertility depletion is considered a cause of chronically low agricultural productivity (Smaling *et al.*, 1997) and persistent land degradation in natural areas (Heywood, 1995). In order to avoid negative impacts due to these losses, the organic matter and nutrients that are lost must be replaced by manure and/or fertilizers. However, sometimes this may be beyond the capability of land users, especially in the case of smallholder farmers who live in poverty.

Losses of nutrients, organic matter, plant cover and soil depth can further lead to a dramatic loss of water storage capacity and water availability for potential growth of new vegetation. Pimentel and Kounang (1998) estimate that under conditions of erosion, water availability for the agricultural ecosystem is reduced by 20-40% in the soil, therefore, causing a reduction in plant productivity of between 10-25%, depending on climatic, edaphic and topographic conditions. While irrigation is seen as a possible solution, at a field scale it may induce problems such as salinization, water and soil pollution or eutrophication of inland waters. In turn, large-scale irrigation may lead to the overexploitation of groundwater aquifers, disconnection of rivers from their floodplains and changes to coastal ecosystems (MA, 2005; Atapattu and Kodituwakku, 2009). Drylands are particularly vulnerable to soil salinization, which is associated with poor management of irrigation and drainage systems producing salt concentrations in the topsoil after evaporation. Excess salts in the root zone cause plants to wilt, even under adequate moisture conditions (Duncan *et al.*, 2008). Another major cause of land degradation and desertification in drylands is overgrazing, which affects the soil-water-plant relationships, especially in areas around water sources. This issue is explored further in the subsequent section and is often attributable to socio-economic and political drivers linked to policy changes and sedentarization of mobile pastoralists.

Climate, climatic variability and climate change: One of the most relevant climatic constraints to productivity, particularly in drylands, is drought. Recurring droughts are intrinsic to the climate of the drylands, being part of their inherent climatic variability. These climatic conditions are usually considered an important source of disturbance in desertification research (Schlesinger *et al.*, 1990), nevertheless the effect of climate fluctuation in “natural” subhumid ecosystems is minimal as only stronger disturbances (e.g., multi-decadal trends in precipitation variations) are needed to drive the ecosystems into the “desert state” (D’Odorico *et al.*, 2005). Consequently, inter-annual variability can enhance the resilience of dryland ecosystems, allowing them to be well adapted to aridity, droughts and even to recurrent wildfires (Di Pasquale *et al.*, 2004). Nevertheless, cultivated lands are usually more vulnerable to higher temperatures and water shortages

(Thomas *et al.*, 2007) being less able to buffer climatic variability.

Likewise, in the past, the impacts of drought were well buffered by traditional land use systems, which included aspects such as nomadic animal husbandry, which could respond to lean phases with mobility and flexibility (Akhtar-Schuster, 1995; Akhtar-Schuster *et al.*, 2000). It is anticipated with medium confidence (IPCC, 2012a and 2012b) that in some drylands, which are considered potentially vulnerable systems, there will be an increase in the magnitude, frequency and severity of drought due to climate change. Thus, more severe and longer lasting droughts could also be signs of climate change. Climate change is further likely to bring higher temperatures for many of the world's drylands. This can enhance evapotranspiration rates, and in areas of low rainfall, could exacerbate salinization. An estimated 33% of the potential arable land is salt-affected in arid and semi-arid regions, while globally, some 20% of the irrigated land (45 million ha) is affected (UNEP, 2008).

The relationship between drought, its impacts and the economic structure of a particular country is complex (Benson and Clay, 1998), yet if agriculture is predominantly rainfed, which is often the case in the drylands, the consequences of drought increase dramatically. In regions such as the Middle East and North Africa (MENA region), per capita water availability in most parts is projected to decline by 50% by 2025 (Abahussain *et al.*, 2002). Such water shortages will certainly impact on any further expansion of agriculture or reclamation of rangelands in the absence of employing technological advances (e.g. drip irrigation).

