



Land Degradation in the Drylands

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Land degradation in the drylands, also called desertification, has affected the world for centuries, even millennia, in Africa, Asia, and Mediterranean Europe, for one or two centuries in the Americas, and 100 years or less in Australia. Among the principal degradation processes are vegetation degradation in rangelands, water and wind erosion, salinization of irrigated and certain semiarid lands, and soil compaction. Farmers, ranchers, and researchers, in general, are aware, from their personal experiences, of the environmental changes land degradation has brought. Unfortunately, there are little good research data on just how much damage has been done. Much of the evidence is from what can be seen, such as gullies, mobile sand dunes, and buried cities, as well as undocumented anecdotes of ancient and modern travelers. Given the uncertain data base, it is no wonder that there are radically different beliefs of the severity and the damage cost of land degradation in the drylands. This review attempts to analyze global information sources and draw tentative conclusions on the significance of on-site and off-site impacts of land degradation. The pressing need is for more reliable data that will help determine the priority the problem should have in national and international planning.

Keywords arid lands, desertification, overgrazing, rangelands, salinization, semiarid lands, water erosion, wind erosion

Controversy, both informed and uninformed, inevitably surrounds and confounds discussions of land degradation in the drylands. The 1977 United Nations Conference on Desertification (UNCOD) gave legitimacy to using “desertification” as a synonym for dryland degradation. A severe and protracted drought in the Sahel region of sub-Saharan Africa provided the rationale for holding the conference. That drought had led to the deaths of untold numbers of livestock and, indirectly, of pastoralists and villagers who sought to survive the ravages of the countryside by fleeing southward to cities and refugee camps. At first glance, drought was the culprit responsible for decimation of livestock herds. Later, the blame was placed on the combination of drought and overgrazing. Still later, as the scope of the conference preparations, under the leadership of the United Nations Environment Program (UNEP), expanded to global drylands, it became obvious that land damage in the drylands was due to more than drought. Dryland degradation affects rainfed croplands and irrigated land, as well, and many more people than just pastoralists. Drought sometimes contributed to the land damage; often it was not a factor.

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The word desertification, as far as is known now, was first used by a French biologist studying grazing lands in arid southern Tunisia (Lavauden, 1927). Lavauden did not expressly define the term but used it in referring to the low grazing productivity of land surrounding a protected 3,500 ha ranch near Maknassy. Range conditions inside the ranch were much better than conditions outside. He attributed the difference to controlled grazing inside the protected area and uncontrolled grazing outside. In 1949, a French forester working in humid West Africa wrote that forest destruction and subsequent severe water erosion caused land damage that he called desertification (Aubreville, 1997). Aubreville, too, did not define desertification in his book. He described the eroded land as being like a desert, abandoned and useless.

Both Lavauden and Aubreville ascribed the land degradation they wrote about to ill-advised human action. The degradation process that they called desertification was vegetation degradation—overgrazing in the drylands of Tunisia and tree cutting in the humid Ivory Coast. At UNCOD, the desertification concept was expanded to include wind erosion, salinization, and waterlogging, primarily, as well as other processes such as heavy metal pollution of soils. In the final analysis, desertification was said to be any process that reduced or destroyed the biological productivity of the land. There was no explicit restriction of desertification to drylands but the actions taken at the conference made it clear that desertification was a dryland problem (UNCOD, 1978).

The definition of desertification currently employed by the United Nations was adopted at the United Nations Conference on Environment and Development in Brazil in 1992 (UNCED, 1992). It says that desertification is land degradation in arid, semiarid, and dry subhumid areas resulting from various factors, including climatic variations and human activities. In this definition, it is clear that desertification, in the context of land degradation, applies only to the drylands. Land degradation, in turn, is defined as the diminution or destruction of the biological productivity of the land. Land refers to soils, plants, and water resources.

According to the *World Atlas of Desertification* (UNEP, 1992), drylands have a ratio of average annual precipitation to potential evapotranspiration (ET_p) of less than 0.65. Hyperarid climatic zones are not part of the desertification definition because they are presumed to be so dry that human degradation is severely limited unless irrigation is practiced. So there can be no desertification. Drylands, then, are the climatic zone with a P/ET_p between 0.05 and 0.65, according to the *World Atlas*.

The most recent attempt to enlist global support to combat desertification occurred when a resolution was passed at UNCED to establish, under United Nations auspices, an international convention on the topic. The full name of the convention (an international agreement) is “United Nations Convention to Combat Desertification in those Countries Experiencing Serious Drought and/or Desertification, Particularly in Africa.” It is commonly known as the Convention to Combat Desertification (CCD) (UNEP, 1995), for obvious reasons. The CCD came into force in 1996 when the requisite number of countries had ratified it.

Leadership in efforts to stop and reverse the environmental deterioration in drylands that is called desertification has come from United Nations (UN) agencies since UNCOD was convened in 1977. UNEP originally had the primary role. At present, the CCD secretariat in Bonn, Germany, is expected to carry out that function. Major other contributing UN agencies have been the World Bank, the United Nations Development Program, the Food and Agriculture Organization, and the agency formerly known as the United Nations Sudano-Sahelian Office (UNSO).

Since UNCOD brought the world’s attention to land degradation in the drylands, there has been a multitude of definitions and interpretations of the term “desertification.” For UNEP, desertification refers to a collection of land degradation processes, of which five have the most severe impact on land productivity. Those five are (1) vegetation degradation, (2) water erosion, (3) wind erosion, (4) salinization, and (5) soil compaction. A sixth process, soil fertility decline, is widespread but is easily controlled if fertilizers are applied.

Even a casual perusal of desertification articles shows that authors have widely different ideas of which land degradation processes are desertification processes. Some writers believe that wind erosion is the sole desertification process. Others think that it is rangeland deterioration. Still others contend that water erosion is the only important process. To add to the confusion, respected researchers such as Mainguet and many Swedish scientists believe that all true desertification is irreversible land degradation (Mainguet et al., 1991; Anonymous, 1991). For this group, desertification is the spread of desert-like conditions. The key difference is "the spread of desert-like conditions." The proceedings of the 1977 conference make it clear that desert-like conditions are the end point of land degradation processes that are not stopped before they become irreversible. For the vast majority of the drylands that wasteland end point never occurs. A 1992 country-by-country global analysis, which had a much better data base than the pioneering 1983 study (Dregne, 1983), estimated that the very severe (irreversible) desertification class included about 780,000 km², only 1.5% of the drylands (Dregne & Chou, 1992).

Of the major land degradation classes, water and wind erosion can cause irreversible degradation. Seldom do salinization and compaction become irreversible. Much of the vegetation degradation can become irreversible if it is in the arid climatic zone. Examples of irreversible degradation include the ruinous water erosion in the humid tropics that Aubreville (1949) labeled desertification and the formation of mobile sand dunes in pastoral drylands. In this review, the focus is on human-induced land degradation in the drylands.

Assessment of Land Degradation in the Drylands

Only four global assessments of the extent and severity of desertification have been published. The first was a map that was included in one of the documents of UNCOD (Dregne, 1977). It was based on very little data or experience and has only historical significance, if any. A so-called World Map of Desertification was prepared by FAO, UNESCO, and WMO (1977) for UNCOD. In actuality, it was a vulnerability (hazard) map that showed nothing about the location or severity of land degradation. A few years later, the first country-by-country assessment was made of land degradation in 100 countries (Dregne, 1983). In that assessment, there were four degradation classes for each of three land uses: irrigation, rainfed cropping, and grazing. Again, the data base was poor. Field experiment data were mainly restricted to water effects on crop yields. Informed opinion, anecdotal evidence, observations by travelers, and published and unpublished reports formed the basis for the numerical estimates. A principal purpose of the exercise was to provide estimates that knowledgeable people could react to and improve upon in an iterative process that would lead to better estimates. The latter hope has not been realized, whether because readers were uninterested, not knowledgeable about their own country conditions, unwilling to publish their estimates, or some other reasons.

