Article

Monique F. W. Slegers and Leo Stroosnijder

Beyond the Desertification Narrative: A Framework for Agricultural Drought in Semi-arid East Africa

In the 20th century, much research was done on desertification. Desertification developed into a complex and vague construct that means land degradation under specific conditions. Projects focusing on land degradation in semiarid East Africa have met with limited success because farmers prioritize drought as the major productivity-reducing problem. Yet studies on long-term rainfall trends have not confirmed that droughts are more frequent. In this article, we combine drought and land degradation effects into an Agricultural Drought Framework, which departs from the farmers' prioritization of drought and accommodates scientists' concern for land degradation. It includes meteorological drought, soil water drought, and soil nutrient drought. The framework increases insight into how different land degradation processes influence the vulnerability of land and farmers to drought. A focus on increased rainwater use efficiency will address both problems of land degradation and drought, thereby improving productivity and food security in semiarid East Africa.

INTRODUCTION

In the 20th century, the concept of desertification, especially in relation to Africa's soils, was a much-debated issue. It has proved difficult to conceptualize desertification, because it has been redefined many times. Different commissions have been set up, many conventions have been signed, and long reports have been written to address the apparent problem of desertification. A great deal of research on natural resource management has focused on this phenomenon. Over the years, different insights have changed opinions on the exact causes of desertification. The evolution of the concept reflected developments in ecology.

The current and commonly accepted definition of desertification came out of the 1992 United Nations Conference of Environment and Development. At the conference, desertification was defined as "land degradation under arid, semi-arid and dry sub-humid climates resulting from various factors including climate variation and human activities" (1). Land degradation is the loss of the land's biological or economic productivity (1). Even though desertification has been defined, 2 questions remain: *i)* To what extent is desertification human induced? *ii)* To what extent is climate change responsible for desertification?

Scientists working on sustainable land use have identified human-induced land degradation as a major factor limiting sustainable production and food security in semiarid East Africa. However, due to their scientifically biased top-down approaches and lack of consensus on major problems (2–7) they have not been very successful in changing farmers' agricultural practices towards a more sustainable use of natural resources. Subsistence farmers in semiarid East Africa have often been unwilling to apply soil and water conservation (SWC) measures to their land, because they perceive drought as their most important productivity-reducing problem (8–12).

Researchers have not looked deeper into how these farmers perceive drought. To overcome productivity problems in a sustainable way, it is important to reconcile the mismatch between the problems perceived by scientists and the problems perceived by the actual users of the environment. Population pressure in the semiarid zones of East Africa is growing, while the productivity of the land is stable or even declining; food security and natural resource depletion are of increasing concern. We therefore argue that the point of departure should be the productivity-reducing problem drought that farmers give most priority to when studying the possibilities to increase agricultural sustainability.

In this article, we put drought into a wide framework that includes land degradation effects into a concept we term "agricultural drought." It will increase insight into how different land degradation processes influence the vulnerability of farmers and their land to drought. The Agricultural Drought Framework (ADF) serves as a common ground for scientists and farmers from which the 2 major problems affecting productivity—drought and land degradation—can be addressed in an integrated manner. It directs focus to more efficient use of rainwater for agriculture.

The first part of this article provides a literature review of the historical development of the concept of desertification according to discourses in natural resource management and in line with changing insights into ecology. In the second part, we stress the need for an alternative scientific focus to approach the pressing problems of decreased productivity and food security in Africa. We propose the ADF, which integrates farmers' perceptions of their priority problem.

DESERTIFICATION AS HUMAN MISMANAGEMENT OF NATURE IN EQUILIBRIUM

The concept of desertification evolved in the 1920s and 1930s in colonial West Africa as a result of concerns about an expanding Sahara; desertification was thought to be caused by the destruction of the Sahara's vegetation cover by nomads (13, 14). The work by Stebbing (15) was particularly influential in the development of the desertification concept and of later discussions about this concept. Stebbing argued that the causes of desertification were indigenous land use, exacerbated by the growth of human and livestock populations. Erratic rainfall was considered as a result rather than a cause of desertification. Savannah vegetation was judged to be degraded forest. Stebbing's report was followed by fieldwork by the Anglo-French Forestry Commission that studied this urgent problem (16). The commission refuted most of Stebbing's assertions and stated that desert borders were not moving southward. Rather, variability of annual rainfall was the cause of temporary changes in vegetation cover. Notwithstanding these critical notes, the general notion of desertification continued to be based on ideas like Stebbing's.

Discussions about desertification that were quite lively during periods of drought from the 1920s until the 1940s all but vanished when weather conditions were wet during the

Table 1. Changing conceptualization of desertification and underlying discourses in ecological sciences and regarding natural resource management.

Problem *vs.* change	Environmental change as a problem, as degradation	Environmental change not necessarily a problem; can be deliberate change
People-environment debate	Land degradation and desertification due to human actions	People suffer due to climate change and harsh climatic conditions
GEM *vs.* Populist discourse	People cause desertification External interventions necessary	Local land users use land sustainably but are hindered by external actions
Malthusian *vs.* Boserupian thinking	Overpopulation and overgrazing exceeding carrying capacity cause land degradation	People have adaptive capacity to deal with population pressure in sustainable ways
Equilibrium *vs.* nonequilibrium paradigm	Movement away from equilibrium is disruption of system Human and natural systems can be seen as independent of each other	Environment is resilient and shows resistance to change Complex reality of social-ecological interaction
Desertification	Human mismanagement major contributor to desertification and reduced rainfall amounts	Climate variability as normal feature of arid and semiarid climates; desertification as form of land degradation and climate change as a contributor

1950s and 1960s (13). Le Houérou (14) argued that desertification was also visible in the 1950s and 1960s. The term "desertification" was popularized again at the 1977 United Nations Conference on Desertification that was held after a decade of severe drought in Africa (17). At that conference, "desertification" was defined as "a reduction of the land production potential in arid, semi-arid and dry sub-humid zones, that may ultimately lead to desert-like conditions" (18). It was generally agreed that the problem was caused by human population growth exceeding the carrying capacity and by inappropriate land use. Indicators and hazard estimators of desertification, which emphasized human-induced causes of desertification, were identified to assess and map desertification (18, 19). Although some researchers were very skeptical about the identified causes of desertification, these remained generally accepted, strengthened by the United Nations Conference on Desertification and a report by the United Nations Environmental Programme (20).

These developments of the desertification concept kept pace with contemporary ideas that had developed from biological sciences and that were based on the belief that nature was in balance. In the first half of the 20th century, the biologist Ludwig von Bertalanffy had developed a systems theory (21, 22). A system is a model of general nature and can be defined as "a set of elements standing in interrelation among themselves and with the environment" (21). A system can be seen as a black box with an input and an output and has the central notion of stability; disturbances are controlled through linear feedback processes.

Until the 1970s, most ecological studies had departed from the presumption of a nature in balance in which notions of stability and equilibrium played key roles (23–27). An ecosystem is a self-regulating system, maintaining itself through feedback processes. It shows resilience; it has the ability to return to its old situation after a disturbance or to adapt to a new situation. When a disturbance is too severe, a system's adaptive capacity decreases to a level at which it is no longer able to cope with disturbances. The result is an ecological crisis. Examples of ecological crises are climate change and desertification.

