Dryland Environments

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ABSTRACT

One-half of the world’s countries have portions or all of their land in dryland environments. These lands and their sub-humid margins represent one-third of the earth’s surface and are the home to nearly 40 percent of the world’s population. It is here where land and environmental degradation is occurring at alarming rates, often leading to desertification, and threatening the livelihood of more than 900 million inhabitants. Drylands are diverse in terms of their climate, soils, flora, fauna, land use, and people. The nature of this diversity and other inherent characteristics of dryland environments are considered in this paper.

INTRODUCTION

One-half of the world’s countries have portions or all of their land in dryland environments. These lands and their sub-humid margins represent one-third of the earth’s surface and are the home to nearly 40 percent of the world’s population (White et al. 2002). It is here where land and environmental degradation is occurring at alarming rates, often leading to desertification, and threatening the livelihood of more than 1 billion people. Drylands are diverse in terms of their climate, soils, flora, fauna, land use, and people. No consistent characterization or practical definition of drylands can be made because of this diversity. One binding feature of all dryland environments, however, is their aridity.
ARIDITY

Aridity results from the presence of dry descending air. Aridity is found mostly in places where anticyclonic conditions are persistent, for example, in regions lying under the anticyclones of the sub-tropics. The influence of subtropical anticyclones on rainfall increases with the presence of cool surfaces. Arid conditions often develop in the lee of major mountain ranges that disrupt the structure of cyclones passing over them, creating rain shadow effects. Rainfall is also hindered by the presence of greatly heated land surfaces temperature-wise. As a consequence, large areas of dry climate exist far from the sea.

Aridity can be expressed in a number of ways as a function of rainfall and temperature. One common representation of aridity is the index used by the United Nations Educational, Scientific and Cultural Organization (UNESCO), expressed as the ratio of average annual precipitation to average potential evapotranspiration, the latter being calculated by Penman's method, taking into account atmospheric humidity, solar radiation, and wind (Baumer and Salem 1985). That is,

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\text{Aridity index} = \frac{P}{ETP}
\]

where \( P \) = precipitation
\( ETP \) = potential evapotranspiration

Three bioclimatrical zones of high aridity are delineated by this index: hyperarid (<0.03), arid (0.03-<0.20), and semiarid (0.20-<0.50). Of the total land area in the world, hyperarid zones cover 4.2%, arid zones 14.6%, and semiarid zones 12.2%. Hyperarid zones are regions where annual rainfall is low, rarely exceeding 100 mm. Rainfall is infrequent and irregular, with sometimes no rain for several years. Sparse annual and perennial vegetation and scattered shrubs feature the landscape. True nomadic pastoralism is frequently practiced. Arid zones are characterized by high rainfall variability, with annual amounts generally ranging between 100 and 300 mm. Vegetation is sparse, comprised of annual and perennial grasses, other herbaceous plants, shrubs, and small trees. Extensive and often nomadic pastoralism are found and there is little farming except where irrigation is possible. Annual rainfall in semiarid zones varies from 300 to 800 mm, depending on the relative occurrences of summer and winter rains. Native vegetation includes a variety of grasses and grass-like plants, forbs and half-shrubs, and shrubs and trees. Rain-fed sustained levels of agricultural production is often supported. Sedentary livestock production also occurs. These three bioclimatical zones, together with their surrounding sub-humid margins (0.50-<0.75), comprise the dryland regions of the world.

