A Synthesis of Restoration Practices for Degraded Croplands in Dryland Regions

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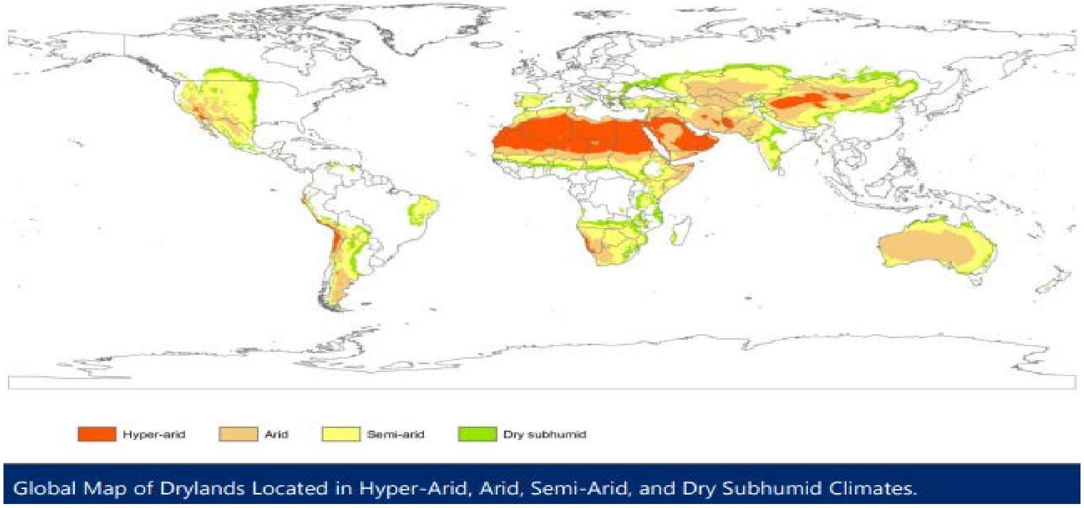
Table of Contents

1.0 Executive Summary

Drylands are areas where rainfall is scarce and highly variable; thus, water is a limiting factor for agriculture and droughts. These are areas where precipitation is balanced by evaporation and evapotranspiration. According to the United Nations Environment Program, drylands in tropical and temperate regions have an aridity index of less than 0.65. Drylands are significant providers of ecosystem goods and services to almost one-third of the global population and support over 2 billion people across the globe. Drylands are comprised of arid, semiarid and semi-humid ecosystems and have a significant role in global food and nutrition security, as 44% of the world's cultivated systems are located in drylands. Drylands contain a diversity of climates, soils, water resources (surface & groundwater) and geological formations. These ecosystems are very susceptible to degradation. Global estimates indicate that 10-20% of drylands are already degraded and about 20 million hectares continue to be degraded each year.

Restoration of degraded croplands are needed to ensure the sustainability of rainfed agriculture, and, thus food security, to meet the growing demands for food, fibre and shelter. Unsustainable agricultural techniques, land and water use, and climate change impacts are the main drivers for the degradation of drylands, which has resulted in the decline of ecosystem services, food insecurity, social and political instability. It has reduced ecosystem resilience to climate variability. The typical rehabilitation measures for restoration of degraded agricultural land are achieved through using agronomic and biological techniques, such as crop rotation, agroforestry, cover crops, vegetative filter strips, residue, and zero or reduced tillage. Although the need to restore drylands is recognized and significant resources have been allocated to these activities, rates of restoration success remain low (James et al., 2013). This report argues the need for a more holistic approach to restoration croplands in dryland regions by incorporating agronomic, ecological, social and economic methodologies.

This study evaluates and provides recommendations for significant gains and successes that have been made by governments, local communities, non-governmental organizations, the scientific and research community, as well as other stakeholders. This project identifies the challenges in the restoration of drylands and suggests recommendations for dryland restoration.



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2.0 Introduction

Drylands are characterized by water scarcity, seasonal climate extremes, and unpredictable rainfall patterns. Water scarcity is the predominant feature of the drylands, although heavy rainfall may occur with variation in rainfall patterns from season to season and from year to year. The lack of reliable water resources constraints the production of crops, forage wood and other ecosystem services.

Drylands are comprised of arid, semiarid and semi-humid ecosystems and most of these areas are located between the latitudes of 20° and 35° (global drylands located in warm-weather climates). The main semi-arid areas are adjacent to (see yellow areas in fig 1) the arid zone and include Mediterranean-type and monsoonal-type climates. Drylands include the world's driest places on earth including the hyper-arid deserts such as the Atacama in Chile and Namibia in southwest Africa (FAO 2004).

Drylands in temperate and tropical regions where the potential amount of water is transferred from the land to the atmosphere are 1.5 times greater than the mean precipitation (United Nations Conventions to Combat Desertification; UNCCD). These are the areas where precipitation is balanced by evapotranspiration. According to the United Nations Environment Program, drylands in tropical and temperate regions have an aridity index of less than 0.65 (Aridity Index= Precipitation/Potential Evapotranspiration: UNEP 2007).

Additional dryland characteristics are presented in Table 1. Drylands are also categorized based on their primary economic functions: rangelands comprise 65% of the global drylands, including deserts; rain-fed and irrigated croplands are 25%, and 10% are forests or rapidly growing urban sites Table 2 (Safirel et al., 2005). This report will be focusing on croplands in a dryland ecosystem.

Table 1. Key characteristics of dryland classification (Adapted from FAO 2004) Aridity Index* = Precipitation (P)/Potential Evapotranspiration (PET)

Climate Classific-ation	**Aridity Index** *	**Average Annual Rainfall (mm): Inter-Annual Variability**	**Growing Season Days (without irrigation) & Typical Rain-fed Crops**	**Examples of Biomes**
Hyper-Arid	< 0.05	150 mm; 100%	0 days; No rain-fed crops	Desert
Arid	0.05 - 0.20	150 - 250 mm; 50 - 100 %	< 70 days; No rain-fed crops	Desert, xeric shrubland, desert scrub
Semi-Arid	0.20 - 0.50	250 – 500 mm; 25 – 50 %	70 -119; days Bulrush millet, sorghum, sesame (suitable for rainfed agriculture)	Savanna, steppe
Dry Sub-Humid	0.50 - 0.65	500 – 700 mm; < 25%	120 -179; days Maize, beans, groundnuts, peas, barley, wheat, teff (suitable for rain-fed agriculture)	Open woodland, savanna, steppe

Drylands cover 40% of the earth's terrestrial surface and support two billion people, 90% of whom live in developing countries (Reynolds et al. 2007a; UNEP 2007), this represents about 35% of the global population (James et al. 2013) that live in drylands (United Nations Environmental Programme (UNEP, 2011; Table 2). The dryland areas have a significant role in global food and nutrition security. These ecosystems store over 45% of the global terrestrial carbon (Millennium Ecosystem Assessment 2005), support 50% of the world's livestock (Allen-Diaz et al. 1996) and provide the world hotspots of biodiversity (Myers et al. 2000). Drylands have a great diversity in climates, soils, water resources (surface and groundwater) and geological formations. These ecosystems are one of the most susceptible biomes to degradation and are under threat across the globe.