African countries are highly vulnerable to climate variability because they are dependent on the weather for agricultural production. Farmers cannot change their crops easily, with the poorest smallholders struggling to afford drought-resistant seeds (Winters *et al.*, 1998). While very few studies have been carried out in Africa linking climate change, droughts and agricultural productivity (Boubacar, 2010), in South Asia, Li *et al.* (2011) reported that drought in farming systems was considered responsible for less than 10–15% of yield losses, even in those systems that are mainly rainfed. They found that other combined water related constraints (irrigation problems, extreme events) were usually responsible for less than 30% of the estimated losses. In an attempt to quantify the influence of environmental drivers, Lobell and Field (2007) found that approximately 30% of the annual variation in globally averaged yields of wheat, rice, maize, soybeans, barley and sorghum could be attributed to climatic variables. The high variability of drought impacts on crop yields may depend on the magnitude and timing of extreme temperatures and droughts. This, in addition to the complex relationship between the effects of CO_2 fertilization (Long *et al.*, 2006) on different crops, makes the development of projections an uncertain and difficult challenge.

Despite the limitations in predicting future climate, taking into account both dryland and non-dryland areas, the consequences of climate change are not expected to have significant effects on global crop yields by 2050 (IPCC, 2007). This is thought to be because yield gains and losses may be counterbalanced between different regions. Some countries in which temperatures become higher may allow crop cultivation to expand into areas that were too cold for cultivation previously, but yields will be reduced in countries with hotter climates at present. Moreover, extreme weather events are likely to create greater variability in productivity. As a result of these changes, differences in food production around the world will be exacerbated. India, sub-Saharan Africa and parts of Latin America are expected to be most affected (World Bank, 2009). Parts of the tropics will become unsuitable for agriculture because of increasing aridity, and sometimes, higher frequencies of floods. Even if annual rainfall remains the same in certain regions, it may be more concentrated in shorter bursts, or spread over longer time periods (Akhtar-Schuster *et al.*, 2000), thus increasing risks of desertification and land degradation, especially in cultivated areas. This requires mitigation measures such as the development of new infrastructure to minimize erosion, runoff and floods, and at the same time, storing water to alleviate droughts, as well as local and regional monitoring systems that enable timely reactions. The predicted longer growing seasons and higher evaporation rates from plants and soil may increase the requirement for crop irrigation, but in regions with severe water shortages, irrigation could be reduced by as much as 34% by 2050 (Nelson *et al.*, 2009).

If sea level rises as projected under climate change, agricultural lands may be lost by permanent inundation, especially in Bangladesh, India, Vietnam or Thailand, affecting the most important rice growing river deltas in the world (Brown, 2009). The worst scenarios predict serious drops in productivity in developing regions, particularly in Africa, by as much as 25% (Cline, 2007). The disappearance of glaciers will reduce flows into the local rivers fed by them and therefore, the potential for irrigation. Many regions could be affected in e.g. South America (Josephus, 2007), China (Qiu, 2008) and Central Asia (UNEP, 2007). Indeed, in dry areas such as the central Andes, the situation could become critical, especially in places such as Mendoza, Argentina. Mendoza is a medium-sized city located on the piedmonts, surrounded by large irrigated areas, the viability of which depends largely on the Andean rivers (Abraham and Villalba, 2008).

Even a relatively small increase of 1 or 2°C in temperature can reduce the grain harvests in major food-producing regions (Kavi-Kumar and Parikh, 2001). The water needed by different crops during their growing period limits the extension and profitability of farmlands and explains partly the difference between the potential and the actual yield in different crops (Table 3), albeit with considerable heterogeneity among regions (Neumann *et al.*, 2010). In developing countries, recent yield increases are higher than in more developed economies. Nevertheless, the yield gaps (the difference between potential yield and actual yield) appears also to be high in many regions, and, most recently (comparison between periods 1965-2000 and 2000-2008) yield growth declined for wheat, rice, and soybeans, although not for maize (World Bank, 2009).