The 1992 assessment was considered by its authors to be considerably better than the 1983 estimates, due to additional field experiments and better literature searches. Its accuracy was still low, presumably, but there was no way to check that because there were no good base data against which to compare estimates. Interestingly, there have been nonspecific claims made that the assessment was inaccurate, but no one has been willing to say what the correct numbers should be. That smacks of mindless criticism that fails to advance understanding of the true magnitude of country or global land degradation.

The fourth global survey, conducted under UNEP sponsorship, was an analysis of human-induced soil degradation for both arid and humid regions. Vegetation degradation was not assessed. The product was a map constructed from the informed opinion of hundreds of soil scientists and others on soil degradation in the drylands of their countries and regions. It is far and away the best representation of

world soil degradation (Oldeman et al., 1990). It provided virtually all the data for the first edition of the *World Atlas of Desertification* (UNEP, 1992), which is not an atlas of land degradation but an atlas of soil degradation, ignoring the most widespread degradation process of all, vegetation degradation. The greatly revised second edition of the atlas attempts to rectify the overemphasis on soil degradation in the first atlas (UNEP, 1997). In this review, nearly all of the information comes from published reports, of varying quality.

Africa

The drylands of Africa amount to about 2,100,000,000ha. Nine countries clustered around the Sahara have more than 100 million each, as does the Republic of South Africa. Land degradation in the drylands of Africa has been studied, to varying degrees, in different parts of the continent for at least 90 years. For the then-British colonies, surveys of the status of soil erosion have been published by Stockdale (1939) and Jacks and Whyte (1988). Similar surveys may have been made for the former French colonies, but the only known land degradation studies were by two biologists, Lavauden (1927) and Aubreville (1949). Those two were, apparently, the first scientists to use the term desertification in a publication. Stockdale stated that Stebbing's (1935) much maligned contention that the Sahara was encroaching on northern Nigeria was not a case of drifting sand but a local wind erosion phenomenon related to overgrazing and cultivation. He also said that northern Ghana was in worse condition than Nigeria, largely due to control of rinderpest in cattle and the subsequent increase in livestock numbers. East Africa (Tanzania, Kenya, Uganda, and Somalia), according to Stockdale, was in much worse shape than the British West Africa colonies. Kenya's erosion was called the most important problem the country faced, so bad that it was impossible to exaggerate. Erosion was severe in both the "White" highlands and in native reserves but it was only a minor difficulty in pastoral Masailand. Stockdale further noted what was to become a global problem: expanding cultivated land reduced the amount of grazing land, leading to increased stocking rates and overgrazing. Tanzania had a serious wind erosion problem near Lake Victoria. Vegetation recovered quickly, though, if the overgrazed areas were allowed to rest for one or two years. Somalia had some overgrazing but vegetation, as in Tanzania, could recover rapidly if overgrazing were controlled.

Lesotho, in Stockdale's view, was a bad example of unchecked water erosion due principally to overgrazing. In Zimbabwe, he claimed, White settlers ignored soil erosion on cash-cropped land (tobacco). The introduction of up-and-down hill plowing in the native reserves was disastrous. No mention was made of conditions in South Africa, Malawi, and Swaziland.

Jacks and Whyte described the severity of water erosion, principally in eastern and southern Africa. They pointed out the bad erosion in the Kenya highlands that followed the coming of Europeans. Also, they noted the badly eroded land in the Karamoja watersheds of eastern and northern Uganda. Erosion was said to be not a pressing problem in Zambia. Overgrazing was severe in the South African veld, and sheet and gully erosion had occurred in large parts of Zimbabwe and Malawi.

Overall, the two 1930s assessments of African British colonies emphasized water erosion nearly everywhere except Egypt, the Sudan, and Zambia. Overgrazing was widespread but not particularly severe. Kenya, eastern Uganda, and Lesotho experienced severe gully and sheet erosion. A review article on erosion and soil productivity in Africa was published by Dregne (1990).

East Africa

Stahl (1994) described the East Africa highlands as having a high agricultural potential but experiencing increased land degradation, especially in Ethiopia. In

contrast, Chege (1993) says that Kenya, with about 70% of its cultivated land in terraces, has one of the best records for soil and water conservation in Africa. The country is said to have increased agricultural production even faster than its high rate of population growth. Chege attributes the reduced erosion to terraces. Upon achieving independence, natives destroyed conservation structures in retaliation for British-enforced conservation that the Kenyans resented (Stocking, 1985). Comparing photographs taken of the Machakos area in 1937, when erosion was severe, with 1991, when erosion was under control, Tiffen et al. (1994) drew the then-heretical notion that dense population pressure could lead to environmental recovery, in some circumstances. They found, though, that economic improvement depended on a combination of off-farm income and production of high-value crops. Grazing land showed little change.

A direct contrast to the successful control of erosion in Machakos (Tiffen et al., 1994) was reported by Oruka (2000) for the humid Muranja District in the central highlands of Kenya. In Muranja, population growth is rapid while cropping becomes less profitable. Erosion is getting worse, land productivity has dropped, and little soil conservation is practiced. Farmers cannot afford to fertilize crops, and there are few off-farm jobs. Agriculture is the main business. The immediate future is bleak.

The Baringo-Kerio Valley in a semiarid bushland of Kenya has long been recognized as an example of human misuse of the land. It was identified by the colonial government in the 1930s as one of the worst eroded areas in the country (Thom & Martin, 1983). Gully, rill, and sheet erosion are prevalent everywhere, particularly on steep slopes into which farmers have reached due to population pressure. It remains degraded today. In an instructive assessment of vegetation degradation in northern Kenya by local tribes (Turkana, Rendille, Samburu, etc.), Stiles (1983) described the role of camels in the livestock herds around Lake Turkana. He felt that the increase in the camel population compared to that of cattle in the herds is probably the most reliable indicator that substantial environmental degradation—in this case, desertification—has occurred in a region. Camels are better able to maintain good condition in degraded land than are cattle.

Land degradation and soil conservation in the semiarid regions of central Kenya were looked at by Ostberg (1987) through the eyes of farmers he interviewed. He noted the large-scale land degradation in many parts of the nation and the frequently successful control of water erosion using a local terrace-building technique called *fanya-juu*. Ostberg also made a perceptive comment that applies widely in the drylands. It was that it is as important to farmers to minimize risk as it is to maximize yields. Ostberg also said that the message that soil conservation is important has spread far and wide in Kenya.

A simple methodology for estimation and monitoring erosion has been devised by Dunne (1977). He developed and tested it in Kenya. It uses comparisons of soil loss around stable elements such as trees, fence posts, and archaeological sites. Cemeteries and religious places can also be noneroded base points sometimes.

A grazing experiment conducted by Oba (1992) in the Turkana region of northwestern Kenya produced a surprising result: six years of protection against grazing eliminated a valuable plant, *Indigofera cliffordiana* J.B.Gillett, which relies on grazing to maintain its vigor. The experiment demonstrated that rehabilitation of degraded pastures was easily achieved by controlled grazing, with periods of rest.