Drylands experience high temperatures, variable rainfall and sparse vegetation cover to minimize radiation effects. This has resulted in low organic matter and nutrients in drylands soils, and rapidly lose a large proportion of this organic matter as CO_2 when exposed to tillage and other conventional agricultural practices. These loses and exposed soils lead to soil erosion in case of an extreme precipitation storm event (Main characteristics of the farming system in dryland- Agriculture organization 2019).

Table 2 Global figures for four type of drylands

Dryland sub-habitat	Aridity index*	Share of global area (%)	Share of global population (%)	% rangeland	% cultivated	% other (including urban)
Hyper-arid	<0.05	6.6	1.7	97	0.6	3
Arid	0.05–0.20	10.6	4.1	87	7	6
Semi-arid	0.20–0.50	15.2	14.4	54	35	10
Sub-humid	0.50–0.65	8.7	15.3	34	47	20
Total		**41.3**	**35.5**	**65**	**25**	**10**

* The ratio of precipitation to potential evapotranspiration.
Source: Safriel et al. 2005

According to the United Nations (UN,2016), the pace of arable land degradation is estimated at 30-35 times the historical rate. UNCCD has estimated that desertification and land degradation could be costing developing countries up to 8 percent of their gross domestic product a year (EMG, 2012). The UNCCD further added that costs are not in economic terms alone, but include social well-being dimensions as well (UN, 2013). UNCCD (2016) has forecasted that 50 million people will be displaced within the next ten years because of the degradation of drylands. Conservative estimates indicate that 10-20% of global drylands are degraded (Millennium Ecosystem Assessment 2005a) and an additional 12 million hectares are degrading each year (Brauch & Spring, 2009).

2.1 What is Land Degradation?

The United Nations Convention to Combat Desertification (UNCCD, 1994) defines land degradation as a reduction or loss, in arid, semi-arid, and dry sub-humid areas, of the biological or economic productivity and complexity of rain-fed cropland, irrigated cropland, or range, pasture, forest, and woodlands resulting from land use or from a single process or combination of methods including processes arising from human activities and habitation patterns (Source: UNCCD, Art. 1). Another definition of the degradation is the reduction in the capacity of the land to provide ecosystem goods and services, over a period, for its beneficiaries (LADA, 2013).

Because of the extent of cropland use in drylands, and the susceptibility of these ecosystems to degradation, it is particularly important to manage these crop land systems responsibly, and in many cases, restore already degraded areas. To restore degraded lands, we must first assess the ecosystem and its land-use history and define a goal for restoring those affected ecosystems.

2.2 What is Ecological Restoration in the Context of Sustainable Agriculture?

The Society for Ecological Restoration has defined restoration as; "the process of assisting the recovery of an ecosystem that has been degraded, damaged or destroyed" (SER Primer, 2004). According to Higgs (1994), ecological restoration is the entire set of ideas and practices (social, scientific, economic, and political) involved in the restoration of ecosystems.

The Sustainable Agriculture Initiative platform has defined sustainable agriculture as "the efficient production of safe, high-quality agricultural products, in a way that protects and improves the natural environment, the social and economic conditions of the farmers, their employees and local communities, and safeguards the health and welfare of all farmed species." (Sustainable Agricultural Initiative Platform, 2010; Fact Sheet by N. Betts 2015).

2.3 Why is Degraded Cropland Restoration Important?

Rain-fed and irrigated agriculture cropping systems are practiced in drylands across the globe. The shift towards high intensity, cheap mass production, and globalization have affected drylands agriculture. Modern agriculture technology has impacted the environment in terms of land degradation, destruction of biodiversity, greenhouse gas emissions and waste accumulation (IPCC, 2001a).

Restoration of degraded croplands is necessary to meet the growing demand of the world increasing population for the provision of ecosystem goods and services and to ensure more sustainable agriculture systems in drylands.

3.0 Project Goal

This project aims to review and synthesize the key factors leading to dryland degradation, and to provide recommendations for mitigating impacts and restoring degraded cropland in dryland regions. These recommendations are targeted towards farmers, land managers, environmental NGOs, agriculture extension officers and other members of dryland communities.

4.0 Methods

A meta-analysis of the literature was conducted and as Schrimer (2018) suggested, a synthetic analysis was conducted to:

- Define and describe the characteristics and distribution of dryland of the tropical and temperate region croplands,
- Describe and indicate the major concerns impacts of degradation on environmental, soil/water resources and social concerns,
- To assess and evaluate restoration actions to address dryland degradation concerns and
- To make recommendations for local and policy stakeholders to consider for the restoration of degraded cropland in dryland regions.

5.0 Objectives

- To identify and assess the environmental and management factors affecting dryland degradation

- To suggest alternative approaches to dryland restoration, and

- To make recommendations for further studies to mitigate management impacts

6.0 Indicators to Assess Dryland Degradation

The assessment of soil properties requires selected soil indicators to determine ecosystem services**.** Net primary productivity, vegetation cover, soil organic matter, presence or absence of plant indicator species, and chemical and physical properties of soil are the key indicators for dryland degradation (Calzolari et al., 2016). Soil indicators are useful for assessment of land suitability for restoration, for planning a restoration strategy, and for ongoing monitoring of progress. Commonly used soil indicators, their functional relevance, and their contribution to ecosystem service are presented in Table 3.

Table 3: List of commonly used soil indicators and their functional relevance
Soil indicators : (E.A.C Costantini et., al 2016)

Soil indicator category	Soil indicator	Relevance to soil processes and functions	Contribution to ecosystem services
Physical	Bulk density	Plant root penetration, porosity, gas exchanges	Biomass production, nutrient cycling, climate regulation
	Infiltration capacity	Runoff/erosion control, leaching	Soil development/conservation, water purification and regulation, flood mitigation
	Water-holding capacity	Retention and transport of water and chemicals	Water purification and regulation, food and fiber production, biomass production
	Topsoil-depth	Rooting volume, habitat for soil fauna	Carbon sequestration, climate regulation, biomass production
	Macro-aggregation, soil structure	Erodibility, nutrient and organic matter retention, crop emergence	Soil development/conservation, carbon sequestration, biomass production
	Surface stoniness	Infiltration rate and effective rootable soil	Soil development/conservation, water regulation
Chemical	Organic matter	Soil fertility and soil structure, pesticide and water retention	Carbon sequestration, soil development/conservation, nutrient cycling, water purification and regulation, biomass production
	Total nitrogen	Plant and soil fauna development	Biomass production
	pH	Nutrient availability, pesticide absorption and mobility	Nutrient cycling, biomass production
	Cation exchange capacity (CEC)	Plant growth, soil structure, water infiltration	Nutrient cycling, food and fiber production, primary production
	Electrical conductivity	Soil water potential, salinity	Water purification and regulation, food and fiber production, primary production
Biological	Soil respiration	Biological activity, biomass activity	Nutrient cycling, water purification and regulation, pollutants purification
	Dehydrogenase activity and Phosphatase	Decomposition rates of plant residues release of plant-available nutrients	Nutrient cycling, food and fiber production, biomass production
	QBS	Mesofauna abundance and adaptation to the soil habitat	Biodiversity pool


Vegetation Cover (Image source: Sustainability.org)

6.1 Soil Cover

Soil cover is associated with various environmental processes and conditions related to soil health, such as organic matter, soil susceptibility to erosion, biodiversity, wildlife habitat, water, and air quality. Vegetation cover is also a determinant of crop productivity and yield (Agriculture and Agri-Food Canada, 2016).