Large areas of drylands are located in North and South America, North Africa, the Sahelian region, Africa South of the Equator, the Near East, and the Asia and the Pacific regions (Figure 1). More specifically, hyperarid zones are located in Saharan Africa, northern and southeastern Saudi Arabia, Ethiopia, and Namibia. Arid and semiarid zones are more widespread, although there is a tendency for them to be found toward the western edges of tropical and sub-tropical areas of the continental masses, a feature that is particularly marked in southern Africa, the Americas, the Indian sub-continent, and, to some extent, Australia.
Figure 1. Dryland regions of the world (adapted from Dregne 1983).
CLIMATE

Rainfall and Temperature Patterns

Dryland environments are characterized generally by inadequate and variable rainfall. Some of these environments have excessive heat while others are cold areas. However, large contrasts in climate occur, such as that found in Tibet and Mongolia. Three major types of climate – Mediterranean, Tropical, and Continental – are found in the drylands of the world. Rainy seasons in a Mediterranean climate normally occur in autumn and winter (Figure 2a). Summers are hot with little or no rains, while winter temperatures are relatively mild. Rainfall occurs during the summer in areas typical of a Tropical climate (Figure 2b). The greater the distance from the equator, the shorter the rainy season is. Winters are long and dry. Rainfall is distributed more-or-less evenly throughout the year in a Continental climate, although there is a tendency toward greater summer rainfall (Figure 2c). Summers are hot while winters are comparatively cold.

Modifications of the three major types of climate are found throughout dryland environments. For example, two rainfall periods occur in Tucson, Arizona, one in the hot summer and another in the cool winter (Figure 3). Although total annual rainfall is frequently less than 300 mm, its distribution into two seasons partly explains the relatively dense cover of small trees, shrubs, and other herbaceous species which is common to the Sonoran Desert of northern Mexico and the southwestern United States.

Rainfall variability and the occurrence of prolonged periods of droughts are a characteristic of dryland regions that must be recognized in the planning and management of natural and agricultural resources (Jackson 1989). Over two-thirds of Africa receives annual rainfall during three months and there are large variations in the amount of annual rainfall that occur. The maximum annual rainfall recorded in Liberia is 1,203 mm, the minimum is 123 mm, and the average is 461 mm. At Meru, Kenya, rainfall amounts in October have ranged from as little as 15 mm to as much as 1,386 mm. Even in the most arid areas, rainfall can be quite variable. The average annual rainfall at the Red Sea station of Hurghada is only 8 mm. In November 1991, however, 41 mm of rain fell in one day. While more examples could be presented, the point made is that average values of seasonal or annual rainfall do not necessarily provide a representative picture of the climatological conditions for many dryland regions.

Rainfall intensity is another parameter that must be considered in planning and management of natural resources. Because the soils of dryland environments often can not absorb all of the rain that falls in large storms, water is often lost from a site by runoff processes (Brooks et al. 1997). At the opposite extreme of the spectrum, water from a rainfall of low intensity can be lost through evaporation when the rain falls on a dry soil surface. Rainfall intensity also relates to the risk of soil erosion. Individual rain drops carry enough energy to be capable of removing top-soil upon impact, causing splash erosion which can degrade or destroy the soil structure through time.

Dryland environments are frequently characterized by a relatively cool and dry season, followed by a relatively hot and dry season, and, finally, by a moderate and rainy season. There are often significant diurnal fluctuations in temperatures that restrict the growth of plants within these seasons. Plant growth takes place between species-specific maximum and minimum temperatures. Extremely high or low temperatures can be damaging to plants. Plants might survive high temperatures if they can compensate for these high temperatures by transpiration, but their growth rates can be affected negatively. High temperatures at the surface layer of the soil result in a rapid loss of soil moisture because of the high evaporation and transpiration rates.
Figure 2. Annual precipitation and temperature in a) Rabat, Morocco, b) Sennar, Sudan, and c) Alice Springs, Australia. (Bars represent precipitation; lines represent temperature)
While problems of low temperature are generally less common in dryland environments, when they occur over relatively long periods of time, plant growth can be restricted. Plants die at prolonged temperatures below 0° C.

Atmospheric Moisture

Atmospheric moisture (humidity) has importance to the water balance of a soil body. There is a tendency for water to evaporate into the atmosphere when the moisture content of the soil is higher than the air. When the opposite is the case, water will condensate into the soil. Atmospheric humidity is generally low in dryland environments. Occasional occurrences of dew or mist along large water bodies can lead to higher humidity in the air than otherwise expected and, therefore, reduce evapotranspiration and conserve soil moisture.