Several scientists have written about the shift of vegetation belts in the Sudan caused by human activities (Cloudsley-Thompson, 1974; El-Kassas, 1977; Lamprey, 1988; Stebbing, 1935). Cloudsley-Thompson believed that vegetation degradation in the savanna zone on the south side of the Sahara began long ago with the expansion of the human population. The concept of an expanding Sahara (desert encroachment) has been attractive to many observers. However, satellite imagery has demonstrated that the vegetation density on the edge of the Sahara varies with the local

rainfall (Tucker et al., 1991). Apparent vegetation shifts are pronounced when there are droughts or wetter-than-normal years. Lamprey's desert encroachment conclusion was disputed by Hellden in the 1988 report. It should be noted, though, that Hellden's research in the area investigated by Lamprey was an analysis of satellite imagery, which is a notably unreliable method for measuring vegetation types when there is no ground truth. Furthermore, Hellden defined desertification as the onset of desert-like conditions (barren land), while Lamprey was analyzing vegetation changes of a less dramatic character. Changes that do not cause formation of a barren desert would not have been measured by Hellden. A later ground study in northern Sudan (Hussein, 1991) concluded that serious vegetation degradation had taken place. The cause was overstocking of livestock. In contrast to Hellden, Ahlcróna (1988) found from her analysis of satellite images that the major factor controlling vegetation productivity in central Sudan was rainfall. Qualitative deterioration of the vegetative cover was related significantly to human-induced land degradation.

In a 250,000 km² region in Darfur Province in western Sudan, Mensching and Ibrahim (1981) found that continuous grazing and browsing in the 100 to 400 mm precipitation Sahel zone had severe consequences for the ecological balance. Degradation usually took place in concentric rings around settlements. Pastures grazed only in the dry season in the 100 to 250 mm zone and in the wet season in the 400 to 900 mm zone were much less degraded. Research on dryland degradation in the central Sudan area (Kordofan Province) by Olsson and Rapp (1991) described the causes and severity of overgrazing of pastoral lands and nutrient deficiencies in cultivated land. Rainfed cropping and sedentary animal husbandry have come to occupy much traditional rangeland in this area, where the rainfall varies from 100 to over 600 mm (Ayoub, 1999). Nomads have been forced into marginal areas where livestock numbers exceed the carrying capacity. Drought worsens the situation (Olsson, 1993). Following the severe drought year of 1984, vegetation recovery was surprisingly rapid, despite only a modest increase in rainfall. The reason seems to be the low level of grazing land exploitation due to the large numbers of people and animals wiped out in 1983 and 1984 (Olsson & Rapp, 1991).

While Burundi apparently received little study, Lewis et al. (1988) have used something like 19,000 Gerlach troughs (small soil-collecting devices) to measure water erosion in Rwanda. With an average erosion rate of 10 Mg ha⁻¹ a⁻¹, erosion is modest. Part of that is due to widespread banana production and a low runoff.

In colonial days, two authors wrote about severe water erosion in the northern Uganda district of Karamoja. Wilson (1960) noted that erosion was worst in the eastern part, moderate in the center, and slight in the west. Overgrazing was said to be the cause of the sheet and gully erosion that scarred the landscape. Heavy grazing had changed grassland to bushlands and thickets, with much of the tree-covered savanna becoming bare rock. In those years, grasslands on black clays were saved by the lack of water for livestock. Chenery (1960) compared the badly eroded land in Karamoja to the badlands of the United States and South Africa.

Much attention, long ago and recently, has been paid to land degradation in Tanzania. Most of the water erosion seems to be concentrated in the vicinity of the Uluguru Mountains in east central Tanzania (Temple, 1972; Rapp, 1975). Stocking suspects that the first efforts to control water erosion in the British colonies began in 1929 in Tanzania with erosion plots to assess the amount of soil washed away (Stocking, 1985). Contour plowing and grass strips had been used in southern Rhodesia (Zimbabwe) in 1913. By the mid-1940s, soil conservation practices were being promoted in all British colonies. Stocking (1985) believed that Malawi, Kenya, and Swaziland had done most to reduce erosion.

A success story in erosion control in Tanzania is detailed in a report by Ostberg (1987). It is the Kondoa Project in the Dodoma region begun in 1973 by the Tanzanian government. The area was known as the Kondoa Eroded Area and was

marked by spectacular gullies. Control practices consisted of constructing bunds, planting trees, building check dams in gullies, planting grass in the lowlands, and banning livestock grazing, a much opposed action. By 1985, Kondo had been transformed and crop production had replaced open-range grazing. It will be difficult to maintain the progress that has been made if the high rate of population increase and in-migration occurs, in addition to hostility toward government edicts (Boserup, 1981; Dejene et al., 1997).

Little is known about land degradation in Somalia except for horrendous human-induced gullies in the overgrazed sand dunes along the Indian Ocean coast near Mogadishu (Mainguet, 1984). Years ago, trees were cut in the coastal strip to provide charcoal for export to Saudi Arabia and other Gulf countries, along with sheep. Efforts to stabilize barren coastal dunes with grasses, forbs, and an introduced vigorous tree, *Prosopis juliflora*, have been effective where livestock could be excluded (Zollner, 1986).

An early report on water erosion on rainfed croplands in the Awash Valley of Ethiopia said that severe erosion occurs in the highlands along both sides of the valley (Pattison, 1974). Erosion also was accelerating on heavily grazed pastoral lands where trees were made into charcoal. Steep lands sometimes were terraced but less-sloping—but obviously eroding—lands were not protected. MacKenzie (1987) asked whether Ethiopia could be saved from the ravages of water erosion. The author noted that, a century earlier, 40% of Ethiopia was forested. By 1985, that had dropped to a mere 3%. Overgrazing was cited as a major cause of land degradation. Terracing has been shown to be effective in increasing grain yields but farmers doubt they are worth the labor they require. The future appears bleak, especially in Wollo and northern Shiva provinces. Campbell (1991) echoed MacKenzie, saying that erosion control is not effective in Wollo. Lal (1985), who had long experience in northern Africa, quoted a 1978 report that about 6,000 km² in Ethiopia's Tigre province were affected by severe water erosion.

Remote sensing was employed by Hellden (1987) to measure rates and amounts of deforestation and fuelwood supply and demand in Ethiopia, as a surrogate for direct assessment of water erosion. Hellden remarked on the paucity of reliable information on water erosion. Hurni (1986) said that perhaps 5 million ha in the subhumid highlands had become irreversibly degraded. Milas and Asrat (1985) were emphatic in saying that 98 million ha of northern Ethiopia have lost so much soil that they have become stone deserts.

Southern Africa

An interesting collection of interviews in a tribal area of Botswana depicted how farmers feel about degradation of rainfed croplands and grazing land (Kinlund, 1996). Farmers agreed that yield decline became noticeable perhaps 50 or more years ago. They attributed the declines to the onset of a drier climate. Introduction of contour plowing was good (cheap) but conservation structures were too costly. Soil fertility was declining, also, they agreed, and fallow periods had been shortened or eliminated. Most villagers were relatively prosperous due to their outside income, despite the low agricultural productivity. Absence of data on soil erosion has led many farmers to dispute the conclusion that erosion is serious. Okigbo (1977) claimed that soil erosion had caused severe damage in Swaziland, Lesotho, and Botswana and appeared to be a problem in Madagascar. Ringrose et al. (1995) believed that increased soil erosion and vegetation degradation occurred in the past decade. According to a study conducted in two places in the Botswana rangelands, water erosion was strongly influenced by vegetative cover (Abel & Stocking, 1987). For both areas, annual erosion varied from 1 to 12 tons per hectare, a relatively moderate amount. An analysis by Dahlberg (2001) of presumed land degradation in northeastern Botswana led to the conclusion that overgrazing and soil erosion were

not clearly evident as major problems. What had appeared to previous observers as conclusive evidence of degradation was now seen as natural changes in response to factors such as drought and restrictive soil conditions. The author's advice to reassess past conclusions of environmental degradation is worthy of action. Reassessments should, of course, include claims of no degradation. Hoffman's (1991) investigation of karoo vegetation in South Africa makes the same point that Dahlberg does. While there seems to be general agreement that rangelands and crop lands are degraded, good data for grazing lands are scarce. Biot et al. (1995) claimed that there had been no loss of livestock production over the last 50 years in Lesotho, despite whatever degradation may have occurred. These authors accepted the possibility or even probability that land degradation had been widespread but claimed there were no data to measure change, up or down.