Hengskijk and Langeveld (2009) suggest that a considerable yield gain is possible by improving access to and availability of water, nutrients and crop protection agents. For instance, countries like Angola, the Democratic Republic of Congo, Ethiopia, Kenya, Mozambique, and Tanzania have low maize yields, currently 0.92 t ha^{-1}, less than a tenth of potential yields (Deininger *et al.*, 2011). However, the reasons for these yield gaps cannot be easily attributed to a particular environmental cause. As explained by Mainguet (1999), any single explanation that does not entail a whole array of causes will only be a caricature. Various attempts to differentiate climatic and land management conditions have nevertheless been carried out. Licker *et al.* (2010) utilized datasets for 18 major crops in the world in conjunction with climate datasets to separate agricultural yields into 100 different climate zones. They also analyzed other crop

Table 3. Actual and potential yield of major crops

Crop	Cultivated area in the world FAO 2010* M ha	Yield 2010 (M tonnes)*	Crop water need (mm/total growing period)	Sensitivity to drought	Actual Yield (t/ha) year 2010*	Potential yield (t/ha)+
Wheat	217	651	450-650	low-medium	3.00	5.1 - 8.2
Maize	162	844	500-800	medium-high	5.22	6.7 -11.7
Rice (paddy)	154	672	450-700	high	4.37	7.1 -10.8
Barley	48	123	450-650	low-medium	2.58	4.3 - 6.9
Soybean	102	262	450-700	low-medium	2.55	3.8 – 5.6
Sorghum/Millet	41/35	56/29	450-650	low	1.37/0.83	7.6 – 8.7
Oats	9	20	450-650	low-medium	2.16	4.0- 4.5 [1]
Potatoes	19	324	500-700	high	17.43	36.9 – 43.7

Data sources: *FAO (Food and Agriculture Organization of the United Nations) data 2010. FAO Statistical Databases Available from: http://faostat.fao.org; (+) Hengsdijk and Langeveld, 2009; [1] Zwer, P. 2012. Yield and production gaps are estimated by comparing potential attainable yields and production (low and mixed input levels), with actual achieved yields and production (year 2000 and 2005). Values provided include regions in arid, semi-arid, dry sub-humid and humid climatic conditions, with high interannual variability in average annual rainfall (mm). According to the UNEP (1992a) classification of Aridity Index (AI), Hyper-arid AI < 0.05 (< 200 mm); Arid: 0.05<AI<0.20 (<200 mm in winter (w) or <400 mm in summer (s)); Semi-arid: 0.21<AI<0.50 (200 to 500 mm w or 400 to 600 mm s) and dry sub-humid: 0.51<AI<0.65 (500 to 700 mm w or 600 to 800 mm s) yield drivers like soil quality, genetics and land management. This work shows that developed countries used to have low yield gaps, especially for maize, wheat, potato and rye in Western Europe, as well as maize and soybean in the United States. When high yield gaps occur in Western Europe, they are often concentrated in southern countries like Spain, Portugal and Italy – countries which also have significant dryland parts. Yield gaps tend to be more variable in Asia. However, clusters of low yield gaps for rice, wheat, millet, potato and rye exist around the more populous provinces of China as well as in some parts of the Indo-Gangetic Basin. The African continent shows the highest yield gaps, especially for maize and rice, with some exceptions concentrated in West and Central Africa for millet or sorghum. Central and South America exhibit low gaps for soybeans, as for maize in Brazil and Argentina. This demonstrates that there is a considerable spread in yield gaps across the world among places with similar climatic conditions and levels of soil moisture availability.

Linking this to the occurrence of desertification, the simple relationship between yield, climate and land degradation is likely to be masked by other practices that may increase productivity in degraded areas (Nkonya *et al*., 2011). This suggests that as climatic changes become more evident, it is important to separate climate change induced land degradation from that caused by human activities, over which land users have control (Vlek *et al*., 2010), thus illustrating the interplay between drivers operating at different scales. Specific environmental drivers must be addressed on plot and field scales. Hengsdijk and Langeveld (2009) identified five constraints that contribute to explaining the yield gap, i.e. (i) limited water availability, (ii) limited nutrient availability, (iii) inadequate crop protection, (iv) insufficient or inadequate use of labour or mechanization, and (v) deficiencies in knowledge. The lack of attention to these aspects creates a risk in maintaining the necessary area of land to produce sufficient food to meet demand, but also highlights the role that human action, institutions and socio-economic and political factors can play, in managing the linked challenges of land degradation, desertification and food insecurity. The next section unpacks those factors in more depth.