Many studies on natural resource management have been derived from these concepts of ecology and systems theory. Leach and Mearns (23) have summed up 3 prevailing ideas and theories that are based on the nature-in-balance paradigm, which have greatly influenced debates in ecological science about human-environmental interactions and which have shaped the desertification concept.

i) The "climax vegetation community" states that each climatic zone supports its own type of vegetation in the absence of disturbance. Clements, a highly influential ecologist in the first decades of the 20th century, wrote about plant succession and the development of climax vegetation (28). The equilibrium between climatic factors and vegetation within a natural environment is disturbed by human interaction.

ii) The second idea presumes a causal link between reduced vegetation cover and decreased rainfall. This idea was already prominent among scientists in British and French colonial empires (15). A direct link was seen between deforestation and climate change. It resulted in the establishment of forest conservation areas in tropical colonial areas to protect these areas against climate change (29). This idea was verified in the 18th and 19th centuries. Arid tropical areas were considered as having been more densely vegetated and in receipt of more rainfall. There was disagreement about the causes of this process of increased dryness. Some scientists saw it as a result of natural processes, while others saw it foremost as the result of human mismanagement (29).

iii) The third theory has its foundations in the Malthusian line of thinking. In 1798, Malthus wrote his "essay on the principle of population," in which he explained his pessimistic view about the inevitable effect of an increase of population size beyond the environment's carrying capacity on food supply. He argued that there are limits to growth; the world is finite and can only support a finite population (30, 31). Many scientists embraced his ideas. Human mismanagement and population growth disturb the natural equilibrium, causing such processes as land degradation (15, 26, 30).

In spite of some disagreement on the paradigm of balanced nature, for most of the 20th century, the sciences on natural resource management remained dominated by this paradigm (24, 27, 32). Discourse on the equilibrium-based conceptualizations of environmental problems and the impact of human actions on the natural environment initiated a shift towards a more nuanced view on ecological crises. This discourse influenced further developments of the desertification concept.

CHANGING CONCEPTS OF DESERTIFICATION

A danger of equilibrium thinking has been the tendency to see environmental change as a movement away from equilibrium or a stable state and thus as problematic (Table 1). Agnew and Warren (33) discussed the failure to distinguish between environmental change and environmental problem. Environmental change refers to any change in the physically observable facet of the environment, and environmental problem refers to environmental issues that affect people's livelihoods. The relation between these 2 concepts has been assumed more often than it has been demonstrated because of the paucity of data, confusing definitions, or temporal and spatial variability in environmental processes. The confusion of definitions has played a major role in the inability of institutions to address the actual problems. Stroosnijder (34) refers to the need to distinguish between land degradation, which is an environmental problem, and land development, which concerns deliberate changes in land use.

Binns (17) refers to the discussion around the environmental problems of Africa as the "people-environment debate." On one side, people adhere to the idea that the environment is the victim of people: human action is causing degradation and desertification. On the other side is the opinion that people are victim of the environment; they suffer under the effects of climate change or the harsh living conditions in arid and semiarid environments. Similarly, Herrmann and Hutchinson (35) refer to the Global Environmental Management *vs.* the populist discourse. According to the Global Environmental Management discourse, people cause desertification, of which they are at the same time the victims. Scientists, aid bureaucrats, and national civil servants are depicted as heroes who provide solutions to environmental problems. In the populist discourse, global capitalism, transnational corporations, and northern consumers are the "bad guys" whose actions have caused a marginalization of local farmers and pastoralists, while the local people are considered both as victims and as heroes capable of sustainable management of their natural environment.

The effect of rural population growth on agricultural production and the natural environment of Africa has been another point of discussion. According to the Malthusian line of thinking, the increased demand for food induces unsustainable intensification and extensification of agriculture (15, 30). At the other end of the discussion spectrum, there is the Boserupian line of thinking of adaptive intensification of agriculture (36–39). This concept posits that local land users are capable of sustainable land use, even under increased population pressure. The well-known Machakos case study (39) showed how population growth increased the sustainability of agriculture through innovative and adaptive strategies.

Since the 1970s, ecologists have moved on from the notion of nature in balance. Past policies on natural resource management were based on 2 erroneous assumptions: that ecosystems have 1 static equilibrium (24, 26, 27, 40) and that human systems are independent from natural systems (41, 42). Currently, equilibrium is considered to be far from a practical reality (27). It takes different forms, constantly fluctuates around a mean, and is metastable in the sense that at certain threshold values the equilibrium goes up or down a level, to an alternative stable state (27, 43, 44). Ecosystems can be defined by 2 properties: resistance and resilience (27, 45). Resistance is the ability of a system to return to a state of equilibrium after a disturbance. Resilience is a measure of a system's persistence: it is the ability to absorb changes, to learn, and to develop (41, 45, 46). The equilibrium notion is believed to be at least a simplification of more complex realities (47).

The assumption of independent human and natural systems has also been superseded by recent ecological insights. Traditional ecology saw biotic components as having great influence on the ecosystem, whereas abiotic components, such as climatic conditions, were relatively stable. Consequently, human activity was seen as having a highly destabilizing effect on a system. Recent ecological insights have revealed that the most important factors contributing to ecosystem change are variability of the abiotic components of a system, such as interseasonal and intraseasonal fluctuations in rainfall. This is especially the case in arid and semiarid tropical ecosystems, in which there is a great natural variability in the physical environment (27, 48, 49).

Holling (50) developed the concept of complex dynamics to describe the evolving nature of complex adaptive social-ecological systems. Because humans are intertwined with ecosystems, resilience should be seen in the context of integrated systems of people and nature (51, 52). Besides ecosystem resilience, social resilience should be taken into consideration as a factor that limits degradation. Social resilience is the ability of groups and individuals to respond to environmental and socioeconomic constraints through adaptive strategies (53). Whether and how physical changes can be resisted depends on the economic, social, and cultural contexts in which changes take place (33). Sustainable development of a social-ecological system is the capacity to create, test, and maintain adaptive capacity and opportunities (50).

General assumptions made during colonial times about desertification, deforestation, soil erosion, and rainfall decline continued to drive much of the environmental policies in Africa until the last decade of the 20th century (15, 29, 54, 55). According to some scientists, these assumptions have been made on false grounds or at least have been strongly overestimated (13, 17, 23, 34, 56–61). They refer to the prevailing ideas about desertification as a narrative. In the next section, we will show how the desertification concept and the desertification narrative have continued to evolve and will discuss the reactions they have provoked.

DEVELOPMENT OF THE DESERTIFICATION NARRATIVE

We showed how the desertification concept came into being, how it has developed, and how it was repopularized in the 1970s. Desertification was seen as a human-induced process, the most important causes of which were overgrazing, overcultivation, and deforestation (18). However, there has always been disagreement about the exact causes and severity of desertification. No consensus exists on the extent to which human factors are responsible for desertification (62) and what role climatic factors play in this. The apparent desertification trends in Africa have generated discourses among scientists, development agencies, and political institutions, some of which see desertification as a human-induced process caused by mismanagement of fragile ecosystems, while others look upon it as a narrative. The last group perceives desertification as a natural process induced by climate variability, to which both people and their natural environment show resilience (53). Local people have developed adaptive strategies to deal with disturbances.

Swift (13) has written extensively about the history of the desertification concept and about the desertification narrative that developed out of criticism of the conceptions of the problem. Swift describes desertification as "a set of ideas about the environment that emerge in a situation of scientific uncertainty and then prove persistent in the face of gradually accumulating evidence that they are not well-founded" (13). Claims made by means of these narratives continue to be propagated for political and economic ends (26). Some refer to the "institutionalization" of environmental issues (33, 35). Natural resource management policies were based on outdated paradigms of environmental problems and their causes (33). Swift is skeptical about the desertification narrative, not because the narrative is false *per se*, but because it has been politically very influential, even though it has been based on disputed and poorly researched ideas.