Vegetation-related parameters such as biomass (above and below ground) and net primary productivity (NPP) are established indicators of degraded land in arid and semi-arid environments (Costantini et., al 2016). A decline in NPP has been observed in drylands by overgrazing in the early stages of degradation (Guodong et al., 2008). However, NPP is also influenced by climatic variations, which makes its suitability limited as an indicator of degraded land.

Bare soil and vegetation cover (shrub, trees, grasses, and biological crust) were used as indicators of dryland degradation in many of the world's drylands (Dregene 1983). Sparse vegetation leads to increased exposure of the land to sun, wind, rain and soil erosion, and the reduction in biodiversity.

6.2 Physical and Hydrological Indicators

Physical and hydrological indicators are difficult to quantify, but the visual evaluation and assessment of soil aggregates and structure have shown to be reliable and effective semi-quantitative methods to assess soil structural quality (Moncada et al., 2014).

According to Costantini et al. (2016), the factors regulating available plant water depend on various soil physical and morphological properties and physiographic land-use factors (Table 4). Water availability and variability are crucial factors in the provision of goods and services in dryland regions. "Green Water Use Efficiency" is the fraction of plant transpiration over precipitation (Stroosnijder, 2009). It is a useful indicator to evaluate whether the productive water (crop production over water use) is maximized while unproductive loss is minimized. This concept aims at reducing nonproductive evaporation and thereby forcing it to transpire through plants, to improve biomass production without reducing the amount of blue water leaving a watershed.

Table 4. (Soil qualities related to plant-available water Source: E.A.C Costantini et., al 2016). In the agriculture context:
Green water; Rainwater taken by plants/crops via soil
Bluewater; Water diverted from rivers, and lakes, groundwater used to irrigate crops.

Determinants	**Drivers**	**Soil qualities**	**Functional soil characteristics**
Water input	Rainfall, irrigation	Infiltration Capacity	Infiltration rate (texture, structure, crakes)
	Groundwater subsurface and surface flow	Deep recharge and surface recharge.	Capillary rise (texture, structure, stoniness) Topography, natural and artificial channels

Water output	Evapotranspiration, Runoff Drainage (rock nature)	Surface cover, Surface morphology Permeability	Mulch, stoniness, crusts Slope, mulch, stoniness, rockiness, crusts microrelief, natural, artificial channels, ditches Hydraulic conductivity
Water storage	Soil volume	Porosity Root penetration	Texture, structure, bulk density, stone volume and weathering; Root explorable volume of horizon, rooting depth of profile
Soil water tension	Soil water adhesion Irrigation, Lithology	Soil water-holding capacity Salinity	Soil water tension curve Electrical-Conductivity soluble salts
Soil water composition	Natural background, pollution Anoxia	Soil water composition Oxygen availibilty	Pollutant content and availibility Air capacity

6.3 Chemical Indicators

Chemical soil indicators measure dynamic soil properties. Monitoring these indicators are essential as they can act as constraints to yield, restricting crop growth and preventing yield potential from being achieved. Cation exchange capacity (CEC) is a measure of soil capacity to exchange and retain nutrients and is linked to inherent soil fertility. CEC is related to soil mineral composition, clay type, and content and soil organic matter. It is a valuable soil property that influences soil structure stability, nutrient availability and soil pH (Costantini et al., 2016).

Soil alkalinity and salinity are also an issue in degraded drylands, particularly in irrigated lands degraded by unsustainable irrigation practices (Costantini et al., 2016). When shallow-rooted annuals replace deeply rooted perennials and the land is kept fallow for long periods as a rotation practice, this may result in a salinity problem. Rainfall can leach salt down the soil profile and into the groundwater, Dissolved salts can then move laterally with groundwater, locally within a catchment or regionally between catchments. Electrical conductivity is the measure of salt amount in the soil and is the most useful and reliable indicator of soil salinity. The application of organic matter (e.g. manure) and bio-solids in soil reclamation measures may decrease the electric conductivity of soil and affect seedling survival.

The water-deficient environment in dryland ecosystems promotes natural salinization processes, as the salt accumulates on or near the soil surface and restricts plant growth and thus harms crop production (Teidor et al., 2007). Global estimates show that nearly 50% of irrigated land in arid and semi-arid regions has a salinity problem to some extent, and 1.5 million ha of land lose their productivity due to salinity (Thomas and Middleton 1993; Rubio and Calvo 2005). The UN Millennium Ecosystem Assessment reports that irrigation has also resulted in unsustainable exploitation of groundwater aquifers, water pollution, eutrophication, and waterlogging problems in addition to salinity problems in drylands (2005a).

6.4 Organic Matter

Soil organic matter (SOM) is an essential resource for providing ecosystem services Figure 2. Above and below ground plant residues are the primary sources of soil organic matter. The soil food chain is sustained by decomposition of organic matter which is utilized by soil micro and meso-funa as an energy source (Schmidt et al., 2011). Soil organic matter stability and persistence depend on the biotic and abiotic soil environment. The residence time of organic matter in soil depends on temperature, microbial activity, and moisture content. Also, soil organic matter is an important soil property and a determining factor for various soil functions and structure stability (water holding capacity), and thus any decline in organic carbon and nitrogen concentrations could be an early warning for land degradation. Soil organic matter has a vital role in determining soil physical properties in regulating the availability of water for vegetation and soil water infiltration and retention capacity.

The input of organic residue is low in degraded drylands because of the disruption of plant cover. Lal (2004) reported that the size of SOM pools in natural ecosystems decreases with temperature. In drylands environment, topsoil is thin and low in organic matter, and highly susceptible to erosion. The reduced and patchy vegetation cover in drylands makes them susceptible to accelerated erosional processes resulting in increasing the loss of organic material and nutrients from the affected ecosystems.