Socio-economic, institutional and political drivers of food insecurity and desertification

The previous section has focused mostly on production aspects of food security in drylands and more widely, linked largely to biocapacity, production and competition constraints. This section focuses more on the distribution-related issues linked to population growth and demographic change, policy reforms, changing consumer demands and markets, as well as the role of the broader international political economy in shaping land use decisions at local levels.

Population and demographic change: Estimates suggest there are currently more than 7 billion people in the world, and under current trends, food production must increase by 70% over the next 40 years to keep abreast of demand (FAO, 2012). As the number of people on the planet increases, this will likely drive land use changes, with population growth being considered a driver of urbanization, deforestation, intensifying agriculture and water demand, and mismanagement of rangeland (Amiraslani and Dragovich, 2011). Indeed, in the Arab region (10% of the world's area), population growth has been stressed as a driving force of desertification (Abahussain *et al*., 2002).

The extraction of natural resources that a growing population demands is often presented as an important cause of land degradation and desertification (e.g. via deforestation and consequent soil erosion). It can also be considered a driver of food insecurity because in many areas (e.g. the dry miombo forests of Zambia) local populations are reliant upon forest products such as caterpillars, honey and wild forest herbs within their diets (Stringer *et al*., 2012). A plethora of development reports argue or assume that resource extraction is carried out by the rural poor within the context of a subsistence economy. It is often considered that the extraction of these resources, leading to the deforestation of the drylands, could be decreased or even halted by the integration of the rural poor into the market economy or by the creation of alternative/modern sources of income (Mortimore *et al*., 2009). This view nevertheless omits to consider that demand for these resources is already market driven—often to satisfy the demand coming from growing populations residing in urban settlements—and the poor people who extract the resources are simply suppliers for this market. The question of population and its links to food insecurity, land degradation and desertification is thus rather complex, extending beyond simple increases in demand, and requiring integrated development and sustainable management of the endogenous resources of the territory, giving visibility to traditional knowledge and technological innovation in food production.

Policy change: Pastoralism is a key cornerstone of diets, livelihoods and survival in many dryland regions, but is also a way of life that is increasingly threatened by policy reforms. One factor that can act as both a driver of policy reform and an effect of it is overgrazing. Overgrazing is a contentious issue when it comes to land degradation and desertification, particularly as agricultural policies tend to encourage and give preference to cultivation and sedentarisation. Worthy development intentions have often driven this approach (e.g. by providing school-based education, banking and health care services in the same way as to a sedentary population), but they can result in land degradation and knock-on effects with regard to milk production and household food security. For example, the ideologically motivated introduction of a new legal and regulatory system, the so-called Open Access System, in the eastern Sahelian Butana Region of the Republic of Sudan in the early 1970s, supported the transformation of the fundamentally important dry season grazing areas of the region into cultivated lands. As a consequence of a reduced land area over which pastoralists could graze their animals, together with the conversion of the region into an open grazing area, which opened up free access to external groups, ethnic groups in the region lost their traditional ´regions of influence´ and thus their exclusive property, for which they had traditional instruments in place to protect their water sources and pastures. These traditional rules and institutions had previously secured their food and other basic needs, but the reforms meant they were no longer viable. The policy shift also resulted in hardships in using their traditional migration paths as they travelled with their herds to follow rainfall patterns to vital grazing areas, as much of the grazing land was converted for crop production (particularly the dry season grazing land). The remaining grazing lands were difficult to reach prior to the start of the crop harvest. Remaining and accessible rangelands showed severe signs of overgrazing. Rangeland species with lower nutritional quality and partial inedibility for domestic herds in certain stages of their growth (e.g. *Urochloa trichopus*) started spreading at the expense of valued dry season grazing plants, such as *Blepharis edulis* (Akhtar-Schuster *et al*., 2000). This created new competition and in many cases, conflict. Furthermore, the sedentarised former pastoralists were specialists in dryland animal production, not crop cultivation, so many people lost their specialized livestock rearing skills and were compelled to shift to arable production without the necessary skills, knowledge and tradition.