Discussions about desertification arose during or shortly after drought periods when vegetation cover was reduced due to water shortage. The desertification narrative was conveniently used by national governments to claim that local land users were not capable of using the land in a sustainable way; pastoralists in particular were accused of being unsustainable land users. Desertification was used by governments to try to change the resource management practices of local land users. It was not seen as a politically charged or controversial concept. Aid agencies used the desertification narrative as a justification for increasing the number of requests for aid (13). The narrative was also convenient for scientists; their idea of climax vegetation destroyed by overgrazing fitted perfectly into the picture of desertification (13).

Political and economic interests have influenced land degradation discussions (29, 63) through environmental and policy narratives that demonstrate the problem and its causes (13, 23). According to Swift, the misplaced attention on the desertification debate diverted the focus from effective approaches to control soil erosion and land degradation processes. The geographical extent of the desertification narrative went from studies at local scale, mainly from the West African Sahel zone, to higher levels and created generalizations of area-specific environmental phenomena. These generalized ideas about desertification have also been extrapolated to semiarid East Africa. Macroscale assessments of land degradation have offered powerful messages to policy makers, however, with the risk of oversimplification and generalizations that have led to conflicting reports of degradation processes at the microlevel (64). Conclusions can only be drawn after profound area-specific research that takes into account the area's current and historical ecological and social situation (23, 26, 34, 61).

What seemed to be a value-free and political neutral concept in the 1970s has become a highly politicized construct. The desertification narrative has generated good discussions and new insights into the area-specific causes and appearances of desertification. Since the 1990s, more accurate and useful methodologies have been developed that are participatory, concerned with the actual users of the natural resources, and based on the indigenous knowledge and institutions of local land users (13). At the 1992 United Nations Conference of Environment and Development, diverging insights were combined into a redefinition of desertification. The new definition emphasizes that desertification is not only human made but also related to such natural factors as climate variability and change. The International Year of Deserts and Desertification in 2006 renewed interest in the urgent problem of desertification. The need for action and increased awareness has been stressed; as much as one-third of the Earth's surface and more than a thousand million people are threatened by desertification (65). There is, however, little consensus on the appropriate way to assess desertification locally (34, 66).

NEED FOR A LOCAL PERSPECTIVE FOCUSING ON DROUGHT

It has proved very difficult to lay the desertification narrative to rest because it would undo decades of research and international debates on environmental processes and interventions (67). Studies in West Africa had shown that vegetation cover had diminished, which was proof of desertification (68). Satellite images from the first half of the 1980s show an expanded Sahara desert, and later satellite images show a retreat of the desert. Critics of desertification argue that the environment is much more resilient than previously thought. It could be concluded that the notion of desertification is erroneous or at least that it has been overestimated (68).

Satellite images merely show vegetation borders and provide no information about biodiversity or the quality of the vegetation cover. There has been a gradual change in research towards the view of a complex landscape that is constantly changing rather than just degrading, a process that may always have been evident to local land users (67). A study by Hutchinson showed that a growing portion (up to 17 %) of variability in vegetation cover cannot be explained by erratic rainfall but might be related to management practices (69). He argues that degradation processes are spatially complex and are no definite proof of the truth of the desertification narrative (69).

Koning and Smaling (70) have collated the opposing views of agronomists (71), who generally adhere to the desertification narrative and of social scientists and ecologists (72), referred to as critical authors, who reject the idea of ecological equilibrium and adhere to a coevolutionary vision of complex dynamics between ecological and social systems (73). The critical authors have made some valid claims that can be summed up as "soils evolve in a complex way, farmers play a key role, and attempts at improvements should be linked to their knowledge" (70). However, on certain tough realities, they have no option but to agree with the agronomists. One such reality is the nutrient depletion in parts of Africa that has been induced by processes of soil degradation, denitrification, and leaching. Indeed, from many studies it appears that decreased soil fertility is a problem (74–78).

However, one should be careful when making generalizations, because other studies have shown opposite trends (26, 58, 64). Studies demonstrating the adaptive capacity of local land users towards environmental recovery cannot be generalized (79). The Machakos case study has been criticized for its lack of historical insight and the use of selective information (79, 80).

Notwithstanding the fact that desertification cannot be put aside as a narrative, there are some observations to be made regarding the concept. First, desertification has a wrong connotation for many people: an image of extending sand dunes of the Sahara desert devouring villages and fields. However, this is not the reality in many semiarid areas of East Africa that are said to be suffering from desertification. Second, over the years, interpretations in terms of causes and effects of desertification have changed, and, ultimately, desertification has developed into a very broad and vague concept whose causal factors form a complex net of interactions among physical, biological, political, social, and economic factors (1). It has become an almost incomprehensive and unmanageable concept to use in practice. Studies addressing desertification require an area-specific approach that does not try to grasp the entire complex concept. For these reasons, we prefer to use the term "land degradation," and we argue that there is a need for an alternative scientific focus to approach the pressing problems of decreased productivity and food security that is more neutral and simpler and that accommodates local perceptions.

In the past 20 years, more attention has been paid to stressing the distinction and interrelatedness between drought and desertification (14, 18, 81). Desertification is considered to be a process of degradation of land resources that reduces productivity (13, 69, 81) in certain climatic zones. Drought is a recurrent and normal feature of a climate, a natural hazard (1, 81) that causes temporal changes in productivity. Temporal changes may easily be confused with long-term degradation (7, 68), especially during a succession of dry years.

Drought seems to occupy the middle ground in the discussion about land degradation. Development actions in semiarid East Africa focusing on land degradation have met with limited success because local land users do not prioritize land degradation as major problem. These land users often

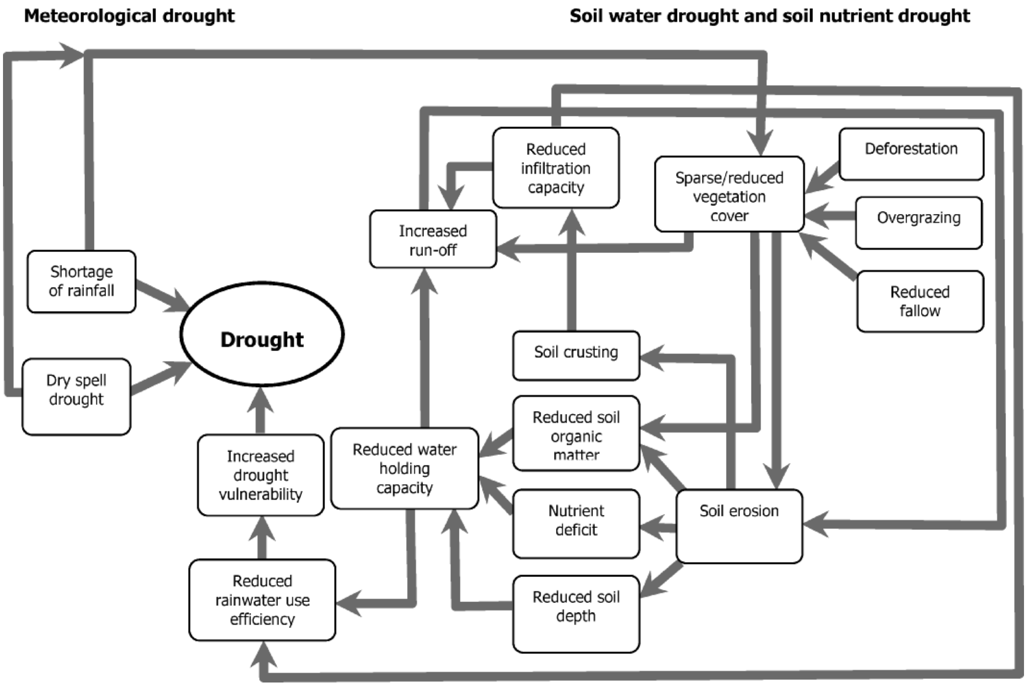

Figure 1. Causes of agricultural drought. Meteorological drought is directly linked to drought, whereas soil water drought and soil nutrient drought cause drought indirectly by increasing vulnerability to drought.

perceive drought as their limiting factor for reaching higher production levels. Although climate variability cannot be influenced easily and directly, it would be possible to reduce the vulnerability of people and their environment to the effects of drought. In the next section, we will discuss different drought concepts, developed in the past, that can help reconcile the paradigms of scientists, development agencies, political institutions, and actual land users and thereby create common ground for sustainable agriculture in semiarid East Africa.

