Journal of Arid Environments xxx (2014) 1–8

Contents lists available at ScienceDirect

Journal of Arid Environments

journal homepage: www.elsevier.com/locate/jaridenv

Achieving Zero Net Land Degradation: Challenges and opportunities

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ARTICLE INFO

Article history:
Received 3 July 2013
Received in revised form
24 December 2013
Accepted 27 January 2014
Available online xxx

Keywords:
Best management practices
Desertification
Polluter pays principle
Soil degradation severity
Soil organic carbon
Soil quality index

ABSTRACT

Land degradation is extensive, covering approximately 23% of the globe's terrestrial area, increasing at an annual rate of 5–10 million ha, and affecting about 1.5 billion people globally. Such detrimental processes call for urgent and comprehensive action to halt land degradation. In this paper, we assess the causes and extent of land degradation around the world, followed by an outline of the various challenges in implementing a global Zero Net Land Degradation (ZNLD) policy. The concept of ZNLD proposes a scheme under which the extent of global degraded lands will decrease or at least, remain stable. To enable this type of scenario, the rate of global land degradation should not exceed that of land restoration. Restoration efforts should include not only croplands, rangelands, and woodlands, but also natural and semi-natural lands that do not generate direct economic revenues. The United Nations Convention to Combat Desertification (UNCCD) envisages achieving this target by 2030. Despite being seemingly ambitious, the target of ZNLD could be achieved if degraded lands are restored to a considerable extent and, at the same time, land-degrading management practices are replaced with ones that conserve soils. To enable effective implementation of these steps, it is necessary to formulate a ZNLD Protocol aimed at managing assessment actions and maintaining of supportive policies and regulations. Restoration projects could be financed through payments for improving ecosystem services, as well as other economic mechanisms. Achieving the target of land degradation neutrality would decrease the environmental footprint of agriculture, while supporting food security and sustaining human wellbeing.

1. Introduction

Land degradation is defined as the reduction of biological productivity and the decrease in the complexity of terrestrial ecosystems (Lal et al., 2012). Processes of land degradation occur in all climatic regions, with 'land' interpreted to include soils, vegetation, and water, and with the concept of 'degradation' implying adverse consequences for humanity and ecological systems (Conacher, 2009). Overall, land degradation affects about 1.5 billion people globally (Gnacadja, 2012b).

Among the above-mentioned 'land' components, the soil is a major source of terrestrial net primary productivity (NPP), the reservoir of the gene pool, the sink of atmospheric carbon, and the reservoir of plant nutrients (German Federal Environment Agency, 2011). Specific types of soil degradation include erosion caused by wind or water, and deterioration of the physical, chemical, and biological properties of soil (Lal et al., 2012). Degraded soils are less able to support vegetation production (Gisladottir and Stocking, 2005). Hence, vegetation is among the first elements to be adversely affected in degraded ecosystems. This loss of native vegetation directly threatens a range of ecosystem processes and services. Soil degradation has been caused by human activities (Conacher, 2009; Zalibekov, 2011), natural factors, or a combination of both (Gisladottir and Stocking, 2005).

Agricultural activities are a major cause of environmental change, altering land productivity, water cycles, drought patterns, the amount of greenhouse gases (GHGs) in the atmosphere (Stavi and Lal, 2013), and biodiversity. Specifically, land resources have come under increasing pressure from competing usages for agriculture, forestry, and pasture, as well as energy production and extraction of raw materials (UNCCD, 2012). Since land degradation processes reduce the rate of carbon sequestration and increase GHG emissions, it is less likely that GHG reduction targets will be met. Also, since land degradation results in loss of productivity, and hence reduced food provision, global food security targets will be

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http://dx.doi.org/10.1016/j.jaridenv.2014.01.016
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Please cite this article in press as: Stavi, I., Lal, R., Achieving Zero Net Land Degradation: Challenges and opportunities, Journal of Arid Environments (2014), http://dx.doi.org/10.1016/j.jaridenv.2014.01.016

missed if land degradation is not successfully addressed (Lal et al., 2012).

Despite being a global phenomenon, the degradation of land has occurred to a much greater extent in drylands, where land is highly vulnerable to degradation due to aridity and water scarcity, than in non-drylands (UNCCD, 2012). Home to 38% of the world's population (2.7 billion people), drylands make up 44% of the world's cultivated lands, and account for 50% of its livestock (Gnacadja, 2012b). Therefore, drylands are the key to supporting habitats, crops, and livestock that sustain most of the global population (UNCCD, 2012). On a global scale, Africa is the region most vulnerable to desertification processes; over 45% of Africa is affected by desertification, and of this area, 55% is at high, or very high, risk of further degradation. If this trend continues, two-thirds of Africa's arable land could be lost by 2025 (UNCCD, 2011b).