Wind

Dryland environments are typically windy, largely because of the scarcity of vegetation and other obstacles that can reduce air movements. Wind moves the moist air that surrounds plants and soil bodies and, as a consequence, decreases atmospheric moisture and increases evapotranspiration rates. Some plants inherently transpire less than other plants and, therefore, are adapted to dry environments. Dust storms are also frequent when little or no rain falls. Soil erosion by wind occurs whenever the soil, vegetation, and climatic conditions are conducive to this kind of erosion. These conditions are encountered in environments with loose, dry, and fine soil, a smooth ground surface, a sparse vegetative cover, and sufficiently strong wind to initiate soil movement. Among the more damaging impacts resulting with wind-blown soil particles is the sorting out of the soil material. Erosion by wind gradually removes silt, clay, and organic material from the soil surface, with the remaining materials being sandy and infertile. The residual sand that piles up in dunes on some landscapes presents a threat to the surrounding lands.
DROUGHT

Occurrences and the effects of drought require special attention in planning and management of natural and agricultural resources in dryland regions. A drought is a departure from the average or normal conditions in which shortage of water adversely impact ecosystem functioning and the resident populations of people. The terms drought and aridity are sometimes used interchangeably and, therefore, incorrectly. Aridity refers to the average conditions of limited rainfall and water supplies, not to the departures therefrom which define a drought.

It is known that drought will likely occur in the future, but it is not possible to reliably predict when they will occur, their severity, or how long they will last. Because of the uncertainties associated with drought and the severity of the impacts, there are many considerations about drought that must be taken into account in planning and management of natural and agricultural resources in drought-prone regions. Drought is generally characterized by shortages of water, food for people, and forage for livestock that can lead to unplanned and often unwise use of available agricultural and natural resources (Box 1). Serious degradation of land and resources can result if contingency planning is not undertaken to meet these shortages.

Box 1

The Palmer Drought Index

The Palmer drought index (Palmer 1965) is used as an indicator of drought severity and a particular index value is often the signal to begin or discontinue a drought contingency plan (Lohani and Longanathan 1997). A drought is defined (by this index) as a time interval of time in the order of months or years in duration during which the actual moisture supply at a location consistently falls short of the climatically appropriate moisture supply. The severity of a drought is considered to be a function of both the magnitude and frequency of the moisture deficiency. While other drought indices have been developed to give (theoretically) better representations of relative wetness and dryness than the Palmer indices (McKee et al. 1993, 1998), the Palmer drought index and its variations have been used for monitoring and decision-making for decades and, therefore, are familiar to the user community. If other drought indices are to replace the Palmer indices, comparisons of the characteristics of the respective indices will be necessary so that users can transfer their familiarity with the Palmer index to the other indices (Guttman 1998).

GEOMORPHOLOGY

Mountain massifs, plains, pediments, and deeply incised ravines and drainage patterns in the drylands regions of the world display sharp changes in slope and topography, and a high degree of angularity. Streams and rivers traverse wide floodplains at lower elevations and, at times, are subject to changes of course and display braided patterns. Many of these landforms are covered by unstable sand dunes or sand sheets. Sand can also inundate grazing lands, fields of agricultural crops, and cities and villages. Other geomorphical features and processes influence soil formation and characteristics, including the distribution of coarse and fine soil fractions from transportation processes, reworking, and disposition by wind and water and the periodic inundation of floodplains. Among the beneficial effects of these influences are the replenishment of soil nutrients and leaching of accumulated salts in the soil.
SOILS

Soils are diverse in their origin, structure, and physical and chemical properties. Important aspects of the formation of soils in dryland environments are the frequently encountered large diurnal changes in temperature that cause mechanical and physical disintegration of rocks and wind-blown sands that score and abrade exposed rock surfaces. The physical disintegration of rocks leaves relatively large fragments which are then slowly broken up by chemical weathering. Vegetation also plays a fundamental role in the process of soil formation by breaking up rock particles and enriching the soil with organic matter from above- and below-ground plant parts. This role can be lessened in dryland environments because of the sparse vegetation and limited development of above-ground plant parts. However, the root systems of these plants are often extensive laterally and vertically extensive and it is this characteristic which mainly affects the soil.