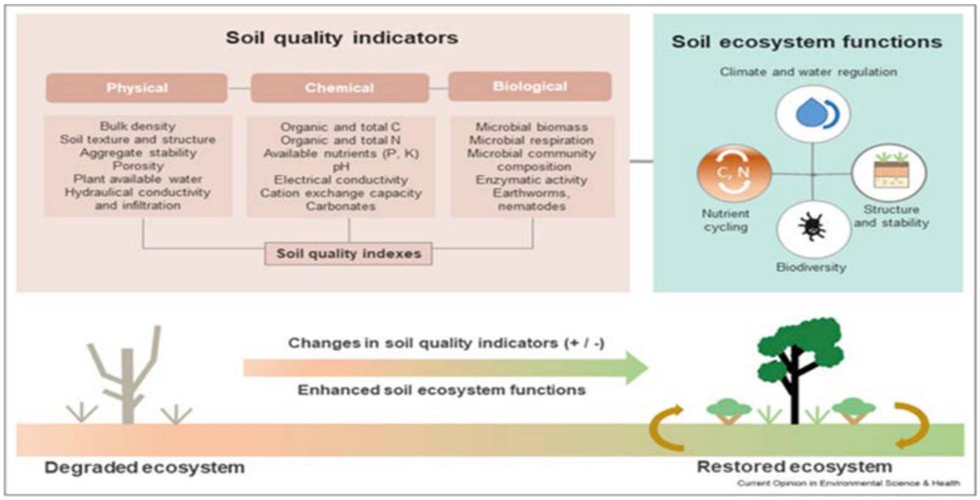

Figure 2 (Source: Soil quality indicators; science direct.com)

6.5 Biological Indicators

Biological indicators have been widely used to monitor soil quality changes and to assess biological fertility (Marinari et al., 2010). Common indicators include microbial biomass carbon, microbial respiration, enzyme activities, and related indices (Table 3 & 5) (Kieft et al., 1998; Bastida et al., 2006).

There are a massive number of organisms known as soil biota in the thin layer of soil surface. These organisms serve as biological indicators of soil health and provide insight into the living components of the soil (Table 5 and Figure 2). These organisms play an important role in organic matter decomposition, nutrient cycling, formation and stability of soil structure and pollutant degradation. Biological indicators are difficult to measure (Ritz et al., 2009). To date, the emphasis has been placed on physical and chemical indicators rather than biological indicators (Oliver et al., 2013).

Soil biota responds quickly to soil management and land-use changes and has been widely used to monitor soil quality changes in space and time to assess biological fertility (Marinari et al., 2010). Soil biota adapts to environmental changes and stress, such as flooding, drought and food shortage. According to Pankhurst et al., (1997) and Dorran and Zeiss (2000), direct measurement of some soil organisms can be related to processes, such as the decomposition of organic matter. Detectable changes in soil

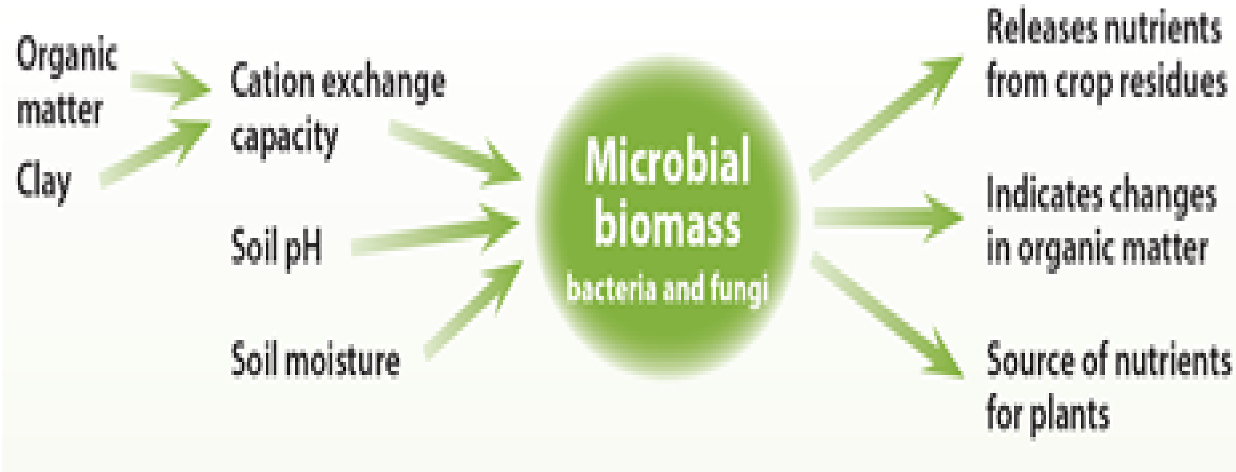

Figure 3. (Soil properties affecting the microbial biomass; Source: Fact sheets microbial biomass soilquality.org.au)

chemical and physical properties are influenced by changes in microbial activity or population. In drylands, the microbial biomass is affected by water scarcity, soil pH, carbon content, climate and land management practices (Figure 3).

Table 5: Biological indicators (excluding soil organic carbon) used in soil quality assessment systems around the world Riches et al. 2013; Biological indicators for soil quality; Australian Journal of Grape and Wine Research 2013 Australian Society of Viticulture and Oenology)

Country	Biological Indicators
USA	SMB (by CFE), PMN, β-glucosidase
USA	SMB (by CFE), PMN, soil respiration
USA	Labile C, PMN, root health
USA	Earthworms, SMB, SIR
Canada	SIR, F:B ratio
Germany	SIR, F:B ratio, MQ
United Kingdom	Soil respiration, microbial diversity, CLPP (micro respiration), PLFA, TRFLP, enzyme activities, microarthropod community, nematode
New Zealand	SMB (CFE), soil respiration, PMN, MQ
Australia	Nematode Community
Australia	Labile C, SMB (by CFE), soil respiration, PMN

CFE, chloroform fumigation-extraction; CLPP, community-level physiological profiling; DGGE, denaturing gradient gel electrophoresis; F:B ratio, fungi: bacteria ratio; MQ, Microbial quotient; PLFA, phospholipid. Fatty acid analysis; PMN, potentially mineralizable nitrogen; SIR, substrate-induced respiration; SMB, soil microbial biomass; SOC, soil organic carbon; TRFLP, terminal restriction fragment length polymorphisms.

7.0 Cropland Degradation–Drivers and Impacts

Land degradation in dryland ecosystems is a complex environmental problem across the globe, Globally, a total area half of the size of the European Union (4.18 million km²) is degraded annually, with Africa and Asia being the most affected (New World Atlas of Desertification 2018) The atlas provided information on anthropogenic activity that affect biodiversity and drives species to extinction, threatens food security, escalate climate change and leads to migration of people from the area.