Zimbabwe is a country where erosion has been recognized as a problem on cultivated land for many decades (Meikle, 1986). In colonial days, the government established Intensive Conservation Areas to control erosion. The program owed its success to several factors: much research in erosion control had been done by the Ministry of Agriculture, aerial surveys were made once or twice each year to check on erosion, commercial farmers supported conservation laws, and extension agents were well trained. One of the earliest experiments on grazing land degradation was conducted by Elwell and Stocking (1976) at a Zimbabwe agricultural research station. As vegetative cover declined under grazing pressure, erosion accelerated rapidly. The experiment was run for 10 years.

Lesotho has been singled out as being one of the worst eroded countries in Africa, if not the world (Bojo, 1991; Speece & Wilkinson, 1982; Millington et al., 1989). Most accelerated erosion has been attributed to migration to Lesotho in the 1880s and the resultant expansion of cultivation to the highlands. The country is dotted with massive gullies. A study of erosion hazard in Lesotho concluded that the hazard, as determined from an erosion model developed in Zimbabwe (SLEMSA: Soil Loss Estimation Model for Southern Africa), was a poor indicator of actual erosion. For the country, the highest hazard was in the highlands where erosion was least, and the lowest hazard was in the lowlands, where erosion was highest (Rapp, 1975; Chakela & Stocking, 1988).

The Republic of South Africa has a lengthy history of recognizing and coping with land degradation, mostly rangeland degradation and erosion (Ross, 1963). The first comprehensive nationwide assessment of erosion came in 1923. A soil erosion advisory council was established in 1930, one year after the first national erosion conference was held. The 1930s saw many soil and veld conservation projects begun and the strengthening of both research and extension activities. A film, *South Africa in Danger*, was produced during World War II to emphasize the erosion problem. Farmer-dominated soil conservation districts were created by the 1946 legislature. In a 1985 sequel to the Ross (1963) publication, Adler (1985) described further soil erosion and vegetation degradation in the Republic. Invasion of grasslands by introduced and native shrubs had, by 1985, become evident nearly everywhere. Replacement of grass by shrubs has laid bare much of the land and brought increased wind and water erosion. Adler said that the man on the street cannot understand how land productivity could increase at the same time that erosion was supposed to have worsened. That perception problem, the same as in the U.S.A Palouse region, puzzles laymen and leads to lessened support for land degradation control. No one, apparently, mentions off-site damage. The problem is global. Casual observers are not aware of the advances that have been made in plant breeding, pesticide control, mechanization, and other technological improvements that reduce erosion effects, but at a price in greater inputs and disturbed ecosystems.

Questions have been raised on the widely held belief in South Africa that an extensive degraded rangeland in the southern part of the country, the Karoo, is expanding (Hoffman, 1991). The Karoo has long been considered to have been

degraded from a perennial grassland to a dwarf shrubland, with a consequent loss of productivity (Hoffman & Cowling, 1990). Overgrazing was said to be the cause. More recently, reviewing reports from early travelers strongly indicates that the Karoo was a mixed grassland-shrubland as long ago as 1777 (Hoffman & Cowling, 1990). Hoffman (1991) concluded that there was no evidence to show that the Karoo was expanding. It seems not to have changed from its present state over the last 200 years.

There is some weak anecdotal evidence from a 1974 television documentary that Madagascar has experienced serious water erosion. Pictures showed massive gullies and landslides. Astronauts were said to have seen a red ring around the island, presumably the result of erosion of the island's red soils. Tree cutting was said to be the main culprit responsible for the erosion. Zachar (1982) cited one example of water erosion in Madagascar. In that place, near Lake Aloatra, annual soil erosion was about 60 Mg ha^{-1} .

One study of vegetation degradation in the Kalahari Desert of Namibia (Spaeth et al., 2000) claimed that serious degradation has been largely confined to circles around villages until recently. Introduction of cattle raising as a replacement for diminished numbers of wildlife was credited with extending overgrazing beyond the immediate vicinity of the villages. Overgrazing and subsequent soil erosion in southern Africa were considered by Huxley (1937), long ago, as the curse of British colonialism. The worst stricken countries were, according to Huxley, Lesotho, Malawi, and Botswana. Cessation of raiding among tribes, introduction of veterinary services, and forced land conservation, although well-meant, increased grazing pressure and native resentment toward the government. Huxley may have been the first scientist to call attention to the adverse effect tse-tse fly eradication had on conserving pastoral resources. He called tse-tse infestation an ally, not an enemy, because it reduced livestock numbers. Huxley also made the famous observation that "Erosion is a problem above all others designed for shelving, so long as these conditions prevail." The conditions to which he was referring were administrative indecisiveness, fear of criticism, and resistance to accepting responsibility. He might have added "lack of information."

West Africa

Land degradation in West Africa received sudden attention in the 1930s when E. P. Stebbing, a British forester, lectured to the Royal Geographic Society in London on what he called the "encroaching Sahara" and the "advance of the desert" (Stebbing, 1935, 1938). Stebbing's idea of a human-induced advance of the Sahara into the populated areas of the Sahel was discredited almost immediately and later discarded by Stebbing, himself. Nevertheless, the advancing desert concept was so tempting to sensationalize that it was described in endless popular articles as a major threat to civilization in Africa. Writers even claimed that the desert front of moving sand dunes was galloping along at a rate of 30 or so kilometers or miles per year, depending upon whether the author was most familiar with metric or English units. Such wild claims trivialized discussion of an important problem.

A comprehensive analysis of land use and erosion control in the extensive subhumid Jos Plateau in Nigeria was made in the mid-1940s by A. T. Grove, a British geographer. His undated FAO report is an excellent description of the development of serious water erosion. It began with trees being cut in the late 1800s to make charcoal, followed by overgrazing on the new deforested lands when Fulani pastoralists moved into the plateau. It was further aggravated by the expansion of rainfed cropping and a shortening of the fallow period as the population increased. Grove noted that most of the trees of the original savanna had been cut down by 1948. He was among the first scientists to call attention to the land degradation and yield losses when fallow periods became shorter and shorter. Okigbo (1977) echoed

Grove in his findings, as did Lal (1977) and Floyd (1965), about damage that erosion had done in eastern Nigeria and the Jos Plateau. Aubreville (1949) was referring to such areas in West Africa when he spoke of desertification (formation of desert-like conditions). Okigbo claimed that there also was severe erosion damage in Swaziland, Lesotho, Botswana, much of East Africa, Rwanda, Burundi, parts of northern Ghana, and hilly areas of Sierra Leone. Lal (1977) listed deforestation, rainfall erosivity, susceptible soils, fire, grazing, cultural practices, and cropping systems as major contributors to African erosion. He endorsed mulching, no-tillage, and a continuous vegetative cover. Traditional farming methods could not meet the needs of a rapidly growing population, in his view. Lal remarked about the off-site erosion damage of reservoir sedimentation. In a later article, Lal (1988) said land degradation was a human-induced condition that was a direct consequence of greed, short-sightedness, poor planning, and the desire for immediate economic returns on the investment. He had no doubt that Africa could feed itself if resources were used better.