AGRICULTURAL DROUGHT FRAMEWORK

Studies on long-term rainfall trends for semiarid East Africa give no undisputable proof of abnormalities and thus have not confirmed farmers' beliefs that drought has become more frequent (12, 82–85). However, the causes of drought can be more complex than a rainfall deficit (51). It is not only an absolute rainfall deficit that causes drought. A relative water shortage as a result of an unfavorable rainfall distribution or land degradation processes can also cause drought-like conditions to occur. These processes influence the efficiency of the rainfall. Farmers rarely link these processes directly to land degradation and may perceive them as drought (46).

In an article on the role of drought in range management, Thurrow and Taylor (86) state that users of degraded rangelands have often claimed that droughts have become more frequent and severe, while the long-term trend of temporal and spatial precipitation has shown no change. Less productive years were identified by farmers as drought years. In cases in which there was no evidence of meteorological drought, Thurrow and Taylor refer to this "drought paradox" as some form of agricultural drought and attribute it to degradation of vegetation and to processes of soil erosion and soil crusting. Others draw similar conclusions (12, 43, 46). Rietkerk (87) claims that soil water and nutrient availability diminish through soil degradation processes. These processes increase the vulnerability of a soil to drought (Fig. 1), and they reduce the capacity of an agroecosystem to absorb environmental shocks (51). Environmental conditions, such as soil water and nutrient availability, and vegetation cover show not only temporal variability but also microscale spatial variability (88, 89), which may explain why farmers do not experience similar drought conditions at a certain moment and within a small area.

Because drought affects many social and economic sectors, scientists in a wide range of disciplines have conceptualized it in different ways (90). Conventional notions of drought focus on biophysical phenomena identified by scientists. These completely bypass the way local land users perceive their physical environment (12). How drought affects people's lives depends on their personal situation. Thus, drought cannot be viewed solely as a physical event; the social impacts should also be taken into consideration, because judgments about a drought's severity and impacts are culturally defined (91).

Fieldwork in West African Burkina Faso has revealed that farmers have different perceptions of drought compared with scientists working in natural resource management institutions (92). The scientists considered drought within a narrow meteorological framework: a rainfall deficit compared with an average expected amount. However, farmers had a broader perception of drought that included land degradation processes (92). Stroosnijder (12) distinguishes 3 drought components based on insights into the inter-relation between drought, land degradation, and biological productivity from the perspective of farmers. These drought components are dry spell drought, soil water drought, and soil nutrient drought. Each of these drought components will be explained below, as part of an ADF (Table 2).

The ADF focuses on a broad concept of drought that accommodates both scientists' and farmers' concerns. Within this framework, "agricultural drought" refers to drought-like plant stress that depresses crop growth, crop development, and crop production and that is caused by a shortage of water in the crop's root zone, a shortage of nutrient availability for the crop, or both. "Dry spell drought" is part of what is called "meteorological drought." The ADF contains indicators for each of the 3 drought types and factors that influence agricultural drought vulnerability (Table 2).

Meteorological Drought

The word "drought" is most commonly used to refer to meteorological drought. Efforts have been made to design a universal definition of meteorological drought that would fit all localities and situations. These definitions reflect climatic abnormalities and are based on a deficit of rainfall from a

Table 2. Agricultural Drought Framework containing 3 types of drought, their indicators, and general factors that influence vulnerability to drought.

	Definition	Drought indicators	Influences on drought vulnerability
Meteorological drought	A situation in which agricultural production is limited due to below-average seasonal rainfall amounts or due to unfavorable intraseasonal rainfall distribution	Annual rainfall	*Natural soil properties*
			Location of land –In topo-sequence –Slope
		Intraseasonal rainfall distribution	*Other weather conditions* –Sunshine –Wind
Soil water drought	Root zone reserves are insufficient to sustain crops and pasture between rainfalls in spite of sufficient rainfall	Infiltration capacity Water-holding capacity Soil organic matter Water use efficiency	*Land management practices* –Cultivation technique –Timing
Soil nutrient drought	Nutrient availability for the plant limits crop growth, crop development, and crop production in spite of available water	Nutrient content Soil organic matter	–Crop type –Crop variety –Fertilizer/manure –Crop residues –Fallow –Soil and water conservation

long-term average. The hazard posed by meteorological drought depends on the rain's timing in the season together with other climatic factors, such as temperature and wind (93). However, perceptions of the meaning of meteorological drought vary significantly. Extended research on meteorological drought and drought mitigation in Europe has shown that it is impossible to make 1 single definition of meteorological drought, because any approach to define it reflects regional and ideological differences (90, 94). What would be considered meteorological drought in a humid area may be considered a wet year in a semiarid area.

Semiarid areas of Africa have great rainfall variability between and within years and have a high atmospheric water demand (95). Within the ADF, meteorological drought is conceptualized as a situation in which agricultural production is limited due to below-average seasonal rainfall amounts or due to unfavorable intraseasonal rainfall distribution.

Indicators of meteorological drought are total seasonal rainfall and intraseasonal rainfall distribution. Within a year, the total amount of rainfall may be normal, yet extended dry spells within the rainy season may cause total or partial crop failure (95). This type of meteorological drought can be termed "dry spell drought" (12). The timing of dry spells within a crop season is crucial for later crop development or even for crop survival. In the initial stage of a plant's emergence and in the stages of crop development, a plant is especially vulnerable to dry conditions.

Soil Water Drought

Rainfall deficit and unfavorable rainfall distribution are not the only causes of agricultural drought. Soil water drought occurs when there is a deficit of soil water in the root zone for sustaining crops and pasture in between rainfall events (94) where rainfall has been sufficiently available. Various land degradation processes negatively influence soil physical properties (12) and ultimately decrease a soil's water infiltration capacity and water-holding capacity (Fig. 1). This reduces rainwater use efficiency and increases a soil's vulnerability to soil water drought.

Soils in semiarid African ecosystems are susceptible to soil water drought. Naturally, the vegetation cover is not very dense. As a result of low biomass availability, soils are low in soil organic matter. Soil organic matter enhances a soil's capacity to store water. Rain showers in this climate zone have a high intensity and are highly erosive; land with a sparse vegetation cover or fields with crops in an initial development stage are especially vulnerable to soil erosion. Little rain water is trapped by the sparse vegetation or juvenile crop. The less water infiltrates the soil, the more water will run off and the higher vulnerability to soil degradation there will be (96). Soil depth decreases as a result of soil erosion, which will reduce the soil's water-holding capacity. Another effect of soil erosion is surface sealing, which reduces infiltration capacity of a soil. Mainguet refers to this reduced infiltration capacity as "edaphic" drought (97).