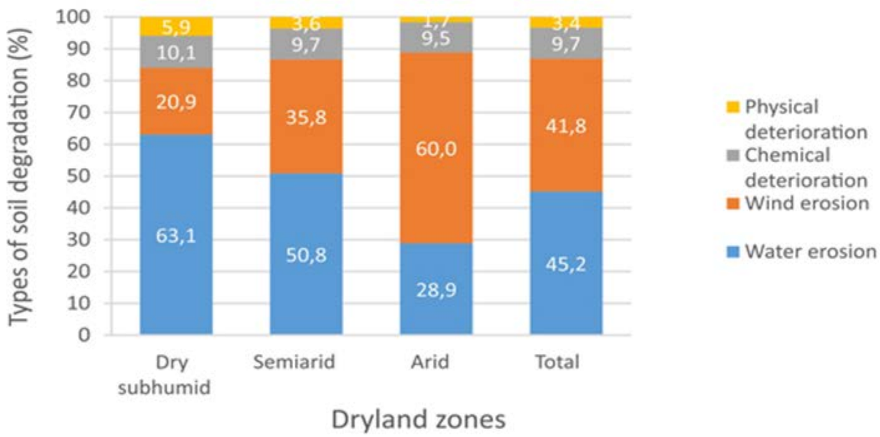

Figure 4: Types of soil degradation (million km^2) in dryland zones. (Data source: UNEP1997).

As stated earlier dryland ecosystems are sensitive to degradation (Reynolds et al. 2007) particularly by wind and water erosion, chemical degradation (acidification, salinization), physical degradation (crusting, compaction, hard-setting; Figure 4) as well as biological degradation- biomass reduction, and declining biodiversity (Sivakumar, 2007). Water is the main driver of soil erosion. In arid and semiarid drylands areas, wind erosion can be a considerable agent of soil erosion (Ravi et al. 2010; Belnap et al. 2011; Fig. 3).

Land degradation involves two interrelated systems: the natural ecosystem and the human social system Figure 5. The factors involved in land degradation are not only biophysical (soil erosion, land cover) but contain social dimensions as well (political stability, income, institutional support human health) (Huber-Sannwald et al., 2005). The population density in drylands has put tremendous pressure on the natural resource base and is a major factor in land degradation, which has resulted in a loss of production capacity of the land (MEA 2005: Saturday, 2018). This has resulted in increased poverty, food insecurity, and degradation of natural resources. The exploitation of natural resources such as deforestation, vegetation for domestic use such as fuelwood and domestic timber are causes of natural resources base degradation (MEA 2005).

Overgrazing and intensive cropping in drylands affect soil resources and make them susceptible to various types of soil degradation, including soil compaction, crusting, erosion (wind and water), salinization, topsoil loss, nutrients depletion and decline in organic matter. (Zika, and Erb 2009).

The soil erosion (wind & water) in drylands results in a reduction of soil depth and ability to store water and nutrients (Mainguet 1986; Grainger 1992) which in turn leads to a reduction in agricultural productivity, adverse environmental effects, and socio-economic problems such as food insecurity and migration (Scherr,1999; Dregne, 2002; Mganga et al., 2015).

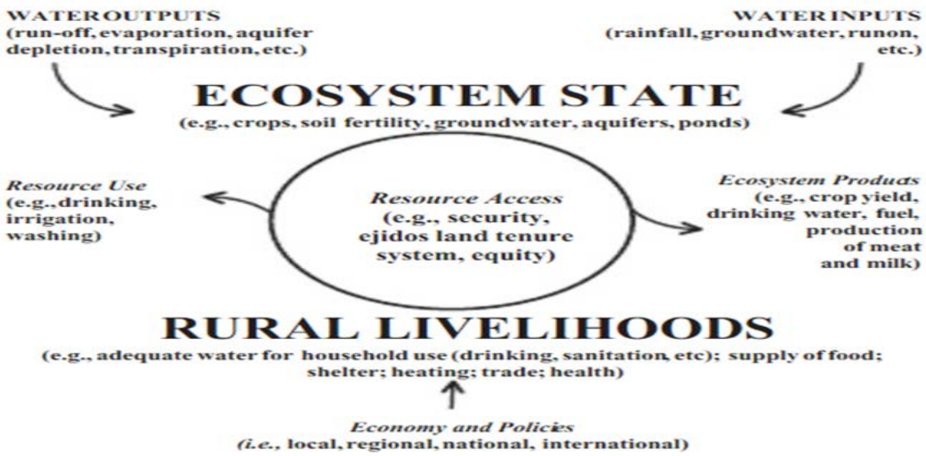

Fig 5: Presents social and biophysical factors in a rural community. The biophysical illustrate ecosystem; socioeconomic dimensions are shown as 'rural livelihood,' respectively, whereas hydrological processes are highlighted to show the biophysical- socioeconomic linkage in a constantly changing environment (Huber-Sannwald et al. 2005)

The nexus of causes, processes and factors serve as a focus for land degradation. The interaction between causes-factors-processes nexus makes land degradation more severe as shown in Figure-6 than each factor in isolation and is impacted by a site-specific situation (Saturday, A. 2018). The overuse of natural resources beyond their carrying capacity has put the sustainability of dryland areas in endangered conditions (Katyal and Das, 1992).

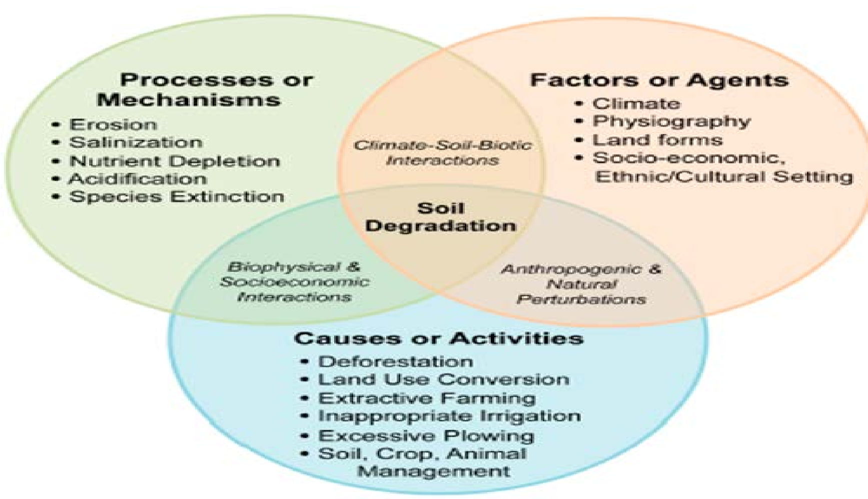

Figure 6: The process-factor-cause nexus - driver of soil degradation

(Source:www.ommegaonline.org/article-details/Restoration-of-Degraded-Agricultural-Land-A-Review/1928)

8.0 Crop Land Degradation–Social Dimensions

As mentioned earlier, land degradation is a social problem that affects land use management, soil productivity and capacity, cultivation and sustainable development (Blaikie and Brookfield, 1987). Erratic rainfall is the main constraint in investment, conservation, and development of these areas. The intensification of political and social pressure contributes to land degradation, societal disruption, and political instability. The loss of fertile land and other natural resources deprives the people of dryland regions from their livelihood. Thus, the displaced population migrates to urban areas or other countries, adding population pressures, which may further results in social and political conflicts.

According to the Natural Heritage Institute, many of the illegal immigrants who enter the United States from Mexico each year are fleeing the country's severely degraded lands, which make up 60 percent of the country's territory (Reese 2011). Worldwide, the International Committee of the Red Cross estimates that 25 million of the world's refugee's 58 percent are fleeing degraded lands.