Of primary importance to planners and managers of natural and agricultural resources are the water-holding capacity of these soils and their ability to supply nutrients. Soil depth and texture largely governs the amount of water that can be held in a soil body. However, the depth of soils in dryland regions is often limited by a hardpan layer, restricting water-holding capacities and rooting depth. These hardpans, often consisting CaCO$_3$ or siliceous materials, can be more-or-less continuous and occur between 5 and 60 cm below the surface. As there is little deposition, accumulation, or decomposition of organic material in dryland environments, the organic content of the soils is low and, therefore, natural soil fertility is also low. The limited organic matter that is present can be quickly lost when soils are cultivated for agricultural crop production. Soils are often characterized by the extensive leaching of nutrients and intensive weathering of minerals on older exposed surfaces.

WATER RESOURCES

Much of the water that is available to people living in drylands regions is found in large rivers that originate in areas of higher elevation. These rivers include the Nile in the Sudan and Egypt; the Tigris, the Indus, the Ganges, the Senegal, and the Niger; and the Colorado in the western United States. Groundwater resources can also be available to help support development. However, the relatively limited recharge of groundwater resources is dependent largely on the amount, intensity, and duration of the rainfall, and soil properties, the latter including infiltrations capacities and water-holding characteristics of the soil, which also influence the amount of surface runoff. Much of the rainfall is lost by evapotranspiration, and, as a result, groundwater is recharged only locally by seepage through the soil profile. Surface runoff events, soil moisture storage, and groundwater recharge in dryland regions are generally more variable and less reliable than in more humid regions. Groundwater is frequently used at rates that exceed recharge.

Water that is available for use in many drylands regions can be affected by salinity. Problems of salinity are more widespread and acute in the drylands than other regions (Armitage 1987). Although most soil bodies contain some soluble salts, it is only when the accumulations of salts attain a level that is harmful to plant survival and growth that a saline condition has developed. In effect, therefore, plants “define” the salinity of soil in terms of their relative tolerances. Mineralization of groundwater resources is also a common problem. The causes of mineralization include the evaporation from water surfaces and shallow groundwater, fossil brines from ancient lagoons and lakes, and airborne salts deposited by precipitation and in the form of dry fallout.
Main Plant Forms

Three plant forms - *ephemeral annuals, succulent perennials, and non-succulent perennials* - are found in dryland environments. Ephemeral annuals appear after rains and complete their life cycle during a short season (+8 weeks). Ephemerals are small in size, have shallow roots and, at times, form relatively dense stands and provide some forage. Succulent perennials store water through the enlargement of parenchymal tissue, thereby reducing transpiration rates. This water can then be consumed in periods of drought. Cacti are typical succulent perennials. Non-succulent perennials that withstand the stress of dryland environments are the majority of plants in these regions. Three forms of non-succulent perennials - *evergreen, drought-deciduous, and cold-deciduous* - are found in the drylands. Evergreen plants are active biologically throughout the year, drought-deciduous plants are dormant in the dry season, and cold-deciduous plants are dormant in the cold season.

Adaptive Attributes

Many plants have adaptations which enable them to reproduce, survive, and grow in some of the harshest environments in the world. The extremes of dryland climates largely dictate the form of the physiological adaptations and ecological requirements of plants in these regions. Xeromorphological leaf structures, physiological controls of transpiration and metabolism rates, moisture and nutrient storage organs, and thorns are common features. Such specializations become less pronounced as aridity becomes less severe and the conditions for plant establishment and growth become favorable. At the more “arid end” of the dryland environmental spectrum, only a few of the specially adapted plants provide food for people or livestock, although leaves and flowers of some plants are useful as supplements. Some plants have evolved specialized rooting systems, while others have unique leaf characteristics that allow them to withstand prolonged periods of drought through a reduction in transpiring surfaces (Box 2). Other plants simply lose their leaves when soil moisture conditions become too dry. *Cuticularization*, the formation of surface plaster-like layers of cutin; *cutinazation*, the impregnation of cell walls with cutin to form a water-tight layer; and special arrangements of stomata in recesses and grooves to provide protection from the dry atmosphere are other xerophytic characteristics of these plants.