Turning to Ghana, Hunter (1972) pointed out the erosion hazard in the savanna of northeast Ghana. He attributed the soil degradation he observed to overpopulation, which led to overworking the land. Although gullies were not frequent, sheet erosion had removed the topsoil in many places. River blindness in the Volta River flood plain kept the human population there low, just as the tse-tse fly did with cattle. It is a terrible disease.

A notable development project in the Kano region of northern Nigeria produced the same result as did Tiffen et al. (1994) in Kenya: more people, less erosion (Harris, 1995). In the Kano area, the author said that lessening erosion was possible only because there were plentiful labor, small farms, and enough livestock to provide the manure needed to keep fields productive. Availability of off-farm jobs was not cited as a contributing factor in reducing erosion in Kano, as it was in Kenya.

French scientists have carried out many experiments on erosion in the former colonies of Burkina Faso, Dahomey, Senegal, Mali, and Niger since 1956 (Mainguet & Chemin, 1991; Roose, 1975; Sterk, 1998). Mainguet, one of the world's foremost experts on sand dunes and wind erosion, published a comprehensive and highly instructive analysis of the fundamentals of the movement of soil particles (Mainguet, 1985). She has had a wealth of experience, particularly around the Sahara, with applying theory to practice in controlling wind erosion. Mainguet identified a little-known kind of wind-rain combination of soil degradation called *wala wala* in Mali (Mainguet, 1984). It appears to be fairly common in places where wind erosion has exposed finer textured subsoils to the impact of raindrops.

Reducing water erosion with *diguettes* has been popular in West Africa for decades (Buerkert et al., 1996). *Diguettes* are lines of stones placed on the contour in cultivated fields. A project initiated in Burkina Faso in 1982 by Oxfam to measure the benefits of stone lines concluded that 10 years was too short a time to separate the effect of rain, alone, from rain plus *diguettes* (Atampugre, 1993). The project did find that building and maintaining stone lines, which was the job of women, increased women's workload. It did have the real merit of increasing community cooperation.

Rapp (1974) reviewed the literature on land degradation in North Africa and in the Sahel region of West Africa. He concluded that vegetation degradation due to overgrazing occurred nearly everywhere in both regions. He described in some detail an erosion and vegetation degradation problem in the Sahel known as *brousse tigre*. The condition is alternating strips of bare land and shrubs that resemble tiger stripes. The strip effect is found only on gentle slopes where the annual rainfall is between 100 and 500mm. From the air, strips appear to be generally parallel, either in straight or curved lines. They are the result of severe overgrazing. A study based in Mali led to the surprising conclusion that rangeland productivity in the Sahel is limited more by low soil fertility than by overgrazing (Bremen & de Wit, 1983).

There is a transition point where water becomes the limiting growth factor when the annual rainfall is less than 300 mm. Above 300 mm, fertility is the limiting factor. The implication of the data is that livestock management options are of little value in the drier north (below 300 mm) and also, in the absence of practices to increase fertility, in the wetter south. The economic value of supplying plant nutrients is unknown. It may well not be economical in the drier areas.

From the results of a French remote sensing project on assessing land degradation in Mali, Mainguet and Chemin (1991) made a very perceptive observation on erosion. She concluded from a north-south transect across Mali that wind erosion dominated when the rainfall was low. Water erosion reached a maximum when annual rainfall was between 650 and 750 mm. Neither was high, for the most part, in the very wet Guinean ecological zone. That generalization appears to hold true around the world. There are exceptions, of course, such as mobile sand dunes in Denmark and deep gullies in the Sahara.

Senegal, where rangelands have long been degraded, was the site of a successful German-Senegal small-scale pastoral development project in the Ferlo area (Le Houérou, 1989). As Le Houérou has shown, many small-scale projects on rangeland improvement have been successful. They usually fail, though, when scaled up to large areas. He estimated that about U.S.\$1 billion has been spent on range-livestock improvement in African drylands, with virtually no positive outcome. An enlightening report on historic vegetation destruction in Mauritania describes how bush fires, deforestation for charcoal and fuelwood, and the introduction of cattle and sheep degraded the vegetative cover in the western part of the country (BOSTID, 1981). Cutting trees and shrubs for charcoal production was done principally for use of the camel caravans that traversed the Sahara in a north-south direction during the last two millennia. Sheep and cattle were brought in during the 11th century. It appears that the coastal zone and nearby mountains were seriously degraded long ago, not just in the last century. Tales of sand dune encroachment in recent decades indicate that some vegetation degradation has happened relatively recently. Publications on land degradation in the drylands of the Sahelian countries tell about centuries of deforestation, overgrazing, and bush fires from Chad to Senegal that have caused accelerated wind and water erosion and rangeland deterioration (Delwaulle, 1973; Michon, 1973; Depierre & Gillet, 1971).

North Africa

Romans have left their imprint on all of the North African countries that were part of the Roman Empire two millennia ago. The three western countries (Morocco, Algeria, Tunisia) constitute the Maghreb region. Roman engineers built cisterns to store irrigation and drinking water and bench terraces with stone walls to capture rain and soil on sloping land. It was not until after the Empire collapsed that erosion became a problem when terraces were abandoned. Uncontrolled runoff from the terraces caused gullies to form that ruined the land. In the last century, sheet and gully erosion have become common. Population growth, deforestation, overgrazing, and expansion of cultivation onto ever-steeper slopes are the major reasons for the increased erosion (Bensalem, 1977). Soil conservation works, in general, still focus on building structures, not emphasizing vegetative control practices.

Deforestation seems to have begun in Roman times. Trees were cut for fuel and charcoal, as well as for buildings, ship construction, and furniture, just as in the eastern Mediterranean in earlier times (Mikesell, 1960). Following the Romans, the Arab conquest of North Africa and Spain led to a surge of tree cutting for building new cities. A rapid increase in goat numbers was responsible for further deterioration in vegetative cover and more erosion. Roose (1971), working in Morocco, pointed out the danger of landslides in the Rif Mountains and elsewhere. He attributed the problem to the fine texture of subsoils underlying highly permeable

surface soils. Roose believed that landslides could be controlled only by taking sloping land out of cultivation and planting trees and shrubs to hold the soil. Water and soil retention structures make the landslide threat worse. The badlands of northern Morocco are a striking example of excessive water erosion but they are the result of natural processes, not human activity (Imeson et al., 1982).

The Division des Sols of Tunisia (Division des Sols, undated) conducted an erosion survey of the country in the 1970s. That survey showed moderate and severe erosion on about one-third of the land north of the Sahara. From his long experience in Libya and the Maghreb countries, Le Houérou concluded that most of the pastoral lands there have been overgrazed for decades or centuries (Le Houérou, 1970; Le Houérou & Hoste, 1977; Le Houérou & Boulos, 1991). There are very few grass-dominated natural ecosystems in North Africa. The notable exception is esparto grass (*Stipa tenacissima* L.) ecosystems. Esparto survives because, as in spinifex communities in Australia, it is almost unpalatable. Shrubs are the principal livestock forage (Le Houérou, 1980).

One fairly comprehensive study on wind erosion in Tunisia showed that the mobile sand dunes, caused by overgrazing in the south of Tunisia, are moving toward the Sahara, not away from it, as conventional wisdom preached (Khatelli & Gabriels, 1998). This is in the same general area where the term desertification was first employed by Lavauden (1927) as a synonym for severe overgrazing.