As indicated, water availability is another important socio-economic aspect in dryland areas and a major determinant of agriculture and livestock production. Drylands people's prosperity and development depend on water availability. Any disruption in the hydrological process (human-induced or otherwise), such as run-off and infiltration carry significant consequences leading to water reduction, which in turn results in loss of agriculture and livestock production. (Lie at al., 2000; Abu-Awwad and Kharabshes, 2000).

Many countries in the world are increasingly facing a shortage of water availability (UN, 2003). This is a more pressing concern in developing countries where the welfare of rural communities is dependent on the hydrological functioning of the local agro-ecosystem (Sharma, 1998). To avoid future human water shortages and undesirable environmental impacts there is a need for understanding the balance of shared water between nature and society (Wallace et al., 2003). Local socio-economic aspects must be taken into consideration in mitigating water scarcity issues.

9.0 Degraded Crop Land Restoration

The interaction between land resources, climate, and human activities determines the productivity and sustainability of the land-use system. According to Katyal and Das, (1992), the sustainability of dryland areas is endangered because of over-exploitation of natural resources beyond their carrying capacity. Soil and water conservation practices maximize the use of limited rainfall water and conserve water and soil resources against the erosive forces of wind and water.

Sustainable agriculture management practices emphasize full conservation and utilization of the available rainfall water and to obtain maximum storage of moisture in erratic rainfall conditions, with minimum losses through evaporation and evapotranspiration (Duveskog et al., 2003). Physical, chemical and biological measures can restore degraded land in dryland agriculture areas. Generally, soil can be protected from erosion by vegetation cover and plant litter on the soil, which also reduces runoff and increases water infiltration into the soil (Zuazo and Pleguezuelo 2008; Liao et al. 2014).

A holistic approach is required to restore degraded land and to further minimize land degradation by sustainable land management practices ensuring sustainable use and management of natural resources (Gebretsadik, 2013).

10.0 Degraded Crop Land Restoration–Water Management

10.1 Degraded Crop Land Restoration–Rain Water Harvesting

Rain Water Harvesting is a technique of collection and storage of rainwater into natural reservoirs or tanks, or the infiltration of surface water into subsurface aquifers before it is lost as surface runoff (Wikivrsity.org). It also involves water conservation techniques that increase stored water in the soil profile by capturing the rain where it falls (Alamerew et al., 2002; Ngigi, 2003). This technique is also used to control soil erosion and conserve moisture by prolonging the water infiltration time into the soil. In situ rainwater is harvested in Indian province (Gujrat Fig 7).

Figure source: (Tnau Agritech Portal Summer ploughing 2016)

10.2 Degraded Crop Land Restoration–Summer Tillage

By plowing of the fields across the slope with special tillage implements in summer, before the monsoon shower, helps to recharge the soil profile, break surface crusts, increase soil moisture and reduce run-off, thus controlling soil erosion. This tillage practice improves soil aeration and increases soil biota activity. Increase in water infiltration capacity of soil increases atmospheric nitrate infiltrate into the soil which leads to improving soil fertility, (Tnau Agritech Portal-summerPlowing, 2016)

10.3 Degraded Crop Land Restoration–Compartmental Bunding

Compartmental bunding is a moisture conservation technique where an entire field is divided into small compartments to capture the rainwater that falls on the field, which controls run-off and reduces soil erosion (Tnau Agritech Portal compartment bunding 2016). This water conservation technique also provides more time for water to infiltrate into the soil and help in increasing moisture content. Moisture conservation through furrows, ridges, mulching and micro-catchment of water around root zone are all useful in-situ moisture and soil erosion conservation techniques.

Figure (Source: Tnau Agritech Portal compartment bunding 2016)

Randy and Franklin (1998) describe the various moisture conservation techniques by reducing evaporation and evapotranspiration in dryland farming. Their summary includes;

- Shelterbelts of trees or shrubs to reduce wind speed and wind erosion and their shadow reduce evaporation by 10-30%.
- Mulch reduces wind speed and soil temperature.
- Subsurface water losses can be prevented by creating a dirt mulch (2-3 inches deep) by shallow tilling, which quickly dry out but is discontinuous from subsurface water.
- Tillage should be repeated after each rain to discontinuity with subsurface water. This is useful for areas where major rainfall events occur with long intervals in between.
- Weed control, as they compete for nutrients and water and this water can evaporate from their surfaces.
- Reducing plant spacing and number in dryland farming helps in conserving moisture as fewer plants are competing for soil moisture.

Proper crop selection for dryland agriculture can reduce moisture evaporation (Randy and Franklin, 1998). Planting of drawf varieties can reduce water losses as these plants have less surface area. Some plants respond to climatic conditions and close their stoma when it is hot, reducing their water loss. Other plants such as corn, curl their leaves during the hot afternoon and open them at night. These changes in the surface area help them to respond to changing climatic conditions.

Rainwater run-off depends on rainfall intensity, distribution, soil characteristics, such as soil water retention capacity, water infiltration rate, slope and vegetation cover. Traditional methods and practices for rainwater harvesting (pond, tanks, ditches, cut-off drains) are useful and important in most drylands areas of the world. Harvested rainwater can be used for supplementary irrigation during water stress at a critical growth stage of drylands crops (Ram, and Davari, 2010).

10.4 Degraded Crop Land Restoration–Irrigation Management

As stated earlier, water is a limiting factor in rainfed agriculture and requires efficient use to improve crop production; This can be achieved by selecting short duration growing crops with low water requirements (Oswal, 1994). Crop selection should be based on the water requirement of the crop and expected rainfall during the growing season. The optimum water requirements of various drylands crops are given in Table 6.

Table 6 Water requirment of drylands crops (Oswal, 1994).

Summer Crops	Water Requirement (mm)	Winter Crops	Water requirement (mm)
Black gram, cowpea, mung bean	25	Mustard	200
Clusterbean, pearl millet, finger millet	300	Barley, pea, safflower	300
Sesame	350	Sunflower, wheat	350
Castor, red gram, sorghum	400		
Groundnut, maize, soybean	350		
Sunflower, tobacco	500		

11.0 Degraded Crop Land Restoration–Land Management

Management strategies for restoration of degraded agricultural land may require different practices depending on the cause of degradation and the restoration goals. For instance, erosion control practices in degraded agricultural areas may be different from restoration techniques to control salinity problems, or the restoration efforts for purposes of increased agricultural production may be different from the restoration techniques where the primary goal is to restore biodiversity and ecological services.

11.1 Degraded Crop Land Restoration–Erosion Control

Non-vegetated and exposed soil surfaces are susceptible to soil erosion by intensive water run-off, and wind erosion may be a dominant force and a major threat that may result in soil and nutrient losses. Various agronomical and biological techniques, such as reduced or no-tillage, crop rotation, agroforestry, residues mulch, vegetative filter strips, shelter breaks, and windbreaks are commonly used for erosion control (Lamb, Erskine, Parrotta, 2005).