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**Box 2**

Adaptations of Plants to Dryland Environments of the Southwestern United States (Went 1955)

Mesquite (*Prosopis velutina*) has roots from 10 to 30 m long that enable the plant to tap into underground lenses of fresh water. This morphological adaptation allows mesquite to occupy flood plains and other sites with relatively shallow groundwater and, in doing so, avoid stresses that other plants undergo during drought. The evergreen creosote bush (*Larrea divaricata*) has a wide-reaching root system and specialized adaptations that reduce competition for soil moisture by surrounding plants. The evenly-spaced pattern of creosote bush that is evident from above is due largely to excretion of toxic substances that kill other plants. Spacing of creosote bush is related to rainfall - the less the rainfall, the wider the spacing. Greater amounts of rainfall seem to leach the “poisons” from the soil.
Annual plants also have characteristics that enable them to survive. Seeds of some annuals remain dormant in the soil for many years and only germinate under special conditions. Many of the annuals in the southwestern United States have no morphological adaptations to withstand drought conditions, but they require only 10 to 20 mm of rainfall before they will germinate. Seeds lie dormant in the upper layers of the soil until this threshold amount of rainfall occurs. Apparently, the mechanism by which seeds discriminate between rainfall of more than the threshold amount is the amount of leaching required to remove inhibitors to germination.

WILDLIFE

Characteristics of Wildlife Inhabiting Dryland Regions

Species of indigenous wildlife inhabiting dryland regions often have physiological and ecological advantages in relation to livestock. Among the more significant of these advantages are their abilities to thrive without an abundance of surface water by their movements in time and space, their use of the sparse vegetation for food and cover, and their minimal impacts on the environment when their populations are balanced properly with the environment (Heady and Heady 1982, Child 1989, Ffolliott et al. 1995). Many of these wildlife species possess attributes of disease, heat, and drought tolerance, and reproductive and meat production characteristics that are generally more efficient than livestock.

Uses of Wildlife Resources

Principal ways in which the wildlife resources are used by people include cropping for meat, skins, and trophies, and viewing and photography by tourists (Heady and Heady 1982, Child 1989). The meat of wildlife is often a source of food for pastoralists and agricultural cultivators of marginal lands in times of drought. It is likely that the importance of wildlife for meat will increase in many countries in the future as the carrying capacities for livestock continue to decline because of overgrazing. Harvesting of wildlife for skins and trophies in many countries is driven mainly by needs for increased incomes, and, as a consequence, populations can be decimated without regard to more sustainable wildfire values. Cropping of wildlife is a form of use on relatively open lands that are not sanctuaries, while viewing and photography are more prevalent in natural parks and reserves where concentrations of wildlife can be seen.

LAND USE

Largely unconfined livestock grazing has historically been widespread in the dryland regions of the world and will continue to be a significant and, in some countries, a dominant land use into the future. The number of livestock can be a measure of one’s wealth and status. Small-scale and mostly rainfed agricultural cropping is found on sites favorable to this form of land use (Ffolliott et al. 2002). Larger-scale more intensive agriculture is practiced where irrigation technology is available and economically feasible. Intensive forestry practices have been uncommon in the past, although this form of land use has been increasing, especially with the establishment of energy plantations for fuelwood (Ffolliott et al. 1995). Interest in dryland forestry as a sustainable land use has been gaining attention by both foresters and local people.
Combinations of agricultural cropping, livestock production, forestry, and other types of production systems are frequently placed on the same piece of lands, either rotationally, simultaneously, or spatially on the same piece of lands. Regardless of the nature of these combinations, attaining ecological stability and sustainable benefits to users of the land is the goal. Combined production systems that include trees or shrubs are known more commonly as agroforestry systems (Nair 1989, Gordon and Newman 1997, Buck et al. 1999). Historically, it has been a common practice for rural people living in the dryland regions to cultivate agricultural crops and tree or shrubs in intimate combinations (Box 3). Agroforestry is recognized by professional and lay stakeholders as a set of systems, practices, and technologies that are capable of yielding food and wood while conserving resources and, when necessary, rehabilitating ecosystem