The percentage of the world land area prone to serious drought more than doubled between the 1970s and the early 2000s, and the world is facing the possibility of widespread droughts in the coming decades (Lee, 2011). Even though droughts occur globally with different intensities and frequencies, their impact depends on the level of social, economic, and environmental vulnerability in the affected area. Specifically, droughts impose threats to rural livelihoods in developing countries, including many countries in Africa and central Asia, where unfavorable biophysical conditions meet with weak socio-economic infrastructures (UNCCD, 2011a). Elsewhere, the recent extreme droughts affecting western Asia and Eastern Europe have caused wheat harvests to decline in Russia and Ukraine by approximately 33% and 19%, respectively, severely diminishing the worldwide wheat supply, and doubling global wheat prices in less than a year. Additionally, in some northern African and Middle Eastern countries, the steep rise in the cost of food has fueled political instability (Sternberg, 2011). For example, the extreme drought in the Eurasian steppe in 2010–2011 resulted in diminished global wheat stocks, and considerably increased wheat prices. Egypt, with its import-dependent wheat market, faced an immediate and steep rise in the price of wheat, causing economic dissatisfaction and social unrest among many of its citizens (Sternberg, 2012).

The growth of the human population and increasing demands for food, water, and energy are expected to dramatically augment pressure on lands (Conacher, 2009). By 2030, the demand for food is projected to grow by 50%, and that of water and energy by 40% each, compared to present levels (Gnacadja, 2012b). The exponential increase of human population calls for a sustainable development that would help meet these future food, water, and energy challenges in an integrated way, and which would ensure efficiency, build resilience, and support social inclusiveness (UNCCD, 2012).

The concept of Zero Net Land Degradation (ZNLD), or land degradation neutrality, was first formally mentioned in 2011, by the president of the United Nations Convention to Combat Desertification (Lee, 2011; UNCCD, 2011a). This concept encompasses two complementary mechanisms: appropriate management of currently non-degraded lands in ways that do not cause degradation, thus halting further loss, and at the same time, restoring already-degraded lands (Gnacadja, 2012b). If the continuing loss of fertile lands is offset by the restoration of already-degraded lands, and the annual rate of reclamation equals that of degradation, then a ZNLD is attained, and the area of global fertile land remains stable (Gnacadja, 2012b). According to this concept, the restoration efforts would ideally be in the same landscape, the same type of ecosystem, and would serve the same community where land degradation has occurred (Gnacadja, 2012a).

The UNCCD set a target of achieving ZNLD by 2030 (Lal et al., 2012). Thus far, however, the conceptual framework of the ZNLD remains unclear, as it includes only a general idea, excludes many relevant aspects, and lacks concrete steps for implementation. Specifically, the types of land-uses and management practices to be included under the ZNLD have not yet been fully addressed. For example, while it is clear that croplands, rangelands, and woodlands are directly addressed under the ZNLD, the restoration of degraded natural or semi-natural lands that do not generate direct economic revenues has not been covered under this framework. Also, the specific means and practices for land conservation and restoration have not been thoroughly discussed under the ZNLD concept. Therefore, the objective of this study is to highlight some of the aspects that are either obscure, or have not been clearly addressed under the ZNLD conception. In addition, this study addresses the urgent need for policy, management, regulations, and funding of projects, aimed at facilitating the monitoring of degradation processes and the restoration of degraded lands.

2. Global land and soil degradation

2.1. *Types of soil degradation*

In the early-1990s, the extent of all degraded lands encompassed a total of 36 × 10^8 ha globally (Dregne and Chou, 1994). The main types of soil degradation, including water erosion, wind erosion, physical degradation, and chemical degradation, encompassed, at that time a land area of 10.9 × 10^8 ha, 5.5 × 10^8 ha, 2.4 × 10^8 ha, and 0.8 × 10^8 ha, respectively (Oldeman, 1994). Recent estimations of land degradation indicate that 3.5 billion ha – 23% of Earth's land area – have been affected by some type and severity of degradation, the annual rate of which is estimated at 5 to 10 million ha (Lal, 2012).