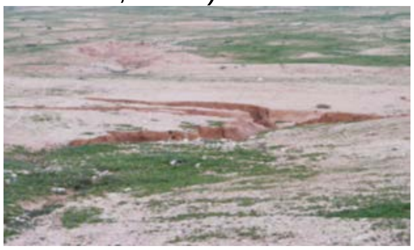

Fig: Water and Soil Conservation
(Project Wadi Attir))

Soil erosion control may also be achieved by providing an adequate amount of vegetation cover on the soil surface, including crops and plant residues. The vegetation cover maximizes water capture, increases the storage of precipitation water and dissipates the energy of raindrops, reducing its impact on soil splash erosion (Saber 2010).

Conservation tillage farming practices leave most of the crop residue on the soil surface, which helps in reducing wind velocity. Winds barriers of annual and perennial crops also minimize wind erosion (Ram, and Davari, 2010). Strip cropping barrier system is used extensively in the U.S. Great Plains and Canadian Prairie Provinces to reduce wind erosion, as an example, strips of erosion-resistant crops being alternating with equal-width strips of land susceptible to wind erosion (Siddoway, 1970).

11.2 Degraded Crop Land Restoration–Physical Conservation

Physical structures are permanent features made from earth, or stones, to protect soil from erosion and retain water where needed (Bashir et al., 2017). Wind erosion can be reduced or prevented by using windbreaks and wind barriers to control wind velocity. Shelterbelts are vegetative barriers for the control of wind erosion that are designed to reduce wind speed. Cut-off drains are made for the protection of cultivated land from un-controlled run-off. These structures capture water from surface run-off and further divert it to streams and canals. Another water and soil conservation technique is the construction of retention ditches along contours to capture and retain incoming run-off water until it seeps into the ground.

Figure: Erosion Control-Windbreaks Traditional Cut-off drains (worldatlastlas.com)

Thus, soil and water conservation practices such as contour tillage, furrow dikes, level terraces, and land levelling can reduce run-off and sediment transportation. According to Nyssen et al. (2010), physical conservation measures complemented with tree plantation may reduce soil erosion more effectively. Leguminous tree plantation increases soil fertility by replacing nitrogen used by crops fixing atmospheric nitrogen and incorporating into the soil and reducing erosion and nutrients losses by leaching into the soil (Buresh and Tian, 1998).

11.3 Degraded Crop Land Restoration–Cover Cropping

Cover cropping in drylands is an important practice for building soil health and making the soil more resilient to drought and other extreme environmental factors (Doran and Zeiss, 2000). Cover crops have a significant impact on various soil processes and functions as soil surface is covered with crops/vegetation that helps prevent soil erosion and soil improvement in-between period of average crop production.

Cereal Rye Cover Crop
Agronomic Crops Network- Ohio University

In addition, the cover serves as a source of organic matter upon decomposition and provides a favourable habitat for microorganisms by regulating soil heat and temperature. However, there are challenges related to adapting this practise such as the selection of cover crop, cost and availability of water for raising the cover crops.

Figure: Forest Life & Preservation
Department Punjab India

11.4 Degraded Crop Land Restoration–Agroforestry

Agroforestry is a land-use management practice in which trees or shrubs are grown around or among crops. Agroforestry can be a source of food and non-food products (food security, nutrition) to local communities, improving livelihoods, and combating poverty by generating income. Tree plantations reduce the magnitude of splash erosion by decreasing the raindrops' impacts on the soil. Trees also help regulate soil temperature by providing a canopy that shades the soil, thus reducing water evaporation. According to Bashir et al., (2017) leguminous tree plantation plays an important role in nitrogen-fixing and nutrient recycling into the deep soil.

In summary, incorporating trees in farming systems have benefits and can provide a wide range of ecosystem services such as;

- Supporting services: pollination and carbon cycling,

- Regulating services: protection against wind, enhance water quality, biological pest control, and nitrogen fixation,

- Provision services: food and non-food products for home consumption and income generation.

As outlined earlier, trees aids in:

- Erosion control and increased water availability.

- Increase soil fertility by high biomass production, nitrogen fixation, mycorrhizal associations, trees have dense and deep networks of fine roots, which allows growth in poor soils.

- Trees rebuild soil organic matter by retrieving nutrients from deeper soil horizons and weathering rock and adding them back to the soil surface as leaf litter.

- Leaching is decreased with deep-rooted tree species, which helps in controlling soil salinization and acidification.

- Tree plantation in terracing, contour cultivation, and strip-cropping reduce soil erosion and increase soil fertility.

- Tree plantation as windbreaks and shelterbelts are useful for control of wind erosion.

- Tree plantation in improved -fallows and alley-cropping systems, can improve soil fertility when their prune branches are applied as a mulch to the soil.

These properly designed and manage agroforestry systems can help restore the degraded cropland and can contribute to biodiversity conservation, climate change adaptation, and mitigation.

11.5 Degraded Crop Land Restoration–Inter Cropping

This involves growing two or more crops on the same land at the same time. This practice minimizes degrading agents such as soil erosion. Raindrops impact is reduced with the soil cover by fast-growing legumes (beans, cowpeas), which provide soil cover early in the season before a canopy by maize or cotton is developed (Satursay, 2018). Intercropping can improve soil productivity of less productive soils (degraded dryland areas) by growing diversified crops on the same piece of land as monoculture practice can reduce soil organic carbon (Lal, 2006).

Figure (source: Intercropping-Kiboko)
(https://kiboko.nl/portfolio-item/intercropping/

Blanco-Canqui, 2009 has suggested incorporating short-rotation woody species into cropping systems to improve soil organic carbon such as castor beans (Ricinus communis L.), a bio-energy crop, which can provide quick ground cover and to contribute carbon into the soil (Wang et al., 2010). Thus, intercropping of caster on degraded land with maize and mung bean has improved land productivity (Jaya et al., 2014)

Agroforestry is a larger version of intercropping, both place two or more plant species and share the same principles (such as nitrogen-fixing plants) nearby, and both provide multiple outputs. As a result, there is higher yield and reduced cost because of sharing single input (Agroforestry-Wikipedia).

Figure: Dryland salinity
www.agric.wa.gov.au

11.6 Degraded Crop Land Restoration–Saline Agriculture

It is difficult to restore saline land to its original condition. The land may be reclaimed to a certain point where some environmental and production benefits can be seen. The identification of a recharge source of groundwater is important in the restoration of saline soil.

In the case of irrigation water, as a recharge source, appropriate measures are required to reduce leakage to the groundwater such as;

• Improving irrigation efficiency (crop water uses efficiency) by improving irrigation layout

• Improvement in surface and recycling drainage and recycling

In case of local recharge from run-off water, the land can be rehabilitated by management practices such as;

• Revegetation of land with local, native perennials, shrubs and pastures

• Grazing management of livestock by fencing and allow grazing when land is dry, and vegetation is fully established. This practice will result in the regeneration of local native species and will provide ground cover (Saturday, 2018).