Soil Nutrient Drought

Soil nutrient drought occurs when nutrient availability for the plant limits plant growth, crop development, and crop production more than water availability (12). Crops require nutrients, and a deficient nutrient uptake by a plant causes soil nutrient drought. Nutrients are made available for crops through such processes as mineralization of organic matter and weathering of minerals (98). Nutrients are taken up by the roots of a plant through soil water. Soil water releases nutrients from a soil and transports these to plant roots. Soil nutrient drought occurs even though sufficient water is available to meet crop needs. Not the entire stock of a nutrient available in a soil be taken up by a plant. Total uptake of 1 nutrient available for a plant depends on the availability of other nutrients in a soil, according to Liebig's law of the minimum. This law states that plant growth is limited by the nutrient most scarcely available according to the plant's needs (98, 99). When the potential supply of a nutrient is the limiting factor for crop growth, the whole stock of that nutrient available for the plant will be taken up. The actual uptake of other nutrients will be below their potential supply (98); their uptake is limited by the scarcest nutrient. When more nutrients are taken up by a plant than are returned to a soil, nutrient stocks of a soil will gradually deplete, increasing the vulnerability to soil nutrient drought (96).

Agricultural Drought Vulnerability

The drought vulnerability of land and its users increases when any of the 3 types of agricultural drought occur. Whether drought occurs and, if so, which drought type, depends on the most limiting of all resources that plants need for their growth and development. Each drought type has its specific factors that influence drought vulnerability. Different drought types can occur concomitantly within an area and successively in time. It is difficult to look at each of the 3 drought types in the framework as isolated processes. Drought types are linked in causal factors and effects and, as such, influence each other. Therefore, it is important to consider agricultural drought as a whole when studying drought vulnerability. There are general factors that influence all 3 drought types and thereby agricultural drought vulnerability (Table 2). These general factors can be divided into 4 categories.

First, every soil type has its intrinsic properties that influence water infiltration and water-holding capacity. Clay soils have a low infiltration capacity, especially when the soil is dry, but their water-holding capacity is high. Sandy soils, on the other hand, have high water infiltration and low water-holding capacities.

Second, the slope of the land and the location within a topo-sequence influence soil moisture content. Sloping land has more run-off than flat land. The location in a topo-sequence influences the soil properties and water availability as well. Runoff contains soil particles and nutrients from uphill. These soil particles and nutrients are deposited on bottom land; as a result of this sedimentation, the bottom soils are deep and fertile compared with soils higher up in the topo-sequence.

Third, besides a season's total rainfall amount and its intraseasonal distribution, other weather conditions play a role in drought vulnerability. Soil water evaporates faster in a hot and sunny dry period than in a cool and cloudy dry period. Evaporation also increases with wind speed.

Fourth, a soil's drought vulnerability is influenced by land management practices, because land management influences water use efficiency (12). Deeper cultivation allows water to infiltrate more easily but simultaneously has the risk of reducing soil fertility when less fertile subsoil is mixed with more fertile topsoil. The timing of agricultural practices is crucial in an area in which rain may come in only a few concentrated rain showers.

A crop's water and nutrient requirements differ for each development stage, as does a crop's drought vulnerability. The latter is dependent not only on the crop's development stage but also on crop type and crop variety.

Each crop has its own soil fertility requirements. Soil fertility management is an important influence on drought vulnerability. The use of fallow, manure, compost, and crop residues will increase the soil organic matter content and will diminish drought vulnerability. However, it should be taken into account that the availability of these resources is limited in semiarid East Africa. It was shown that land around the homestead and land used by rich farmers have a higher fertility status (100).

The use of conservation technologies, such as SWC measures (12), rainwater harvesting (101), and conservation agriculture techniques (102), helps in several ways when these are carefully selected according to local conditions and use of the land. It stimulates the infiltration of water into the soil, thereby reducing runoff. When using a combination of SWC measures and other practices that stimulate land cover, water holding, and water infiltration capacities, the runoff will be more manageable. This will improve the efficacy of SWC structures during intensive showers. With less erosion, fewer nutrients will be removed by runoff. Some conservation techniques increase biomass and will have a positive influence on soil organic matter content, whereas others reduce evaporation by increasing soil cover (12, 102).

HOW TO REDUCE AGRICULTURAL DROUGHT VULNERABILITY?

The objective to reduce agricultural drought vulnerability is a challenging one. In semiarid East Africa, soils are generally poor; rainfall is erratic, and when it falls, it often comes in highly erosive showers. Even within an area of uniform rainfall distribution, soil moisture and nutrient contents vary due to a variety of factors, as explained above. Complex relations between soil, water, and plants influence agricultural drought vulnerability. There is no straightforward way to assess agricultural drought vulnerability. It depends not only on such biophysical factors as climate conditions and soil properties but also on such management factors as land use and the management practices of local land users and their strategies to cope with drought. The farmers who live in this region have a limited availability of resources. Efforts to reduce agricultural drought vulnerability should therefore be area specific and take into account local perceptions and management practices.

Efforts that strive for more efficient use of rainwater most likely target agricultural drought. Studies in the south of the Sahel show that of every 100 mm of rainfall, only 10 to 30% is actually used by vegetation (62, 103), while 30 to 50% of the infiltrated water will finally evaporate and 10 to 30% will disappear through underground flow. Another 10 to 25% of the rainfall will run off immediately (62). A useful approach developed within the discipline of ecohydrology focuses on this partitioning of rainfall. This approach divides rainfall into productive and unproductive and into green and blue rainwater (62). The portion of rainfall that infiltrates the root zone will partially be used by crops and vegetation; it is termed "productive green water." The remaining portion of green water will evaporate and is unproductive at that moment. The portion of the rainfall that disappears through overland and underground flow, blue water, does not contribute to production in that area and therefore is unproductive at this scale.

More efficient use of rainwater can be achieved by reducing biophysical deficiencies that cause agricultural drought (104). The most obvious and commonly known way to reduce rainfall deficiencies is to optimize blue water use through rainwater harvesting and supplemental irrigation (104). This reduces the vulnerability to dry spell drought (105). However, more can be gained by using an integrated approach that targets the productive use of both blue and green water. This can be achieved by improving soil water and soil nutrient properties. Rockström (104) showed that an integrated water and land management approach that improves rainwater availability and techniques and timing of cultivation practices and soil nutrient management practices has a positive effect on yield and water productivity. When a bigger portion of the rainfall is eventually used as productive green water, a practice called "more crop per drop," vulnerability to agricultural drought as a whole will decrease. It will be a good alternative for classical SWC programs because the starting point can be farmers' priority problem drought while land degradation concerns are taken into account.

CONCLUSION: TOWARDS A COMMON GROUND

Desertification has developed into a politicized concept and has become a very broad, complex, and vague construct. The severity of desertification and land degradation has not always been correctly assessed, which has led to overestimation of these processes that cause environmental stress. Initiatives to determine which areas in the world are threatened by desertification and to assess causes and severity of desertification have not been very successful because different processes take place on a local scale: each environment shows a different level of resilience to environmental stress, and local land users have adopted different adaptive management strategies to cope with environmental stress.

Over time, programs dealing with land degradation and desertification have become more localized and participative, which is a good step forward. However, programs still depart from the productivity-reducing problems identified and perceived by scientists, even though local land users in semiarid East Africa identify another priority problem: drought. This difference in the perception of the problem limits the success of scientists working on problems of land degradation and desertification. A new approach is needed, one that takes as its starting point the farmers' priority problem of drought. It can be the missing link towards more sustainable and productive agriculture.

It is impossible to influence the amount and timing of rainfall. Therefore, a more efficient use of the available rainwater, more "crop per drop," is desirable. More efficient use of rainwater will reduce drought vulnerability. This can be achieved by optimizing the use of rainwater that infiltrates in the root zone and of water that otherwise disappears through overland and underground flow, thereby reducing a soil's vulnerability to agricultural drought.