Over and above the adverse effects of numerous other processes, accelerated erosion is of special importance. Simulations of historical changes that tracked potential soil erosion from 1901 to 1980, revealed an increasing trend during this period. Such a trend has been found in all continents except Europe. Overall, human activity has increased soil erosion in most parts of the world to rates ranging between 8 and 90%. Globally, soil erosion has increased during this period by approximately 60% due to human activity (Yang et al., 2003). The global average value of potential erosion at the beginning of the 21st century was estimated at 10.2 ton ha^{-1} $year^{-1}$, and global loss of soil through erosional processes has been estimated at ranging between 24 (Lee, 2011) to 75 billion tons of fertile soil (Gnacadja, 2012b).

Salinization and sodification of soils are also widespread, occurring in all climatic regions, and are caused by natural conditions, human activities, or a combination of the two (European Soil Portal, 2009). Most human-caused soil salinization and sodification is found in croplands and results from the use of saline underground water for irrigation and the utilization of flood irrigation in the valleys of large river basins. In addition, salinization also occurs in the soils of coastal aquifers and of dryland farming systems due to saline seepage. Altogether, approximately one billion ha of land have saline or sodic soils (Squires and Glenn, 2010).

Soil pollution is also widespread. Sources of pollution can vary, including contaminants from households, agriculture, and industry. Contaminants encompass several types, such as heavy metals, polycyclic aromatic hydrocarbons (PAHs), and dioxins (Turner, 2009). Specific examples for agriculture-derived pollution are the contamination of surface water and groundwater with nutrients and chemicals; the emission of substances, such as ammonia and particulates into the air; and the pollution of soils with remnants of fertilizers, pesticides, and herbicides (Grossman, 2007). Soil contamination risks include plants absorbing contaminants through the soil; groundwater becoming contaminated as it

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interacts with and flows beneath the soil; and bioaccumulation, occurring when livestock or humans ingest contaminants from vegetation growing in contaminated soil (Turner, 2009).

Depletion of soil organic carbon (SOC) is another specific type of degradation, resulting in decreased soil quality and fertility (Lal et al., 2012). It has been reported that after land-use conversion, some croplands have lost one-half to two-thirds of their original SOC pool, with a cumulative loss of 30–40 tons of carbon ha^{-1} (Lal, 2004). Specifically, erosion eliminates large amounts of SOC from agro-ecosystems' topsoil. Whether emitted to the atmosphere as carbon-dioxide (CO_2) (Lal and Pimentel, 2008), buried in off-site terrestrial depressions, or deposited in aquatic bodies (Harden et al., 2008), the on-site, smaller concentrations of SOC decrease the soil's quality and productive capacity (Stavi and Lal, 2013).

2.2. *Assessing land/soil degradation*

Producing a global assessment of land and soil degradation is a challenging task. For example, different data sets reveal wide variations because of the different methods and criteria used to estimate degradation processes. Therefore, a uniform criteria and standard methodology to assess land degradation are of high importance. Also, an appropriate assessment of degradation is crucial for choosing an application suitable for restoration efforts (Eswaran et al., 2001).

One of the most effective tools used to assess land and soil degradation is that developed by the Food and Agriculture Organization (FAO), which combines measures of both 'land' and 'soil'. This tool includes the following components:

- Type of soil degradation, traditionally considered as one of the following: water erosion, wind erosion, chemical deterioration, or physical deterioration (FAO, 1999). In addition, it is emphasized that the depletion of SOC should also be considered as a specific type of soil degradation (Lal and Pimentel, 2008; Stavi and Lal, 2013).
- Degree of soil degradation, defined in terms of reductions in land productivity: light (somewhat reduced productivity); moderate (greatly reduced agricultural productivity); strong (biotic functions largely destroyed; non-reclaimable); or extreme (biotic functions fully destroyed, non-reclaimable) (FAO, 1999).
- Relative extent of land degradation, as a percentage of the land-unit affected: 0–5%; 5–10%; 10–25%; 25–50%; and 50–100% of land-unit affected.
- Causative factors of land degradation: deforestation; overgrazing; agricultural activities; overexploitation of vegetation; or industrial activities (FAO, 1999).