Revegetation with salt-tolerant plants such as halophytes, which can accumulate high concentrations of salts in their shoots, is a possible management strategy (Barrett-Lennard, 2002). Halophytes plantations can significantly lower salt concentrations in most saline soils through evapotranspiration, which result in lowering water tables and reduced waterlogging in the soils. Plantations with salt-tolerant species can improve saline soils to more productive lands by the production of litter, which increases the soil organic matter and nitrogen content (Mishra et al., 2003) and by lowering the water table.

Soil pH has an essential role in soil reclamation, as pH tolerant plants may be used for restoration purposes. According to the study by Hasanuzzaman et al., (2014), halophyte plants have been successfully used for recovering agricultural productivity in degraded saline and alkaline soils, and for reclaiming these soils by actively extracting salt. Tejdor et al. (2007) reported that the use of volcano mulch (basaltic pyroclasts) reduces soil salinity as much as 86%, resulting in leaching of soluble salts beyond the root zone.

12.0 Degraded Cropland Restoration–Livestock Farming

Another approach for sustainable natural resource management in dryland farming is diversification of cropping system by integrating rainfed agriculture with livestock farming. There are several environmental benefits of diversified cropping systems to the farmers such as manure availability to the farmers, reduction in the need for chemical fertilizers, improvement in the quality of products, improvement in soil fertility and organic content of the soil and reversing biodiversity loss (Bell et al., 2014).

13.0 Degraded Crop Land Restoration–Biological Measures

Marger and Thomas (2011) reported that the use of cyanobacteria (microbial inoculant) as a biological soil reclamation measure could fix atmospheric nitrogen and through photosynthesis, contribute nitrogen and carbon to the dryland. Cyanobacterial soil crusts are the key component of a macrobiotic crust in a dryland environment. (Issa et al., 2007). This soil reclamation measure improves soil biochemical and physical properties in arid regions, including soil fertility, soil structure, water retention capacity of the land and aids in the recovery of damaged soil crust (Pandey et al., 2005; Issa et al., 2007).

Soil macrofauna, such as termites, are key components of many dryland ecosystems. They are nature best recyclers and act like green machines and, can modify soil physical and chemical and microbial properties through foraging and mixing of plant material (Marger and Thomas, 2011) These organisms aerate the soil, allow rainwater to infiltrate into the ground and facilitate mixing of nutrients. Mando et al. (1996) observed that mulching in drylands increases the termite's activity, which results in the regeneration of woody plants. Another study by Traor'e et al. (2008) showed that termite mounds are preferred sites for the increase in the natural population of woody plants in tree savanna.

14.0 Degraded Cropland Restoration–Social Dimensions

Restoration of drylands requires coordinated rehabilitation efforts involving stakeholders, governmental and non-governmental and mainly local communities. Participation of all stakeholders is the key to the success of a restoration project and may be achieved by strengthening local organizations, which enable local people to implement and sustain restoration activities (Marques et al., 2016).

Local communities are the main stakeholders in restoration projects who are most influenced by projects' activities. The local communities should be involved to participate in project activities from project conceptualization to implementation and management (Marques et al., 2016). Restoration projects should consider the socio-economic needs and values of the local community to sustain their interest and participation (Sayer et al., 2004). Community participation is the key to the long-term success of a restoration endeavour (Chokkalingam, 2005). Furthermore, strengthening the local community organizations will empower local communities in decision making.

Figure: worldagroforestry.org

Traditional ecological knowledge (TEK) has social dimensions and significance in the conservation of natural resources. According to Gadgil et al. (2003), traditional ecological knowledge has been utilized over the past few decades for the management of natural resources. Gadgil et al. 2003 have defined TEK as a cumulative body of knowledge, practice, and belief, that has evolved by adaptive processes and has transferred through generations by cultural transmission, it is about the interaction of living beings (including humans) with one another and with their environment.

Various traditional crop management practices are available in dryland areas and have been tested for long under climate stress conditions. These traditional production practices may be incorporated into a dryland cropping system for the rehabilitation of degraded cropland. There were a number of traditional drought-resistant crops in dryland areas that used to been grown have disappeared or replaced with other crops (e.g Maize) overtime for instance, drought-tolerant crops such as sorghum, millets, pigeon pea, cowpea and green gram can reduce transpiration and even may cease growing in unfavourable condition and resume growth when growing condition are favourable (Busia county in western Kenya-2016). Traditional ecological knowledge can provide useful and valuable information in less time and at low cost in restoration ecology of degraded croplands.

15.0 Conclusion

Increasing population, adverse climatic conditions (droughts) and unsustainable agricultural practices are the drivers of cropland degradation in drylands. Cropland degradation poses a severe threat to the livelihood of 1.5 billion people across the globe and 250 million residents of drylands areas resulting in a reduction of the provision of ecosystems services and reduction in the ecosystem's resilience to natural climate variability.

These factors further increase the problems of food insecurity and social and political instability, particularly in third world countries. Degraded cropland restoration in drylands areas has promising success stories by technical aspects of restoration, which are achieved through various agronomic and biological management techniques, such as crop rotations, agroforestry, cover crops, vegetative filter strips, residue, and reduce or no-tillage practice.

This review has identified that most restoration strategies are focused on scientific and technical research, addressing the complex issues related to restoration only, ignoring the societal needs. Cropland restoration needs to be addressed at the landscape-level, taking into consideration the biophysical and socioeconomic components to prevent environmental degradation.

The restoration strategy in degraded cropland needs to be expanded on sustainable land management practices by taking into consideration traditional ecological knowledge, biodiversity-based agricultural practices, socioeconomic needs and values of local communities. The integration of biophysical and socio-economic components in planning and executing phases of restoration projects can result in the successful rehabilitation of degraded cropland in dryland areas.

16.0 Recommendations

Although there are many solutions to the degradation, notably focused on the basic soil resource, and the other biophysical factors, this analysis suggests that the dominant drivers of degradation are the combinations of socio-economic factors and the more recent impact by climate change. Thus, restoration approaches that include socio-economic factors should be promoted and not simple reclamation approaches, which focus dominantly on the biophysical factors.

Based on this analysis, the following recommends include:

- To ensure the involvement of local people in the decision-making process for the long-term success of restoration projects and to develop trust between stakeholders.

- To recognize and promote traditional ecological and practices and integrate them with modern scientific techniques in mitigation plans of degraded drylands.

- To promote the collaboration of scientists, researchers, the academic community, policymakers for mutual learning, and developing a strategy for the restoration of dryland.

- To facilitate capacity building of policymakers, restoration practitioners, land managers, agriculture extension officers on environmental issues and mitigation strategy.

- To address the communication gap in transmitting scientific knowledge and research findings to policymakers at the government level.

- To educate and provide technical assistance and training material at the local level, encourage scientists, researchers, the academic community to develop training modules and provide training to the local trainers.

- To promote integrated watershed-level approach in the restoration of degraded dryland

- To provide a mechanism for allocation of funds for research on the cost-benefit analysis of restoration projects

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