In this article, we have presented a framework on agricultural drought (ADF) containing 3 drought types—meteorological drought, soil water drought, and soil nutrient drought—that concentrates on drought vulnerability. This framework focuses on how agricultural drought influences drought vulnerability and on how types of agricultural drought relate to land degradation processes. The ADF directs focus to rainwater use efficiency and offers an alternative approach to the classic SWC programs undertaken to increase the sustainability of land and water management practices. It takes into account farmers' priority problem (drought) and scientists' concern for land degradation.

The development of the ADF is only the first step towards an approach that focuses on farmers' priority problem of drought. It should be remembered that the framework approaches drought scientifically. The next and crucial step is to study farmers' perceptions of drought and drought vulnerability, to answer the question of what farmers really mean when they complain about drought, and to translate these into the scientific drought types within the ADF.

References and Notes

1. UNCCD 1994. United Nations Convention to Combat Desertification in countries experiencing serious drought and/or desertification, particularly in Africa. UN. (http://www.unccd.int/convention/text/convention.php)
2. Van den Bosch, R. and Sterk, G. 2005. *Tools for Catchment Level Soil and Water Conservation Planning in the East African Highlands. Tools for Participatory Soil and Water Conservation Mapping. Tools for Financial Analysis of Soil and Water Conservation Measures*. Tropical Resource Management Papers, 65. Wageningen University and Research Centre, Wageningen, 115 pp.
3. Tenge, A.J.M. 2005. *Participatory Appraisal for Farm-level Soil and Water Conservation Planning in West Usambara Highlands, Tanzania*. PhD Thesis, Wageningen University and Research Centre, Wageningen, The Netherlands.
4. Bekele-Tesemma, A. 1997. *A Participatory Agroforestry Approach for Soil and Water Conservation in Ethiopia*. PhD Thesis, Wageningen University and Research Centre, Wageningen, The Netherlands.
5. Kiome, R.M. and Stocking, M. 1995. Rationality of farmers' perception of soil erosion: the effectiveness of soil conservation in semi-arid Kenya. *Glob. Environ. Change 5*, 281–295.
6. Cartier, S. and De Graaff, J. 1998. Differences between farmers and scientists in the perception of soil erosion: a South African case study. *Indigenous Knowl. Dev. Monit. 6*, 8–9.
7. Ringrose, S., Chanda, R., Nkambwe, M. and Sefe, F. 1996. Environmental change in the Mid-Boteti Area of North-Central Botswana: biophysical processes and human perceptions. *Environ. Manage. 20*, 397–410.
8. Östberg, W. 1995. *Land Is Coming Up: The Burunge of Central Tanzania and Their Environments*. Stockholm Studies in Social Anthropology, 34. Stockholm University, Stockholm, 258 pp.
9. Beshah, T. 2003. *Understanding Farmers: Explaining Soil and Water Conservation in Konso, Wolaita and Wello, Ethiopia*. Tropical Resource Management Papers, 41. Wageningen University and Research Centre, Wageningen, 245 pp.
10. Hella, J.P. and Slegers, M.F.W. 2006. *Exploring Drought Perceptions: Missing Links Prioritizing Actions for Improved Productivity in Semi-arid Tanzania. Proceedings of a Seminar Held at 21 June 2006*. Sokoine University of Agriculture, Morogoro: Wageningen University and Research Centre/Sokoine University of Agriculture, 46 pp.
11. Biamah, E.K. 2005. *Coping with Drought: Options for Soil and Water Management in Semi-arid Kenya*. PhD thesis, Wageningen University and Research Centre, Wageningen, The Netherlands.
12. Stroosnijder, L. 2008. Modifying land management in order to improve efficiency of rainwater use in the African highlands. *Soil Till. Res.* Accepted.
13. Swift, J. 1996. Desertification: narratives, winners and losers. In: *The Lie of the Land: Challenging Received Wisdom on the African Environment*. Leach, M. and Mearns, R. (eds). James Currey/International Africal Institute, London, pp. 73–90.
14. Le Houérou, H.N. 2002. Man-made deserts: desertization processes and threats. *Arid Land Res. Manag. 16*, 1–36.
15. Stebbing, E.P. 1937. The threat of the Sahara. *J. Roy. Afr. Soc. 36*, 3–35.
16. Aubréville, A. 1973. *Report of the Anglo-French Forestry Mission Nigeria-Niger (December 1936–February 1937)* (In French). *Rev. Bois. For. Trop. 148*, 3–26.
17. Binns, J.A. 1997. People, environment and development in Africa. *S. Afr. Geogr. J. 79*, 13–18.
18. Le Houérou, H.N. 1996. Climate change, drought and desertification. *J. Arid Environ. 34*, 133–185.
19. Mabbutt, J.A. 1986. Desertification indicators. *Clim. Change 9*, 113–122.
20. UNEP. 1984. *General Assessment of Progress in the Implementation of the Plan of Action to Combat Desertification1978–1984: Report of the Executive Director*. UN Environmental Programme, Nairobi, 23 pp.
21. Von Bertalanffy, L. 1972. History and status of general systems theory. *Acad. Manage. J. 15*, 407–426.
22. Von Bertalanffy, L., Rapaport, A. and Whyte, L.L. 1958. General systems: yearbook of The Society for the Advancement of General Systems Theory. *Br. J. Phylos. Sci. 9*, 170–171.
23. Leach, M. and Mearns, R. 1996. Environmental change and policy: challenging received wisdom in Africa. In: *The Lie of the Land: Challenging Received Wisdom on the African Environment*. Leach, M. and Mearns, R. (eds). James Currey/International Africal Institute, London, pp. 1–33.