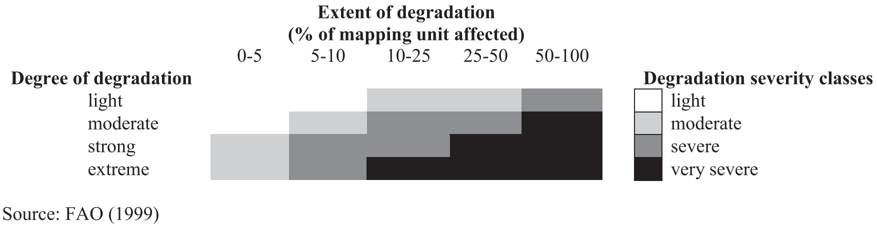
Degradation severity is obtained by combining the degree of degradation with its spatial extent. With four classes for degree, and five for extent, twenty combinations are possible. These are grouped into four degradation severity classes: light; moderate; severe; and very severe (Fig. 1). A very severely degraded area can mean, for example, extreme degradation affecting 10–25% of a land-unit, or moderate degradation affecting 50–100% of the unit (FAO, 1999). Applying this procedure has yielded an inclusive summary of the state of land degradation severity by region (Table 1). This table shows, for example, that at the end of the 20th century, approximately 90% of the terrestrial area of Europe was degraded to some degree. It is emphasized that under the ZNLD policy schemes, data collection should be ongoing in order to enable a regular update regarding the status of land degradation at local, regional, and global levels.

2.3. *Monitoring changes in soil quality indicators*

As discussed above, soil quality is a major component affecting the productive capacity of lands. Overall, soil quality is defined as the capacity of the soil to function within natural or managed ecosystem boundaries, sustain plant and animal productivity, maintain or improve water and air quality, and support human health and habitation. Useful indicators are those that are sensitive to change and respond to management. Assessment of soil quality starts with the setting of a standard baseline value, or reference value to be used for comparison. Some indicators can be tested on-site and with simple tools, while others require more complex field tests, or sophisticated laboratory analyses. Assessments can be made to help identify areas of special interest, or for comparing land-units under different management practices (NRCS, 2001).

There are different ways of evaluating and scoring soil quality parameters. In most of them, the overall score is partitioned into physical, chemical, and biological components. Criteria can be weighted according to the relative importance of a given indicator, and its relationships with other indicators. Under some of the methods used to evaluate soil quality, SOC is treated as a separate component because of its importance in controlling the potential productive capacity of soil (Desta, 2004). The type and number of indicators used depends on the scale of the evaluation (i.e., field, farm, watershed, or region) and the soil functions of interest. For example, water infiltration rate and soil aggregate stability help indicate the capacity of the soil to retain water and resist runoff and erosion. Changes in SOC, including active SOC or particulate SOC, may indicate changes in potential productive capacity. Increased soil bulk density may reflect limits to root growth, seedling emergence, and water infiltration (NRCS, 2001).

To evaluate soil quality, indicators can be assessed at a single point in time, or, preferably, monitored over time, enabling the identification of changes or trends in the functioning of soil. Monitoring can be used for determining the success of management practices or the need for additional management adjustments (NRCS, 2001). However, the inherent differences among soils, the complexity of environments within which soils exist, and the variety of management practices, complicate the establishment of a



Extent of degradation
(% of mapping unit affected)

Degree of degradation	0-5	5-10	10-25	25-50	50-100
light	□	□	░	░	▒
moderate	□	░	▒	▒	■
strong	░	▒	▒	■	■
extreme	░	▒	■	■	■

Degradation severity classes
□ light
░ moderate
▒ severe
■ very severe

Source: FAO (1999)

Fig. 1. Land degradation severity classes.
Source: FAO (1999).

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Table 1
Land degradation severity by region (% of area by severity class).

	Light	Moderate	Severe	Very severe	Total degraded lands
Sub-Saharan Africa	24	18	15	10	67
North Africa & Middle East	17	19	28	7	71
Asia & Pacific	12	32	22	7	73
North Asia	14	12	17	4	47
South & Central America	27	23	22	5	77
Europe	21	22	36	12	91
North America	16	16	16	0	48

Modified from FAO (1999).

specific rating against which all soils can be compared. Therefore, an elaborate indexing procedure is needed to enable such comparisons among different soils (Karlen et al., 2003).