Whereas in traditional pastoral nomadic societies animal husbandry played or still plays an important role in securing daily food (Holter, 1994a; b), sedentarisation and the degradation of grazing lands in the proximity of settlements in the Butana Region in the Republic of Sudan (Akhtar-Schuster, 1995) has led to fewer animals and/or triggered the spatial decoupling of animal herds from households as they go in search of grazing lands. This has reduced the household production and consumption of milk (from camels, sheep or goats), cheese, butter and meat (Holter, 1994b) and has weakened household capacity to buffer the effects of drought, giving rise to malnutrition and enhanced conflicts between the different ethnic and between different user groups. It should nevertheless be noted that policies that do not seek to encourage sedentarisation can also be problematic in dryland areas for both land quality and food security, particularly where they are associated with inappropriate water development (e.g. wells that are too large or close to one another, or too densely dug) in areas far from settlements, so there is a difficult balance to be reached in ensuring that development benefits are delivered without causing the loss of traditional practices and/or environmental damage.

A similar negative outcome for land quality and food security is apparent as a result of the legal framework for land tenure and in weaknesses of social services, which evolved out of various historic and institutional influences from administration under South African apartheid laws (e.g. discriminatory homeland systems, contract labour and influx control (Devereux *et al.*, 1995)). This led to a weak institutional framework and confusion over roles and jurisdiction. For instance, in the Nuwefontein and Nabaos communities of southern Namibia, it led to an increase in poverty, thus increasing food insecurity in the marginalised low-income rural households. Intense grazing on the communal grazing sites lowered phytodiversity and led to an increase in seasonal as well as inter-annual fluctuation in feed supply of the animals. Only a small number of farmers derived higher cash incomes in the area, which they also use to provide supplementary feed to their animals in drier periods (Akhtar-Schuster *et al.*, 2003). Animals from most households, however, entirely depend on the grazing resources in the communal lands, thus continuously degrading the land. In southern Namibia, the search for alternative sources of income has led to migration. Family systems and thus social stability can suffer and nutrition and health may decline as it is mainly the elderly and young children who remain behind in the degraded communal lands. Such outcomes suggest that land rights institutions need to be monitored and amended and attention needs to be paid to the distribution of costs and benefits linked to policy actions. In the Butana Region in the Republic of Sudan such amendments happened for instance by (re-)enforcing limited, locally administered rights and obligations of land users by the state once again (Kirk, 1994).

Markets, prices and large-scale land acquisitions: With global food prices rising by 50% in the past two years and projected to move inexorably upwards in the years ahead (GOS, 2011) the global land rush is putting particular pressure on Africa, the location of 45% or 200 million hectares of the world's available uncultivated land (Perry, 2011). Some commentators consider that today a 'land grab' is taking place (Scheidel and Sorman, 2012), with much of the acquired area not just used for food production, but also biofuel plantation, large-scale cash cropping, irrigation programmes and government/private ranching schemes (de Schutter, 2011). Often land is acquired or leased in the south by investors from the north. For some, this is said to represent a form of neo-colonialism (cf. Carmody, 2010). At the heart of the issue is the large-scale conversion of land use, in many cases, away from food crops. Similarly, with long-term land leases being negotiated in many cases, it is often easy for those leasing the land to fail to invest in maintaining its quality, with important implications for degradation and desertification. Such competition represents an important demand-side driver of food insecurity due to competition over land, but also is a supply-side issue linked to distribution. If much of the food produced on leased land is exported to the country of origin of the investors, the countries in which the food is being produced may find themselves at the centre of a food shortage and a desertified land resource.