Box 3

Examples of Agroforestry Practices in Dryland Regions

Neem (Azadirachta indica) has been planted in windbreaks of two rows in the Majja Valley of central Niger for more than 25 years (Persaud et al. 1986). Local villagers began to harvest fuelwood by varying methods from the oldest windbreaks 10 years after their initial plantings. Harvesting the fuelwood by removing branches overhanging the alleys from trees in both rows maintained the environmental benefits of the windbreaks in controlling wind erosion and, in doing so, increased the yields of millet and other cereals planted in adjoining fields.

The Dehesa system in southwestern Spain consists of two closely relative agroforestry practices (Maranon 1988, Joffre et al. 1989). Livestock are grazed in woodlands that are dominated by Quercus ilex, with Q. suber and Q. faginea occasionally intermingled, at which time the practice is silvopastoral in nature. Cereals are cropped on one-fifth of the area every 5 years, when the practice is agrosilvipastoral. Mature Q. ilex trees are harvested for fuelwood, other local wood products, and acorns. When they are present, Q. suber is harvested for cork every 10 years and Q. ilex is lopped every 8 to 12 years to enhance production of acorns.

Multipurpose trees are agroforestry systems in themselves. A well-known multipurpose tree in the Sahelian region is Acacia albida. Farmers value the tree for fodder and green manure and it is harvested for tannis and gums, charcoal, and wood for carpentry (Hocking 1987). A unique feature of A. albida is its leaflessness in the rainy season, which minimizes its competition with agricultural crops. The tree also provides shade for people and their livestock.

Consumptive and non-consumptive uses of wildlife resources, recreational activities and tourism, and amenity plantations of trees and shrubs are also important components in many efforts to attain conservation and sustainable use of dryland systems. Although it is not always possible to place monetary values on these components, they frequently make economically significant contributions to overall developmental activities and the general well-being of local people. It is necessary, therefore, to consider the varied roles that wildlife, recreation and tourism, and amenity plantations play in dryland regions when addressing issues related to land use.
PEOPLE

Almost 75% of the people inhabiting dryland environments live in semiarid zones, 25% in arid zones, and only 1% in hyperarid zones. The mostly rural human population densities are generally less than 1/km² in the hyperarid zone, below 5/km² in the arid zone, and about 10/km² in the semiarid zone (FAO 1989a). The populations inhabiting dryland regions is 72% agricultural, 7% animal-based, and 21% urban. Increasing populations of people moving into spreading urban areas is a major demographical feature of the dryland regions, however, paralleling this migration in other regions.

Rural people living in drylands are arranged roughly into nomadic, seminomadic, transhumant, and sedentary populations. Nomadic people are found in pastoral groups which depend on livestock for subsistence and, whenever possible, farming as a supplement. Following the irregular distribution of rainfall, they migrate in search of pastures and water for their animals. Seminomadic people are also found in pastoral groups which depend largely on livestock and practice agricultural cultivation at a base camp, where they return for varying periods of time. Transhumant populations combine farming and livestock production during favorable seasons, but seasonally they might migrate along regular routes when forage for grazing diminishes in the farming area. Sedentary farmers practice rainfed or irrigated agriculture. Land use practices are often a form of agroforestry in structure and function.