24. Scoones, I. 1999. New ecology and the social sciences: what prospects for a fruitful engagement? *Annu. Rev. Anthropol. 28*, 479–508.
25. Leach, M., Mearns, R. and Scoones, I. 1999. Environmental entitlements: dynamics and institutions in community-based natural resource management. *World Dev. 27*, 225–247.
26. Mazzucato, V. and Niemeijer, D. 2000. *Rethinking Soil and Water Conservation in a Changing Society: A Case Study in Eastern Burkina Faso*. Tropical Resource Management Papers, 32. Wageningen University and Research Centre, Wageningen, 380 pp.
27. Baker, K.M. 2000. *Indigenous Land Management in West Africa: An Environmental Balancing Act*. Oxford University, New York, 288 pp.
28. Clements, F.E. 1916. *Plant Succession: An Analysis of the Development of Vegetation*. Carnegie Institute Publications, Troy, 512 pp.
29. Grove, R.H. 1994. A historical review of early institutional and conservationist responses to fears of artificially induced global climate change: the deforestation-desiccation discourse 1500–1860. *Chemosphere 29*, 1001–1013.
30. Hardin, G. 1968. The tragedy of the commons. *Science 162*, 1243.
31. Meadows, D.L., Meadows, D.I. and Randers, J. 1972. *The Limits to Growth: A Report for the Club of Rome's Project on the Predicament of Mankind*. Universe Books, New York, 207 pp.
32. For a detailed historical review on the evolution of concepts of equilibrium and nonequilibrium in ecology, see Baker (27) and Scoones (24).
33. Agnew, C. and Warren, A. 1996. A framework for tackling drought and land degradation. *J. Arid Environ. 33*, 309–320.
34. Stroosnijder, L. 2007. Rainfall and land degradation. In: *Climate and Land Degradation*. Sivakumar, M.V.K. and Ndiangui, N. (eds). Springer Verlag, Berlin, pp. 165–193.
35. Herrmann, S.M. and Hutchinson, C.F. 2005. The changing contexts of the desertification debate. *J. Arid Environ. 63*, 538–555.
36. Boserup, E. 1975. Impact of population-growth on agricultural output (Comment). *Q. J. Econ. 89*, 257–270.
37. Kandeh, H.B.S. and Richards, P. 1996. Rural people as conservationalists: querying Neo-Malthusian assumptions about biodiversity in Sierra Leone. *Africa 66*, 90–103.
38. Tiffen, M. and Mortimore, M. 1994. Malthus controverted: the role of capital and technology in growth and environment recovery in Kenya. *World Dev. 22*, 997–1010.
39. Tiffen, M., Mortimore, M. and Gichuki, F. 1994. *More People, Less Erosion: Environmental Recovery in Kenya*. John Wiley & Sons Ltd., Chichester, 311 pp.
40. Botkin, D.B. 1990. *Discordant Harmonies: A New Ecology for the Twenty-first Century*. Oxford University Press, New York, 241 pp.
41. Folke, C., Carpenter, S., Elmqvist, T., Gunderson, L., Holling, C.S. and Walker, B. 2002. Resilience and sustainable development: building adaptive capacity in a world of transformations. *Ambio 31*, 437–440.
42. Walker, B., Carpenter, S., Anderies, J., Abel, N., Cumming, G., Janssen, M., Lebel, L., Norberg, J., et al. 2002. Resilience management in social-ecological systems: a working hypothesis for a participatory approach. *Conserv. Ecol. 6*, Article 14.
43. Rietkerk, M. and Van de Koppel, J. 1997. Alternative stable states and threshold effects in semi-arid grazing systems. *Oikos 79*, 69–76.
44. Schröder, A., Persson, L. and De Roos, M. 2005. Direct experimental evidence for alternative stable states: a review. *Oikos 110*, 3–19.
45. Holling, C.S. 1973. Resilience and stability of ecological systems. *Annu. Rev. Ecol. Syst. 4*, 1–23.
46. Stocking, M.A. and Murnaghan, N. 2001. *Handbook for the Assessment of Land Degradation*. Earthscan Publications Ltd., London, 169 pp.
47. Rasmussen, K., Fog, B. and Madsen, J.E. 2001. Desertification in reverse? Observations from northern Burkina Faso. *Glob. Environ. Change 11*, 271–282.
48. Landres, P.B., Morgan, P. and Swanson, F.J. 1999. Overview of the use of natural variability concepts in managing ecological systems. *Ecol. Appl. 9*, 1179–1188.
49. Pickup, G. 1996. Estimating the effects of land degradation and rainfall variation on productivity in rangelands: an approach using remote sensing and models of grazing and herbage dynamics. *J. Appl. Ecol. 33*, 819–832.
50. Holling, C.S. 2001. Understanding the complexity of economic, ecological, and social systems. *Ecosystems 4*, 390–405.
51. Rockström, J. 2003. Resilience building and water demand management for drought mitigation. *Phys. Chem. Earth 28*, 869–887.
52. Richards, P. 1985. Environmental crisis in Africa: ecology versus political economy? *Afr. Affairs 84*, 486.
53. Bradley, D. and Grainger, A. 2004. Social resilience as a controlling influence on desertification in Senegal. *Land Degrad. Dev. 15*, 451–470.
54. Stamp, D. 1940. The southern margin of the Sahara: comments on some recent studies on the question of desiccation in West Africa. *Geogr. Rev. 30*, 297–300.
55. Aubréville, A. 1949. *Climates, Forests and Desertification of Tropical Africa*. Société de d'Edition de Géographie Maritieme et Coloniale, Paris, 351 pp. (In French).
56. Bradley, P.N. 1997. Foreword. In: *Societies and Nature in the Sahel*. Raynaut, C. (ed). Routledge, London, pp. xiii–xix.
57. Scoones, I. and Toulmin, C. 1999. *Soil Nutrient Budgets and Balances: What Use for Policy?* Managing Africa's Soils, 6. Russell Press, Nottingham, 24 pp.
58. Mortimore, M. and Harris, F. 2005. Do small farmers' achievements contradict the nutrient depletion scenarios for Africa? *Land Use Policy 22*, 43–56.
59. Henao, J. and Baanante, C. 2006. Agricultural Production and Soil Nutrient Mining in Africa: Implications for Resource Conservation and Policy Development.