A further market-linked aspect of food insecurity, this time related to a budgetary limitation issue, is that the poor simply cannot afford to purchase the appropriate amount or the adequate quality of food (FAO, 2011a). In dryland areas that are desertified as well as those prone to drought and crop failure, this problem is particularly acute. In 2008, oil prices rose to $147 a barrel. Coupled with this, food prices vastly increased, leading to protests in 61 countries throughout the globe (Oxfam, 2011). Oxfam (2011) reports that food prices are forecast to increase further by 70-90% by 2030; and that is without factoring in the effects of climate change which could see prices double again. While representing a food security concern for the poorest and landless, high food prices could also offer tremendous opportunities for Africa's farmers, who are gradually moving from subsistence to commercial farming. For a positive transition to happen without degrading natural resources or depreciating natural capital assets, an innovative approach to cost/benefit analysis must be adopted, which includes broader socio-economic considerations in land use decision making.

In the wake of the 2007/2008 food price crisis, the international response to the food security challenge has been the creation of a number of initiatives and programmes set up to tackle some of the key dimensions that cause food insecurity. A vast majority of such measures consist of donor-supported programmes targeting the poorest and most vulnerable groups through relief operations in developing countries (GM, 2012), including in many dryland countries. Short-term relief programmes nevertheless tend only to patch over the problem. Much remains to be done to address the root causes and risks of food insecurity. One long-term solution that is being proposed taps into the capital markets' growing appetite for social, ethical and responsible investment, or so-called "impact investing" (Morgan, 2010). As policy makers have started to put pressure on businesses to internalize negative externalities through environmental regulations, sustainability has become a central issue in many sectors and industries (Mercer, 2009). From the analysis of emerging trends in the capital markets for sustainable investments[2], it appears plausible that investment decisions are increasingly integrating environmental, social, and corporate governance (ESG) criteria (Mercer and UNEP, 2007). This seems to be the most fertile ground on which to build a sustainable food security strategy for the future. It thus should be explored in detail, how the production of sustainably produced dryland agricultural products could be labelled as both environmentally and socially friendly, thus directing these products towards a growing group of consumers worldwide who are ready to pay more for sustainably produced agricultural products (Painter, no date). This would enable the much criticised yet heavily lobbied subsidies in the agricultural sector to be bypassed, and could open new market opportunities for smallholder farmers from drylands, providing much-needed income at a time when food prices look set to continue to rise, as well as being a mark of production practices that have not contributed towards land degradation.

Excess consumption and post-harvest waste: Consumption patterns seem to be following an unsustainable trajectory, according to several analyses and projections[3]. Current global production and consumption patterns are very unevenly distributed, with calorific intake being the lowest in the world in countries such as Ethiopia, Haiti, Eritrea and Angola (<2000 kcal/person/day). In contrast, consumption in countries such as the USA, Israel and many European countries exceeds 3200 kcal/person/day (FAO, 2006). Interestingly, some of both the highest and lowest consuming countries have significant dryland regions. However, even in countries with low consumption levels, vast amounts of wastage are occurring. The FAO (2011b) estimates that in developing countries, more than 40% of food losses occur at the postharvest and processing stages, while in developed countries, more than 40% of losses occur at the retail and consumer levels. To provide some contextualisation, the total food waste by consumers in industrialized countries (222 million tons per annum) is almost equal to the entire food production in sub-Saharan Africa (230 million tons per annum). Fish losses alone are estimated at 10 to 12 million tonnes per year, accounting for around 10% of the total production from capture fisheries and aquaculture.

Beyond the traditional Gross Domestic Product-related income-loss figures, much higher costs emerge when the social and environmental damages caused by excess production to sustain a globally inflated demand are included. These encompass, for example:

- Costs related to the supporting functions of ecosystems (e.g. biodiversity costs)
- Costs related to the regulating functions of ecosystems (i.e. those related to the disruption of nutrient cycles, soil formation cycles, air purification cycle, water purification cycle, etc.)
- Costs related to the cultural functions of ecosystems (i.e. recreational values, aesthetic and ethical values, non-use option values, existence values)

This suggests that post-harvest concerns such as food storage options could play an important role in helping to attain food security, particularly in drought-prone drylands with their seasonal rainfall structure and pronounced dry seasons. In the Republic of the Sudan for example, a traditional grain storage system ´matmura´ was used by subsistence farmers to buffer lean production phases in the Sahel (Akhtar-Schuster, 1995; Ibrahim, 1987). Although a traditional system, the revival of such a locally controlled grain storage mechanism can be a

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[2] Sustainable investment is used as generic term to describe investment strategies centered on long-term; thus seeking to contribute to sustainable development by integrating investors' financial objectives with restrictions on ecological and social issues or concerns (WEF, 2011).