There is often little distinction between a farmer and a pastoralist. People living in dryland environments generally take into account the limitations of the local conditions they confront and adopt to whatever land use is suitable and feasible in seeking their livelihood. However, the delicate balance that is achieved through traditional forms of farming and livestock production is easily upset; this is shown by a general deterioration of grazing lands in dryland regions. A main cause of this deterioration - often referred to as desertification in its most severe form - is the over-population of people and their livestock, where agricultural cropping and pastoralism become competitive rather than complementary forms of land use.

DESERTIFICATION

A map of the dryland regions of the world (Figure 1), when compared to a world map of desertification (Figure 4), shows a close correlation between the drylands and the locations of areas that are likely to be affected by desertification. This correlation is often explained by the fragile dryland environments undergoing aeolian and fluvial erosion, soil salinization, and loss of vegetation by overgrazing by livestock, over cutting of fuelwood and trees, and other excessive uses of the land and natural resources by people (El-Baz 1991). The prevailing climate also exerts a persisting stress on both soil and vegetative resources. Relatively little disturbance can cause instability and imbalance, leading to desertification as a result. Desertification plagues all regions of the world and results from varying combinations of climatic and other natural stresses and human activities.
Figure 4. Desertification in the world (adapted from the United Nations 1977).
The United Nations Environment Program (UNEP) has estimated that 35 million km$^2$ of the dryland regions of the world, an area approximately the size of both North and South America, are affected by desertification or the threat of desertification (FAO 1989b, UNEP 1992). Nearly 25 million km$^2$ of this area has been classified as exposed to either high and very high desertification risk. Equally important is the fact that 30,000 km$^2$ are reduced to a state of “uselessness” every year, a loss that is expected to continue into the future unless remedial actions are taken. Destruction of the impacted lands’ productive capacity brought about by desertification costs the world more than $75 billion each year.

The multitude of problems that constitute desertification defy a single solution. The magical “magic bullet” does not exist nor is it realistic to expect that it will ever exist (Mouat et al. 1995). Physical, biological, and economic and other social factors causing desertification vary so widely and are found in such a bewildering array of combinations that most of the “formula-based solutions” for dealing with the issues of desertification are incomplete and insufficient. Desertification control and the related resource development is likely more a social activity than a technical one. Desertification, therefore, is largely a problem for people to mitigate.

**CONCLUDING COMMENTS**

Sustaining land use is a challenge to the people living in dryland environments. Problems commonly faced by these people include desertification, inadequate knowledge of more productive land-use practices, and low levels of investment. The issue of desertification has already been discussed. However, people can also confront major problems in attempting to attain a level of sustainable land use because of their inadequate knowledge of alternative land use practices (Ffolliott et al. 1995, Squires and Sidahmed 1998). Many people have a “tradition” in agriculture that is not always matched by a similar attitude toward other land uses such as forestry, wildlife ranching, or ecotourism, all of which have become profitable enterprises in many dryland regions of the world. This lack of appreciation can be a barrier to the initiation of these land uses, especially on marginal agricultural lands. The barriers are often overcome through the education of people, extension services, and, most of all, through demonstrating the benefits obtained through more diversified land-use activities.

The drylands of the world also suffer from the vicious cycle of low productivity, low levels of investment, and, as a result, poverty. Investments, apart from those made for irrigated agriculture activities, are relatively low (Marples 1986, Ffolliott et al. 1995, Squires and Sidahmed 1998). Low productivity, low levels of investment, and land degradation often leading to desertification are responsible for regional poverty and income disparities. The poverty and hunger that are prevalent in sub-Saharan Africa is a poignant example of this situation. Other critical problems include the inherent problem of water scarcity, tenure considerations, and ineffective developmental policies. Improving this situation requires that a variety of technical and institutional problems be solved. Among these solutions is increasing the level of investments in appropriate agriculture, alternative land use practices, and other appropriate income-generating interventions. Other solutions are designing strategies for risk management and implementing programs for more equitable land distribution and levels of income.
REFERENCES