Zachar (1982) wrote in a general way about the severe water erosion he had observed in the semiarid Atlas Mountains of Algeria and Morocco. He pointed to the short life of reservoirs in the rivers draining the mountains. Some became choked with silt in 20 to 50 years. He said that in one reservoir (Sig, in the Tell Mountains) over 800,000m³ of silt were deposited annually. The seriousness of erosion and rangeland degradation in Algeria was ascribed by Benchetrit (1972) to systematic destruction of forests by pastoralists, sedentarization of pastoralists, and expansion of cropland into steeper and drier areas as well as greater cutting of trees for fuel to meet the needs of a growing population.

Human-induced salinity in irrigated areas is common from Morocco to Egypt. It is especially serious in Algeria, Tunisia, and the Nile Valley and Nile Delta. Natural saline depressions are widespread on the Sahara margin of the Maghreb countries.

African Wind Erosion

As a land degradation process, wind erosion is a normal component of the dryland environment, with strong winds common at one time or another during the year, frequently in spring. On-site damage by human-induced wind erosion is a result of a low level of vegetation cover, which allows wind to reach its maximum velocity near the soil surface. The damage to the soil comes when wind-borne soil particles cause a cascading effect, fall back to the ground, strike the soil, and kick more particles into the air, in a chain reaction. The damage becomes severe when erosion causes formation of blowouts that may remove 50 cm or more of the soil and carry it downwind. A second form of on-site damage occurs when young plants, particularly, are blasted by air-borne sand. A third form is burying plants or scouring the soils around plants and exposing roots.

The only known analysis of on-site wind erosion on a large scale was made in the state of New Mexico, the fourth largest state in the United States (Davis & Condra, 1989). On-site damage costs were U.S.\$10 million per year. Off-site costs, obtained in a companion study in New Mexico, were U.S.\$450 million, 45 times greater than the on-site costs (Huszar & Piper, 1986). Off-site costs include the damage sand particles and dust do to machinery, automobiles, buildings, airport visibility, transportation routes, human and livestock health, and so on. Dust particles can be carried aloft to heights > 3,000 m and thousands of kilometers downwind. One of the notable examples is the dust from the Sahara that crosses the Atlantic Ocean and is deposited

in Florida, in the United States (Morales, 1977). That transport of dust probably has been going on since the last Ice Age. In Africa, the dust-bearing wind of the Sahel dry season is called the harmattan. It probably has an unhealthy effect on human health.

Among those who have written comprehensively about wind erosion north of the equator, particularly in the Sahel, are Mainguet (1984), Mainguet and Chemin (1991), Buerkert et al. (1996), and Sterk (1998). It has become apparent that wind erosion has had only a modest adverse effect on soil productivity. The estimations of Dregne and Chou (1992) of dryland degradation are much too high. Since wind erosion occurs only when the wind is blowing, it seems likely that the increased evapotranspiration caused by wind is more detrimental to plants than are the soil effects (Siddoway, 1970; Skidmore et al., 1974). More research needs to be done on these questions and on damage costs.

National Research Capabilities

The African continent, as a whole, appears to have only a small group of well-trained local professionals. Even today, nearly 40 years after achieving independence in the 1960s, expatriates from the former colonial powers still play an important role in the scientific establishment of most countries. An interesting point of view about the influence of colonial scientists on the knowledge of vegetation in Africa was published by Whitlow (1984). He reviewed the history of vegetation studies there. On the positive side, European scientists brought much-needed expertise and carried out considerable botanical research. On the negative side, Whitlow said that expatriates did little training of Africans. They also published their research in foreign journals and established herbaria in their countries, not in Africa. The unhappy result was to make it difficult for Africans to get access to African studies. Today, expatriates still do much of the local research under contract to donor countries, as the donors seek to maintain influence abroad. And both expatriates and Africans prefer to publish research papers in prestigious European and American journals. Progress has been made in recent decades to strengthen African institutions, but change is slow to come. This holds true for nearly all scientific disciplines and in most countries. The names of authors in this review demonstrate that.

Summary

Any continental assessment of land degradation suffers from the paucity of reliable data. This review is no exception. In the final analysis, the conclusions that are drawn depend on informed opinion. Satellite imagery, when it has higher resolution, offers the promise of filling part of the data gap. The limitation now is the need for ground checking (ground truth) of satellite-derived information. While reliance must presently be placed on the wisdom of knowledgeable people and supplemented by good data, it is still unsatisfactory. The fact that numbers of people in the world dying of lung cancer, area of forested land, persons with HIV or AIDS, population, living in poverty are all the result of some data and a lot of informed opinion does not make it acceptable to stop collecting data. The same is true for land degradation.

A major uncertainty in assessing rangeland vegetation degradation is what the original pristine or climax vegetation was. That information is essential in evaluating what changes have occurred, and when. That question seems to be particularly difficult to resolve in subtropical and tropical climates. As in the Karoo of South Africa, the potential for improvement depends upon what the environment could support before humans entered the picture. Introduced species may increase total edible biomass, in the short run, but what will be the long-term impact? Rabbits in Australia epitomize the issue.

If some writers on the subject of rangeland vegetation degradation are correct, deliberately set fires, overgrazing, fuelwood cutting, and sedentarization have

brought deterioration to nearly all of the rangelands in East, West, and North Africa and to goodly sections of Zimbabwe, the Republic of South Africa, and eastern Botswana. In West and North Africa the loss in productivity may be a few hundred years old, as is believed by some to be true of South Africa's Karoo. As rainfed farming spread to more marginal lands, pastoral lands became smaller and more heavily grazed.

Water erosion has reached the stage of gully formation in the drylands of Tanzania, Somalia, Uganda, Kenya, Ethiopia, the Maghreb countries, Zimbabwe, Malawi, Lesotho, South Africa, and, perhaps, Mozambique and Madagascar. Sheet and gully erosion are found on both overgrazed rangelands and rainfed cropland. Wind erosion is most pronounced in the Sahel countries, from the Sudan to Senegal and Mauritania, but it occurs practically everywhere in the drylands. How much damage it does is not clear. Mobile sand dunes are not uncommon, and in Somalia, Egypt, and Mauritania, they can be seen advancing toward villages. An almost continuous sand sheet encourages erosion across the region.

Excessive soil salinity on irrigated land is found in some oases in the Sahara, in the delta and valley of the Nile River, and in many places in North Africa. Dryland salinity seems to be absent in Africa. The Gezira between the Blue and White Niles in the Sudan has something of a sodicity problem. As is true globally, nutrient deficiencies are present in nearly all cultivated land. They probably are getting worse as crops and their residues are removed and few or no nutrients added. In the acidic drylands of the Sahel, aluminum and, possibly, manganese excesses cause toxicity damage to crops. Soil compaction undoubtedly is widespread on mechanized farms and some fields worked by animal power. There is no knowledge of just how badly compaction affects crop yields in Africa.

Little attention has been paid to the off-site effects of land degradation in Africa. Water and wind erosion are the processes that generate most off-site damage. Off-site effects of wind erosion probably are significant in the Sahel, and those of water erosion may or may not be important.

Asia

The drylands of Asia fall nicely into four groups: China and Mongolia, India and Pakistan, Central Asia, and the Middle East. Together, the drylands cover approximately 2,100,000,000 ha, most of which is in China, India, Iran, Mongolia, Saudi Arabia, and the Central Asian republics.