3. Agricultural lands versus natural ecosystems

Degradation of agricultural lands is one of the major threats to the future of humankind (Oldeman, 1998). The degradation of these lands would not only decrease food production, but would also alter the provision of other services essential for human well-being, including regional and global climate regulation, and habitats for biodiversity (Lee, 2011). Therefore, ZNLD addresses the degradation of environmental and ecosystem services related to agricultural activities. Yet, under the current scope of ZNLD, only 'agricultural' lands, including croplands, rangelands, and woodlands, would be considered for conservation and restoration efforts. At the same time, the ZNLD discussions have not addressed the degradation of environmental and ecosystem services in natural or semi-natural lands that do not provide direct economic revenues. For example, the ZNLD does not consider open or natural spaces that have not been used for crop production, livestock grazing, fuelwood collection, or the logging industry. Obviously, the most relevant land-uses are open public lands that are considered to be nature reserves, protected habitats, or merely unused lands. Degradation of natural and semi-natural lands can be caused by several factors, including military training exercises that lead to harsh ecological perturbations (Wilcox et al., 2012), illegal disposal of domestic or industrial wastes and pollutants (Kawamoto and Urashima, 2006), mining activities (Shrestha and Lal, 2011), earthworks, and other infrastructural works that severely damage the ground surface or modify natural water courses (Ward and Rohner, 1997).

The ZNLD's disregard of non-agricultural lands excludes the possibility of resources being allocated towards their restoration. It is therefore stressed that restoration of degraded natural or semi-natural, open, public, and non-used lands should be regarded in a similar manner to that of agricultural lands. Yet, an important, unanswered question is how to fund restoration of these lands. Obviously, the inclusion of these lands under the ZNLD target would require far greater resources.

4. Specific, promising conservation and restoration practices

4.1. Tillage practice and crop residue management

A common means of sustaining the soil quality and productive capacity of croplands is through the management of tillage intensity and crop residues. In terms of tillage, the lower the intensity, the smaller the disturbance to the structure of the uppermost soil layers. If implemented concomitantly with the retention of crop residues on the ground surface, then reduced tillage or no-till (NT) systems would decrease raindrop impact, lessen aggregate slaking and clay dispersion, and protect the soil against water and wind erosion. The retention of residues also increases water infiltration and decreases evaporation loss, favoring crop yields where water availability is a limiting factor for productivity. In addition, the resultant increase in SOC concentration further improves the structure formation and stability of the soil (Govaerts et al., 2007), and augments soil health. In many cases, competing needs for the crop residues, such as feed for livestock, fuel for domestic cooking or heating, or construction materials, necessitate its removal from the fields (Huggins and Reganold, 2008). In general, crop residues are also extensively utilized as feedstocks for the emerging bioenergy industry. Either way, the elimination of crop residues from the field's surface aggravates soil erosion and degradation (Lal and Pimentel, 2009), and therefore, must be minimized.

4.2. Plant nutrient management

One of the major environmental concerns in agricultural lands relates to nutrient management. Plant nutrients could be returned to the soil through either organic-based amendments, such as livestock manure or compost, or mineral fertilizers. However, these organic or chemical soil-additives are highly prone to spatial (over-the-ground surface) and vertical (through the soil profile) redistribution, imposing a risk of pollution and eutrophication of above- and below-ground water sources (Franzleubbers et al., 2007; Isermann, 1990). Also, these amendments could emit large amounts of GHGs, including CO_2 and nitrous oxide (N_2O), to the atmosphere (Aneja et al., 2009; Matsumoto et al., 2008). Several studies have demonstrated that the use of biochar — the solid byproduct of the pyrolysis process for the production of bioenergy — as a soil amendment increases the non-decomposable fraction of SOC, resulting in smaller emissions of CO_2 from soil (e.g., Lehmann, 2007). At the same time, the biochar increases the water-holding capacity of soil (Laird et al., 2010) and its cation exchange capacity (CEC) (Glaser et al., 2002), augmenting the crop's access to water and nutrients. The greater retention of water and nutrients in the rhizosphere increases the use efficiency of irrigation and fertilizer, lowering the need for these agronomic inputs, and decreasing the off-site and on-site environmental footprints of agriculture.

4.3. Agro-forestry

In terms of soil erosion control, one of the most efficient means is the breaking of the spatial consecutiveness of slopes. This may be implemented by either constructing earth structures, such as contour-based terraces (Lal, 1997), or maintaining vegetation buffer strips that encompass herbaceous (Jacinthe et al., 2009) or woody plants (Wray, 2004). With reference to the deliberate combining of trees or shrubs in croplands, specific practices of agro-forestry systems could sustain a range of agronomic and environmental benefits. For example, such systems could provide food for human consumption, fodder for livestock, and timber for building. At the same time, these systems sustain many ecosystem services, such as increasing species diversity, enhancing wildlife habitats, fostering natural food webs, improving ecosystem health, and augmenting carbon sequestration.