[3] The Ecological Footprint, for instance, measures how much land and water area a human population requires to produce the resource it consumes and to absorb its carbon dioxide emissions, using prevailing technology (http://www.footprintnetwork.org/).

challenge as its deterioration can also be seen as a result of foreign aided free grain supply (Ibrahim, 1987). Careful consideration of storage conditions must be provided too. FAO (1999) reports that a World Bank Grain Storage Project Mission in Pakistan noted significant losses of food while in farm storage due to insects, rodents and fungi when storage extended over a period of 3 months or more. Improved storage and the development of e.g. drying facilities for maize could nevertheless help to reduce post-harvest waste and losses.

It is further vital to sensitise and educate the global consumer in drawing attention to consumer sustainability and food waste issues and the private sector could play a key role in this. Kissinger (2012: 9) states that "sustainability is a pre-competitive issue, and should not be left to the consumer to make an informed choice about, but rather should underpin all products the consumer can choose from". This highlights that focus should not only be on supply-side export-led policies such as agricultural intensification and Genetically Modified foods, but that steps also need to be taken to take greater care of the food we already grow. This would help to reduce the food production demands placed on land and could help to reduce further land degradation and desertification.

Towards the sustainable land management to combat desertification and land degradation and improve food security

The previous sections have reviewed a number of key environmental and political-economic drivers of food insecurity, taking into account the implications for land degradation and desertification in both drylands and other parts of the world. It is clear from the synthesis above that the drivers and challenges of supply and demand side issues are closely interlinked. This section presents sustainable land management as a route towards a more integrated approach to tackling the most closely related aspects of food insecurity, land degradation and desertification. It provides some examples of sustainable land management activities that have resulted in improved food security and reflects on some of the lessons learned from past interventions.

To specifically deal with the complex issue of land degradation in drylands, the UNCCD identified sustainable land management (SLM)[4] as a superior, crucial strategy to ensure sufficient food production in the most vulnerable countries suffering from hunger and malnutrition (GM, 2012). Indeed, it is clear that there is a confluence of interests between land and soil conservation, crop productivity, climate change and human wellbeing and this may be achieved by SLM in a win–win strategy-particularly in areas at risk of desertification, with human, water and natural constraints, as is the case for areas under high rainfall erosivity - slopes and high erodible soils (Giller *et al.*, 2009). There are many concrete examples showing how SLM practices can be adopted, including a wide variety of practices such as crop rotation, fallow periods, soil fertility and organic matter management, reduction of tillage, crop residues and mulch management, water harvesting etc. In turn, it is possible to assess how these management strategies can help to improve land quality and human living conditions, thus enhancing food security (Sanchez and Swaminathan, 2005).

For example, Wezel and Rath (2002) have demonstrated that improvement or restoration of soil productivity is possible in agricultural lands of the Sahel, by controlling erosion, and restoring native vegetation cover combined with the use of manure from livestock. Badgley *et al.* (2007) compared different food crops in the developed and developing world and found that in developed countries organic systems produced 92% of the yield obtained by conventional agriculture while in developing countries the yield was 80% more than conventional agriculture. Pretty and Hine (2001) reported yield increases of 50 to 100% for rain-fed crops after the adoption of SLM practices in Africa and Latin America. Araya and Edwards (2006) found that compost applications produced a similar yield increase to chemical fertilizers in Ethiopia. Hundreds of similar experiences could be cited and several reviews on the current situation of practices involved in SLM and their implications can be found in

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[4] Sustainable land management is defined as the adoption of land use systems that, through appropriate management practices, enables land users to maximize the economic and social benefits from the land while maintaining or enhancing the ecological support functions of the land resources (GM, 2008).