China and Mongolia

Until recent years, it seemed that desertification (land degradation in the drylands), in the minds of natural resource scientists, consisted only of wind erosion (Zhu & Liu, 1981, 1983; Yang & Zhu, 1984; Zhu et al., 1988; Xia et al., 1993). Gradually, awareness that rangeland degradation, in the absence of wind erosion, was serious became recognized (NAS, 1992). Salinization of irrigated land had been known for 2,000 years in valleys along the Yellow River in the Ningxia and Inner Mongolia autonomous regions. In the past 10 years, it became obvious that salinity was a much more pervasive problem than had been believed (Dregne et al., 1996). Vast areas of rangelands in the Xinjiang Uygur Autonomous Region in far western China have saline surface soils, naturally. Rainfed croplands in northeastern China's Heilongjiang Province and many sandy rangelands in the Mu Us Desert in Inner Mongolia and Shaanxi are naturally salty. The salt problem in rainfed croplands of Heilongjiang may be due to the same factors responsible for dryland salinity in Australia, Canada, and the United States: rising water tables in saline subsoils when deep-rooted shrubs and grasses are removed.

Little attention had been given to water erosion in drylands by the scientists working on desertification until the national committee for implementation of the United Nations desertification convention was established. That committee has prepared a number of excellent small-scale maps showing the distribution of climate types, desertified lands, wind and water erosion, salinization, and degraded rangelands and croplands (CCICCD, 1997). Informed opinion undoubtedly played the dominant role in the mapping exercise.

Wind erosion and its control have received, by far, the greatest research and development attention of all the degradation processes. A very large program of reforestation was launched in 1978, under the title of Sanbei Shelter-Forest System, to construct shelterbelts in 551 counties that were not economically developed (Sanbei Bureau, 1989). The project is scheduled to last 73 years. The word *sanbei* means three norths, for northeast, north, and northwest China. Planting trees for windbreaks has long been standard operating procedure in new irrigated areas all across the north of the country.

The most notorious example of water erosion in all of China is the Loess Plateau, most of which lies in the drylands. Loess (wind-borne silt) is highly susceptible to water erosion. Erosion on the Plateau is almost unbelievable in its intensity (Mei & Dregne, 2001). The Plateau is drained by the Yellow River, which gained its name from the color of the sediment it carries. An unknown fraction of the erosion is human induced. The sediment load in the river is so great that dams constructed in the middle of a section of the river to store irrigation water, generate electricity, and control floods have lost much of their function due to sediment deposition behind the dam. So much sediment has built up in the lower section of the river, where it crosses the North China Plain, that the bottom of the channel stands several meters above the surrounding plain. The situation poses a terrible threat to the millions of people living next to the river who would die if one of the dikes along the channel should break during a flood.

As noted for salinity problems in irrigated lands, land degradation has a long history in China (Zhao, 1991). Human activities are credited with changing some of the semiarid Mu Us grasslands of northern Shaanxi Province, south of the Yellow River, into a landscape of shifting sand by about 1100 B.P. Government campaigns to change pastoral lands in southern Inner Mongolia into croplands led to advanced wind erosion in the Mu Us sandy lands in the mid-1800s. The occupation of new lands would end with the next severe drought, only to be tried again in the next rainy period. Good grazing land became poor cropland, a story that has been repeated around the world.

The water erosion threat in the arid, semiarid, and dry subhumid Loess Plateau has worsened steadily during the centuries following the first unification of China in 220 B.P. The capital of unified China was near Xian in the extreme south of the Loess Plateau. With population increases, forests in the south were cut down and grasslands in the north were plowed, leading directly to enhanced erosion. Geologic erosion continued at its high rate. One record of ancient wind erosion in present-day Inner Mongolia noted that damage had occurred since at least 1660 B.P. (Zhang, 1990). Land degradation affects around 2,600,000 km² of the 3,300,000 km² of drylands (excludes extremely arid areas) and amounts to over 27% of the national territory. Wind erosion on cultivated and pastoral lands affects more land than any other degradation process. How much damage it does is unknown. Degradation of rangeland vegetation is said to be second. Water erosion and salinity are much less extensive but are very important locally, as in the Loess Plateau and the valleys of the Yellow River. Early research on desertification was conducted at the Institute of Desert Research in Lanzhou (Lanzhou Institute, 1977), which may account for the emphasis on wind erosion.

For Mongolia, S. Sangidansranjav, director of the Gobi Center in Ulaan Baator, has given a general description of desertification in an unpublished and undated

report. He said that the principal anthropogenic factor causing land degradation is overgrazing. Pastoralism is, by far, the most important economic activity in the country. In olden times, when nearly all of the population was engaged in nomadic cattle raising, pressure on the vegetation was low because of the periodic moving of homes and livestock throughout the year. When pastoralists were brought together in communities under the Communist government, overgrazing increased around the settlements. By the 1980s, the traditional system of nomadism had largely been replaced by a sedentary life in towns and villages, and severe vegetation degradation around the communities was becoming common.

The extensive character of present-day overgrazing in Mongolia was noted by Kharin et al. (2000). They also mentioned wind erosion and the cutting of trees and shrubs in the drylands, as well as commenting on the weakening of the traditional system of family support. Kharin (1997) constructed a map of land degradation in Mongolia. That map indicates that rangeland degradation and water erosion severity varies from slight to moderate. Wind erosion is of moderate or severe intensity. An analysis of satellite imagery (Sneath, 1998) concluded that relatively little pasture degradation appears to have occurred. Certainly, Mongolian grazing lands are in better condition than in adjoining Russia and China.

India and Pakistan

Hot arid zones constitute most of the drylands of India and are centered on the states of Rajasthan, Haryana, and Gujarat. A cold desert region of little extent lies in the Ladakh region of Himalayan India. Grazing areas in the country have become diminished by the extension of cultivated lands at a time when livestock numbers have exploded (Ahuja, 1977), placing heavy pressure on the remaining rangeland. In India, wind erosion and rangeland vegetation degradation in the western states in and bordering on the Thar Desert are the main degradation processes. Water erosion dominates in the semiarid and dry subhumid zones in the eastern hills. Salinization is common in the irrigated flood plains of the tributaries of the Indus River. Little is known of the extent of soil compaction.

Sehgal and Abrol (1994) have published a national map of human-induced soil degradation at a scale of 1:4,400,000. Still lacking is a map of rangeland deterioration. The basic information in the publication came from the National Bureau of Soil Survey and Land Use Planning. The report covers the entire country. Since there is a shortage of reliable information on the specifics of soil degradation, the authors relied on their own experiences and that of their colleagues. Fortunately, both authors have a wealth of experience. The total area of drylands was estimated by Dregne and Chou (1992) to be about 160,000,000ha. Rapid increases in the human and livestock population of the drylands in the past, and presumably continuing into the present are the principal causes of tree and shrub cutting, overgrazing, and expansion of croplands (Acharya et al., 1977; Mann & Singh, 1977; Ahuja, 1977; Faroda, 1999). About 80% of the rangelands are said to be in poor or very poor condition. Wind erosion is the single most extensive soil degradation process (Sehgal & Abrol, 1994).