Specifically, agro-forestry systems are considered to be an efficient means of restoring degraded lands (Nair et al., 2010). The use of trees and shrubs in reforestation and afforestation systems has proved to efficiently restore the productive capacity of degraded lands by controlling erosional processes and sequestering large amounts of carbon in soils, root systems, and canopies (Behan and Misek, 2008). Specifically, forestry systems have been successfully used to restore heavily-salinized croplands (e.g., Hbirkou et al., 2011).

4.4. Restoring degraded rangelands

Several management practices could be used for restoring degraded rangelands. The most obvious is controlling livestock pressure to prevent overstocking and avoid damage to vegetation and soil (Coughenour, 1991). More drastic interventions could include contour ripping (Wilcox et al., 2012) or other modifications of the ground surface meso-topography (Shachak et al., 1998). Another means of rangeland restoration includes the use of organic soil-amendments, such as composted dairy manure (Wilcox et al., 2012) or biosolids from waste-water treatment (Moffet et al., 2005), aimed at improving the soil's physical and chemical qualities, and increasing its productive capacity. In addition to these soil additives, utilizing biochar in degraded rangelands can improve soil characteristics and increase NPP, and, at the same time, sequester large amounts of carbon over the long term in these agro-ecosystems (Stavi, 2012).

5. Formulating the ZNLD mechanism

5.1. Management and regulations

The overall increase in pressures on lands and soils require, at the highest priority, the formulation of a specific ZNLD Protocol (Lal et al., 2012). Monitoring the pace towards achieving the ZNLD targets requires means of assessing levels of land degradation and restoration (German Federal Environment Agency, 2011). Yet, some challenges related to the mode of data monitoring and management, remain unresolved. For example, land degradation is not a static, but rather, a dynamic process. Therefore, monitoring of rates, causes, and effects of land degradation should be continuous, and sequential updates are required (Cherlet, 2012). Also, for better targeted investments, these monitoring and assessment efforts should aim at quantifying the costs, benefits, and impacts of sustainable land management on food security, water availability, and climate change mitigation (Gnacadja, 2012a). This would enable the promotion of scientific study, legal protection, and policy responses on a global basis. Providing the most innovative technologies, the ZNLD mechanism could produce a comprehensive and dynamic report on the state of world lands in order to overcome existing gaps in scientific knowledge and to provide policy makers, land managers, and other stakeholders with better information and scientific advice for land management (German Federal Environment Agency, 2011). At the highest priority, measurements, monitoring, and verification of land status on different temporal and spatial scales should be conducted on benchmark sites in global hot spots of degradation (Fig. 2), such as sub-Saharan Africa (Lal, 2012). This mechanism would require a scientifically credible, transparent, and independent assessment of land status. Also, recommendations should be policy-relevant, but not policy-prescriptive, and would be provided by a globally-agreed-upon, strong and effective science–policy interface (Lee, 2011).

To deal with these challenges, policy makers have to set up ambitious, but attainable goals for ZNLD. Also, a strong international framework, addressing land degradation, is needed to ease global action (UNCCD, 2012). This would enable the authorization of an international legal mechanism committed to land and soil issues, which would allow for political support to strengthen the current weak and fragmented international structures advocating land and soil issues (Lee, 2011). This mechanism would empower farmers, herders, and foresters to protect and restore lands through improved access to technologies and finance tools (Gnacadja, 2012a).

To ensure maximum efficiency and cost-effectiveness, this mechanism would have to include cooperation with stakeholders from a range of international institutions. Considering effective and synergic efforts, the appointed mechanism could achieve the ZNLD target by the year 2030 (Lal et al., 2012), while promoting food security, enhancing ecosystem services, eradicating poverty, eliminating malnutrition, and increasing economic, social, and cultural sustainability (German Federal Environment Agency, 2011).

5.2. Financing of projects

5.2.1. Essential considerations

A comprehensive assessment of land degradation is needed, specifically in order to increase public awareness of its economic consequences. Also, translating economic knowledge into tools to support improved policy-making and practices in land management is crucial (UNCCD, 2011b).