Summary International Center for Soil Fertility and Agricultural Development IFDC. (http://www.africafertilizersummit.org/Online_Press_Room/Soil%20Nutrient%20Mining%20in%20Africa%20Report%20Final.pdf)
60. Mazzucato, V., Niemeijer, D., Stroosnijder, L. and Röling, R. 2001. *Social Networks and the Dynamics of Soil and Water Conservation in the Sahel*. SA Gatekeeper Series, 101. IIED, London, 24 pp.
61. Scoones, I. (ed). 2001. *Dynamics and Diversity: Soil Fertility and Farming Livelihoods in Africa*. Earthscan, London, 244 pp.
62. Falkenmark, M. and Rockström, J. 2004. *Balancing Water for Humans and Nature: The New Approach in Ecohydrology*. Earthscan, London, 247 pp.
63. Scoones, I. 1996. Transforming soils: the dynamics of soil-fertility management in Africa. In: *Dynamics and Diversity: Soil Fertility and Farming Livelihoods in Africa*. Scoones, I. (ed). Earthscan Publications, London, pp. 1–44.
64. Muchena, F.N., Onduru, D.D., Gachini, G.N. and De Jager, A. 2005. Turning the tides of soil degradation in Africa: capturing the reality and exploring opportunities. *Land Use Policy 22*, 23–31.
65. IYDD 2006. International Year of Deserts and Desertification, 2006. (http://www.iydd.org)
66. Véron, S.R., Paruelo, J.M. and Oesterheld, M. 2006. Assessing desertification. *J. Arid Environ. 66*, 751–763.
67. Batterbury, S. and Warren, A. 2001. The African Sahel 25 years after the great drought: assessing progress and moving towards new agendas and approaches. *Glob. Environ. Change 11*, 1–8.
68. Helldén, U. 1991. Desertification: time for an assessment. *Ambio 20*, 372–383.
69. Hutchinson, C.F. 1996. The Sahelian desertification debate: a view from the American south-west. *J. Arid Environ. 33*, 519–524.
70. Koning, N. and Smaling, E. 2005. Environmental crisis or "lie of the land"? The debate on soil degradation in Africa. *Land Use Policy 22*, 3–11.
71. Such authors as Breman, Ehrlich, Meadows, and Stoorvogel.
72. Such authors as Holling, Gunderson, Mazzucato, Niemeijer, Fairhead, Leach, Scoones, Tiffen, and Anderson.
73. Holling, C.S. 1995. What barriers? What bridges? In: *Barriers and Bridges to the Renewal of Ecosystems and Institutions*. Gunderson, L.H., Holling, C.S. and Light, S.S. (eds). Columbia University Press, New York, pp. 3–34.
74. De Jager, A. 2005. Participatory technology, policy and institutional development to address soil fertility degradation in Africa. *Land Use Policy 22*, 57–66.
75. Gachimbi, L.N., Van Keulen, H., Thuranira, E.G., Karuku, A.M., De Jager, A., Nguluu, S., Ikombo, B.M., Kinama, J.M., et al. 2005. Nutrient balances at farm level in Machakos (Kenya), using a participatory nutrient monitoring (NUTMON) approach. *Land Use Policy 22*, 13–22.
76. Somda, J., Nianogo, A.J., Nassa, S. and Sanou, S. 2002. Soil fertility management and socio-economic factors in crop-livestock systems in Burkina Faso: a case study of composting technology. *Ecol. Econ. 43*, 175–183.
77. Stoorvogel, J.J. and Smaling, E.M.A. 1990. *Assessment of Soil Nutrient Depletion in Sub-Saharan Africa: 1983–2000. Volume I: Main Report*. Winand Staring Centre, Wageninegn, 137 pp.
78. Nandwa, S.M. and Bekunda, M.A. 1998. Research on nutrient flows and balances in East and Southern Africa: state-of-the-art. *Agr. Ecosyst. Environ. 71*, 5–18.
79. Boyd, C. and Slaymaker, T. 2000. *Re-examining the "More People Less Erosion" Hypothesis: Special Case or Wider Trend?* ODI Natural Resource Perspectives, 63. London Oversees Development Institute, London, 13 pp.
80. Siedenburg, J. 2006. The Machakos case study: solid outcomes, unhelpful hyperbole. *Dev. Policy Rev. 24*, 75–85.
81. Kassas, M. 1995. Desertification: a general review. *J. Arid Environ. 30*, 115–128.
82. Conway, D., Mould, C. and Bewket, W. 2004. Over one century of rainfall and temperature observations in Addis Ababa, Ethiopia. *Int. J. Climatol. 24*, 77–91.
83. Nicholson, S.E. 2001. Climatic and environmental change in Africa during the last two centuries. *Clim. Res. 17*, 123–144.
84. Seleshi, Y. and Camberlin, P. 2006. Recent changes in dry spell and extreme rainfall events in Ethiopia. *Theor. Appl. Climatol. 83*, 181–191.
85. Seleshi, Y. and Zanke, U. 2004. Recent changes in rainfall and rainy days in Ethiopia. *Int. J. Climatol. 24*, 973–983.
86. Thurow, T.L. and Taylor, C.A.J. 1999. Viewpoint: the role of drought in range management. *J. Range Manage. 52*, 413–419.
87. Rietkerk, M. 1998. *Catastrophic Vegetation Dynamics and Soil Degradation in Semi-arid Grazing Systems*. Tropical Resource Management Papers, 20. Wageningen University and Research Centre, Wageningen, 153 pp.
88. Rietkerk, M., Dekker, S.C., De Ruiter, P.C. and Van de Koppel, J. 2004. Self-organized patchiness and catastrophic shifts in ecosystems. *Science 305*, 1926–1929.
89. Dekker, S.C., Rietkerk, M. and Bierkens, M.F.P. 2007. Coupling microscale vegetation-soil water and macroscale vegetation-precipitation feedbacks in semiarid ecosystems. *Glob. Change Biol. 13*, 671–678.
90. Vogt, J.V. and Somma, F. (eds). 2000. *Drought and Drought Mitigation in Europe: Advances in Natural and Technological Hazards Research. Vol. 14*. Kluwer Academic Publishers, Dordrecht, 325 pp.
91. McMahon, T.A. and Finlayson, B.L. 2003. Droughts and anti-droughts: the low flow hydrology of Austrailan rivers. *Freshw. Biol. 48*, 1147–1160.
92. Slegers, M.F.W., Zougmoré, R. and Stroosnijder, L. 2005. *Closing the Gap Between Priority Problems for Natural Resource Management in Burkina Faso: Exploring Drought Perceptions of Farmers and Natural Resource Management Institutions*. Erosion, Soil and Water Conservation Group, Wageningen University and Research Centre/ICRISAT, Wageningen, 47 pp.
93. NDMC. 2008. What is drought? Understanding and Defining Drought. National Drought Mitigation Centre. (http://www.drought.unl.edu/whatis/concept.htm)
94. Lloyd-Hughes, B. 2002. The Long-range Predictability of European Drought. (http://forecast.mssl.ucl.ac.uk/docs/BLHThesis2002.pdf)
95. Barron, J. 2004. *Dry Spell Mitigation to Upgrade Semi-arid Rainfed Agriculture: Water Harvesting and Soil Nutrient Management for Smallholder Maize Cultivation in Machakos, Kenya*. PhD Thesis, Department of Systems Ecology, Stockholm University, Stockholm, Sweden. (http://urn.kb.se/resolve?urn=urn:nbn:se:su:diva-98)
96. Graaf, S.v.d. and Breman, H. 1993. Agricultural Production: Ecological Limits and Possibilities. Projet Production Soudano-Sahélienne. (http://www.gcw.nl/kiosk/sahel/RAP3/RAP3A.HTM)
97. Mainguet, M. 1999. *Aridity: Drought and Human Development*. Springer-Verlag, Berlin-Heidelberg, 302 pp.
98. Janssen, B.H., Guiking, F.C.T., Van Der Eijk, D., Smaling, E.M.A., Wolf, J. and Van Reuler, H. 1990. A system for quantitative evaluation of the fertility of tropical soils (QUEFTS). *Geoderma 46*, 299–318.
99. Knecht, M.R. and Göransson, A. 2004. Terrestrial plants require nutrients in similar proportions. *Tree Physiol. 24*, 447–460.
100. Zingore, S., Murwira, H.K., Delve, R.J. and Giller, K.E. 2007. Influence of nutrient management strategies on variability of soil fertility, crop yields and nutrient balances on smallholder farms in Zimbabwe. *Agric. Ecosyst. Environ. 119*, 112–126.
101. Hatibu, N. and Mahoo, H. 1999. Rainwater harvesting technologies for agricultural production: a case for Dodoma, Tanzania. In: *Conservation Tillage with Animal Traction*. Kaumbutho, P.G. and Simalenga, T.E. (eds). ATNESA, Harare, pp. 161–171.
102. Knowler, D. and Bradshaw, B. 2007. Farmers' adoption of conservation agriculture: a review and synthesis of recent research. *Food Policy 32*, 25–48.
103. Stroosnijder, L. and Koné, D. 1982. The balance of soil water. In: *The Productivity of Sahel Pasture: Study of Soils, Vegetation and Exploitation of These Natural Resources*. Penning de Vries, F.W.T. and Djitèye, M.A. (eds). Pudoc, Wageningen, pp. 133–165. (In French).
104. Rockström, J. 2003. Water for food and nature in drought-prone tropics: vapour shift in rain-fed agriculture. *Philos. Trans. R. Soc. Lond. B Biol. Sci. 358*, 1997–2009.
105. Barron, J., Rockström, J., Gichuki, F. and Hatibu, N. 2003. Dry spell analysis and maize yields for two semi-arid locations in east Africa. *Agr. Forest Meteorol. 117*, 23–37.
106. We acknowledge Jan de Graaff and Peter de Ruiter for reading a previous version of the manuscript and the three referees and the Associate Editor of this journal for their critical reviews and valuable comments.
107. First submitted 19 July 2007. Accepted for publication 13 February 2008.

Monique F. W. Slegers is a PhD student in the Erosion and Soil & Water Conservation Group at Wageningen University. She has an MSc in Rural Development Sociology. Her PhD study is about farmers' perception of drought and their vulnerability to drought and is performed in Tanzania and Ethiopia. Her address: Department of Environmental Sciences, Wageningen University, 6708 PB Wageningen, The Netherlands.
E-mail: monique.slegers@wur.nl

Leo Stroosnijder is a professor in the Erosion and Soil & Water Conservation Group at Wageningen University. He holds a PhD in Soil Physics. His fields of expertise are: soil and water conservation, system analysis, agronomic modeling, land use planning and policy. His address: Department of Environmental Sciences, Wageningen University, 6708 PB Wageningen, The Netherlands.
E-mail: leo.stroosnijder@wur.nl