Wang *et al.* (2007); Shi-ming and Sauerborn (2006) in China; Africa (Descheemaeker *et al.*, 2010), Bayala *et al.*, 2012); Australia (Bennet *et al.*, 2010; Luo *et al.*, 2010); Europe (Holland, 2004; Jacobsen *et al.*, 2012); Asia (Gupta and Seth, 2007; Erenstein and Laxmi, 2008; Sahrawat *et al.*, 2010; Farooq *et al.*, 2011) and South America (Batlle-Bayer *et al.*, 2010).

At the global level, the World Overview of Conservation Approaches and Technologies (WOCAT: http://cdewocat.unibe.ch/wocatQT/qt_report.php) provides a well-structured electronic and largely open-access platform to capture best practice SLM technologies used by land users (Schwilch *et al.*, 2011). This would be usefully complemented with a similar system to catalogue knowledge on traditional food securing mechanisms, linked also to options for food storage and waste minimization. Knowledge management and knowledge dissemination as well as awareness-raising are therefore vital in sharing good SLM and food securing practices. It should nevertheless be noted that the application of SLM and its resulting effects are environment-specific. For example, conservation agriculture needs to be tailored to local conditions because its potential is site-specific and depends on the local climatic, bio-physical and socio-economic conditions (Bolliger *et al.*, 2006; Lahmar and Triomphe, 2008; Giller *et al.*, 2009).

The key role of human activities in driving food insecurity, as introduced in Table 1, suggests that problems of food insecurity and desertification could be mitigated or even reversed through the adoption of effective countermeasures, policies and strategies, as the majority of the drivers are factors that to a greater or lesser extent can be controlled. This includes policies that focus on more technocratic solutions. While the above experiences show that SLM can help to increase food production, it remains vital that socio-political and socio-economic mechanisms and drivers are taken into account when developing solutions that are intended to be rolled out more widely. The challenge is further complicated due to the need for interventions to operate across different levels, scales and sectors. A successful response to food insecurity is a function of the ability of a system to effectively and efficiently respond to a specific disturbance factor. Most of the time, however, several disturbance factors and boosters present simultaneously, creating self-reinforcing loops and rebound effects (Scholz, 2011). This makes the responses and solutions more complex, and necessarily more integrated – a factor that has not always been appropriately considered in previous interventions. For example, the Plan of Action to Combat Desertification (PACD) that was adopted in 1977 following the drought-led famine in the Sahel failed largely because it neglected to integrate technical solutions with other equally important socio-political and socio-economic considerations (UNEP, 1992b).

Conclusion

This paper has argued that land degradation and desertification are exogenous issues that can amplify and aggravate the food insecurity problem. Addressing desertification, including land, soil, water and plant degradation, can thus facilitate or ease the food security dilemma, but may not completely solve it in the presence of other underlying causes. The paper has outlined many of those underlying causes, conceptualising them in relation to demand-side and supply-side issues. Although as comprehensive as permitted, there are nevertheless other causes that are beyond the scope of the paper to include. Overall, we conclude that an integrated solution to food insecurity will naturally (though indirectly) often target the drivers of land degradation and desertification. Our analysis has suggested this needs to:

- blend demand and supply-side measures to adequately address the different facets of the problems being tackled;
- take a transdisciplinary approach, i.e. based on the integration of theoretical and applied knowledge in all relevant domains as key strategies for understanding complex human-environment systems;
- promote an equitable distribution of the burden among all beneficiaries based on a thorough understanding of direct and indirect costs, benefits and externalities;
- be institutionalised, i.e. recognized and enforced by the national or international law;
- be consistent and coherent across all concerned countries, sectors and actors;

- be financially sustainable, i.e. not exclusively dependent on public subsidies in the long run; and
- be scalable, i.e. applicable from the local to the global level.

It is acknowledged that advancing towards these solutions will take time and significant resource investments. However, given the huge range of sustainability challenges with which the planet needs to contend, preserving the status quo does not remain a viable option.

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