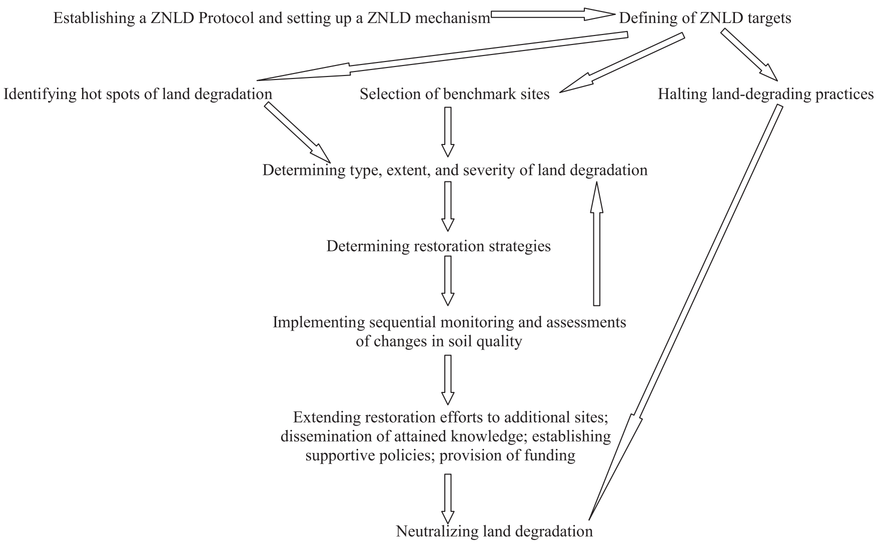

Fig. 2. Flow chart of the implementation of the ZNLD steps.

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Because land degradation processes take place over time, intertemporal considerations would characterize farmers' decisions related to land-use and management. Hence, the benefits derived from using lands need to be maximized over time, and farmers must continuously choose between land-degrading and land-conserving practices. From an economic perspective, the profits derived from implementing land-degrading practices are continuously compared with the potential benefits that could be derived from the adoption of land-conserving practices. A rational farmer will let degradation take place until the benefits from adopting conservation practices equal the costs of allowing further degradation to occur. From the farmer's point of view, yield decline due to land degradation would be that threshold. However, from society's viewpoint, all – both on-site and off-site – costs should be considered in order to yield an "optimal" social rate of land degradation (Nkonya et al., 2011). These costs include the deterioration of a range of ecosystem services, such as a lower rate of carbon sequestration, lesser hydrological conductivity, greater soil erosion, off-site pollution of water sources, and decreased biodiversity (Dale and Polasky, 2007).

An approach of payments to land managers for provisioning of ecosystem services is an important strategy toward the adoption of recommended management practices (Lal, 2012). This approach is economically rational, a market-based mechanism for sustainable environmental management. Since land degradation is expressed by a decline in productivity, which is caused by degradation of ecosystem services, this mechanism can be an appropriate tool in preventing land degradation and promoting the restoration of degraded lands. Yet, the flow of ecosystem services may cross boundaries at various scales, from farm to district, national, regional, and even global. Therefore, beneficiaries of ecosystem services are often located away from the ecosystem that provides the services. These services, therefore, carry a status of 'public goods.' Yet, if the provision of services is intentionally increased by the owner of the providing ecosystem, then the beneficiaries have to pay the owner an amount that at least covers the involved costs. This market-based payment tool can be used either as economic incentives, or as performance payments. The latter can be made conditional on achieving well-defined goals (Lal et al., 2012).

Yet, payments for providing ecosystem services are not the sole condition for halting degradation processes and adopting restoration practices. For example, government policies and other institutional factors can lead to either privately or socially non-optimal rates of land degradation. Also, uncertainties about the future benefits of conservation measures reduce farmers' motivation to adopt them. For example, lack of information about future damage caused by land degradation, the unclear state of land-tenure rights, distorted or volatile market prices, and the absence or weakness of credit markets are among the factors that could inhibit farmers from investing in soil conservation practices (Nkonya et al., 2011). Therefore, full access to information, transparent land-tenure policies, and easy market entry are essential for encouraging farmers to adopt conservation practices (Rinaudo, 2012).

A possible mode of tackling the financing of land conservation and restoration is by comparing the costs and benefits of action (i.e., halting degradation or restoration of degraded lands) versus the cost of inaction (i.e., "business-as-usual"). An appropriate economic tool for a systematic comparison of all costs and benefits of land-degrading practices versus land-conserving practices is the cost-benefit-analysis, which can be used to discount costs and benefits to come up with a comparable value, based on the assumption that the values become smaller the more distant they are into the future. This procedure makes future costs and benefits comparable by using the present net value of investments in conservation measures versus continued degradation. The present net value is the discounted net benefit gained or the net cost imposed. Sensitivity analysis allows coping with uncertainties by analyzing the sensitivity of results to variations in the risk factor (Nkonya et al., 2011).

5.2.2. The polluter pays principle

Restoring degraded lands is potentially expensive, requiring high costs for its implementation. Under certain conditions, liability for restoration could be easily imposed on a clearly-defined entity that is responsible for the degradation of lands, such as mining companies, industrial factories, or military forces. In other cases, where the factors causing the damage are obscure, securing funding for restoration activities could be more challenging.

The polluter pays principle (PPP) is interpreted as involving both cost allocation and cost internalization. As a principle of cost allocation, the PPP addresses the question of "who pays" for pollution prevention and control (Tobey and Smets, 1996), and requires polluters to bear the expense of preventing, controlling, and cleaning up pollution (Grossman, 2007). As a principle of cost internalization, the PPP seeks to improve economic efficiency by internalizing the external environmental costs of production and consumption into market prices. This raises the question of what environmental costs and "how much" should be paid. Since its adoption by the Organization for Economic Cooperation and Development (OECD) in 1972, the PPP has become an important component of environmental policy (Tobey and Smets, 1996). Though the PPP originated as an economic principle, since the 1990s it has been recognized internationally as a legal principle. Subsequently, the PPP has played further important roles in national and international environmental policies (Grossman, 2007).

In its early stages, the PPP was mainly directed at the industrial sector, and there was little discussion regarding the application of its principles to agriculture and other non-point pollution sources. Since the 1990s, the application of the PPP to agriculture has received increasing attention (Tobey and Smets, 1996). Nonetheless, applying the PPP to agriculture has been difficult to date, due to the nature of this sector. For example, in many countries, environmental laws do not require agricultural producers to internalize all pollution costs. In other cases, environmental subsidies to agriculture could interfere with the allocation of these costs. During the last decade, however, several countries have enacted stricter environmental regulations, aimed at making the PPP cover the pollution of soil, water, and air resources resulting from agricultural activities (Grossman, 2007).

Recently, several developing countries in Asia, Africa, and South America have adopted a variation of the PPP through judicial, legislative, and constitutional reforms focused on the mitigation of environmental harm through governmental liability. This new scheme guarantees compensation for victims when polluters cannot be identified or are insolvent. Redesigning the original rationale of the PPP, this scheme suggests that the primary aim is to provide prompt compensation to the victims of environmental damage, and only secondarily to impose liability on the responsible parties. In many cases, this "government-pays" concept has resulted in governments being quite responsive to the threat of direct liability, considerably increasing their motivation to monitor and prevent risks of pollution in order to avoid financial costs associated with these environmental issues. Specifically, this scheme is preferable in situations characterized by widespread poverty and judicial uncertainty (Luppia et al., 2012).

It is consequently stressed that the PPP should not only cover pollution of soil, water, and air resources, but also on-site and off-site losses in the quality and potential productivity of soils due to physical deterioration, erosion, water logging, salinization, and SOC depletion. Also, different types of land degradation, including detrimental modifications to water channel courses, infestation of

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exotic plant species, and loss of biodiversity, should also be covered under this scheme. If properly managed, the PPP could considerably augment capacity to finance project that restore degraded soils and lands, increasing the likelihood of achieving the target of ZNLD by 2030.

6. Conclusions

Extensive soil and land degradation has been caused by natural factors and human activities. Urgent action is needed to halt degradation processes and restore degraded lands. Despite the fact that scientific knowledge and technology exists, much of it is fragmented and non-consensual. Therefore, authoritative, frequent assessments of type, degree, extent, and causative factors of soil and land degradation are crucial. Standardized methodology is also needed to assess the key soil/land attributes, aimed at evaluating the effectiveness of restoration measures. An accepted mechanism should be formulated in order to lead efforts of land degradation neutrality on a global scale. Considering effective international collaborations, such a mechanism could effectively disseminate practical knowledge about restoration practices, and make sure that governments promote and support sustainable land-use for the benefit of humankind. Under such a scenario, setting a 2030 target of ZNLD could be achievable. However, the related challenges outlined must be systematically and effectively addressed.

Acknowledgments

The authors gratefully acknowledge three anonymous reviewers, whose comments resulted in a considerable improvement of a previous version of the manuscript.

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Please cite this article in press as: Stavi, I., Lal, R., Achieving Zero Net Land Degradation: Challenges and opportunities, Journal of Arid Environments (2014), http://dx.doi.org/10.1016/j.jaridenv.2014.01.016

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Please cite this article in press as: Stavi, I., Lal, R., Achieving Zero Net Land Degradation: Challenges and opportunities, Journal of Arid Environments (2014), http://dx.doi.org/10.1016/j.jaridenv.2014.01.016