Pakistan has about 75,000,000ha of drylands, 94% of the country. Rangelands occupy most of the arid zone. Rainfed cropland (barani) amount to nearly 5,000,000ha, which is about one-fourth of the total cropland. According to a 1981 survey, 4.2 million of the 15 million ha of irrigated land are salt-affected (Sabir-ur-Rahman, 1984). Heavy animal pressure and tree cutting are the principal reasons for the widespread degradation of rangelands (Majeed & Jafri, 1984). Erosion-prone loessial soils of the rainfed croplands of the Potwar Plateau have many deep gullies and much sheet erosion. Rafiq and Mian (1975) believed that most of the gully erosion on the barani lands was natural, whereas the sheet erosion was human induced. In two areas typical of the loessial deposits, gullies were visually

conspicuous but occupied only 2 to 3% of the cropland. Other old reports say that up to 40% of the loessial soils have been destroyed for present use by sheet and gully erosion (USAID, 1969). Another (Agricultural Enquiry Committee, 1975) claims that 5,000ha of cultivated dryland are lost each year by water erosion in Punjab Province, alone. Around 240,000ha were moderately affected and 40,000ha severely affected by erosion. The USAID (1969) report claimed, interestingly, that severe erosion occurred when the widely used terraces were abandoned. More recently, Arshad et al. (1995) have described vegetation in one pastoral area, the Cholistan Desert. They attribute it to high human and livestock populations. Wind erosion is most common in the south of Pakistan, where rangeland degradation has led to the mobilization of sand dunes. Salinization and waterlogging of irrigated land in the Indus watershed has been a big problem for a hundred years. A long-standing program of salinity control covering several million hectares is known as SCARP (Salinity Control and Reclamation Project).

Central Asia

Little detailed information on land degradation is available for most of the former Soviet Union republics except for the high degree of salinity in the irrigated lands and the long history of vegetation degradation in the grazing areas (Kharin et al., 2000). These authors said that 90% of the irrigated land is affected by salinization associated with inadequate drainage. A more likely figure is 50 to 60%. Excess salt has led to abandonment of approximately a half million hectares of irrigated land in Kazakhstan alone. Degradation of the vegetative cover is the main type of land degradation in Central Asia. About 25% of the rangelands in Kazakhstan are said to be degraded. That number seems low. Fifty percent of Turkmenistan rangelands are listed as being moderately to severely degraded, as are 42% in Uzbekistan. Tajikistan probably has 40 to 50% of its irrigated land in the Vaksh Valley salinized. No estimates could be made of degradation in Kirgызstan. An analysis of land degradation in Kazakhstan by Baitullin and Bekturova (1997) gave different estimates from those of Kharin et al. (2000). The former stated that 60% of the nation's territory suffers from degradation. The large majority of that occurs on rangelands. Salinization of irrigated land on the shores of the Aral Sea is very severe due to drying of the sea but the area is comparatively small. Wind erosion affects about 20 million hectares of dryland cropland (the "Soviet Union's New Lands") and 25 million hectares of pasture land.

Middle East

For the purposes of this article, the Middle East includes the countries from Afghanistan to Turkey and all of the Arabian Peninsula. Drylands amount to over 480,000,000ha. Most of the Arabian Peninsula is extremely arid (climatic desert). In the Middle East, the more accessible areas have been occupied for thousands of years and have been heavily grazed for at least a thousand years, more or less (Schechter & Galai, 1977; Beaumont, 1981). Sheep, goats, and cattle are numerous. The famous Fertile Crescent of rainfed cropland runs from present-day Jordan and Israel around to Lebanon, Syria, Turkey, Iraq, and Iran. It was in the northern Fertile Crescent where wheat and barley were domesticated, along with other crops and livestock (Harlan, 1992; Lev-Yadun et al., 2000). Heavy grazing and cultivation pressure apparently has eradicated many palatable and nutritious species. Destruction of the cedar forests of Lebanon, Syria, and Jordan began 3,000 or more years ago (Naveh & Dan, 1973; Mikesell, 1969).

Deterioration of rangelands in Iran has become accelerated in the last 100 years but has gone on for centuries (Pearse, 1971; Nemati, 1977). Overgrazing and tree and shrub cutting for fuel were the degradation culprits throughout the arid regions of the Middle East (Middleton & Thomas, 1997). Similarly, water erosion in the dry

subhumid zones has been severe for centuries (Beaumont & Atkinson, 1969; Ryan, 1982). Overgrazing and wind erosion are identified as the main land degradation processes in the Arabian Peninsula (Nahal, 1995; Omar & Abdal, 1994), with salinization common in irrigated land and water erosion present in the hills of Yemen. Terraces have been used for centuries in Yemen, many of which have been abandoned by farmers who went to the oil-rich countries for employment.

Salinity is the dominant problem in the irrigated lands of the Mesopotamian Plain of Iraq and Iran. It is as bad and difficult to control as anywhere in the world (Dougrameji & Clor, 1977; Ghassemi et al., 1995). Salt buildup in Iraqi soils has had a severe effect on Mesopotamian civilizations for 4,000 years (Beaumont & Atkinson, 1969).

Water erosion has affected the uplands and bare mountains of Afghanistan, Iran, Turkey, and Iraq for millennia (Zachar, 1982) and continues today. The vast expanse of delta land at the mouth of the Tigris-Euphrates river system attests to the high erosion in their watersheds (Jacobsen & Adams, 1958). Scientists in Syria prepared a map of human-induced soil degradation for the entire country showing the extent of water and wind erosion and salinization of irrigated land (Ilaiwi et al., 1992). Almost all of the salt problem occurs along the Euphrates River. The authors estimate that moderate to severe water erosion affects 150,000 ha, wind erosion more than 800,000 ha, and salinization 110,000 ha, most of it in the eastern part of Syria. No figures are given for vegetation degradation on rangelands but most pastures have been overgrazed for centuries.

Summary

As is the case with the rest of the world, reliable data on the extent and severity of land degradation in Asia are scarce (Dregne, 1992). China, India, and Syria have set an example for other countries to follow by constructing maps and databases. As more information becomes available, further refinement can be made. In time and with several iterations, the degradation picture will emerge more clearly and more reliably. We can only hope that additional countries will find data collection, including vegetation degradation not just soil degradation, a valuable exercise. It appears that vegetation degradation is a long-term problem in all of southern and southwestern Asia from India west. Recent overgrazing in the two remaining large countries of Mongolia and China seems to be pretty much confined to around settlements (Mongolia) and areas where expansion of cultivation has reduced the amount of pastoral land (China).

Water erosion is an everpresent problem wherever sloping land is cultivated or, as in China's Loess Plateau, where soils are highly erodible. It is well to remember that probably between one-half and one-third of the Plateau's erosion is believed to be natural, not human induced. This means, almost certainly, that no more than one-half or two-thirds of the erosion can be eliminated under the best of conditions. Structures, mainly level terraces, can hold soil back from the drainageways but erosion on the uplands will continue. In the remainder of China and Asia, vegetation degradation on sloping lands will continue to assure that water erosion is a problem.

Wind erosion is widespread everywhere except, perhaps, northern Mongolia and the Mediterranean countries plus Jordan. It is an open question about how much on-site and off-site damage wind erosion actually does. Salinization of irrigated land is very severe in Central Asia and some parts of the Yellow River basin of China and the Indus Valley of Pakistan and India. Elsewhere, probably most irrigated land has a greater or lesser salinity threat.

Australia

Australia is about 85% dryland, by far the most of any continent. It has no extremely arid climatic zone. Of Australia's total area, 60% is used for agriculture

(grazing, 90%; cropland, 10%). It has one of the world's best knowledge bases on land degradation, while also having the lowest percentage of degraded rangeland. The reason for having a lot of rangeland in good condition is that about 32% of the rangelands are not utilized. That situation occurs because spinifex rangelands have a largely unpalatable vegetative cover and good quality water is scarce. The country has some soil degradation problems that are scarce or missing on other continents. Those special problems are dryland salinity and scalds (Working Paper, 1982). Dryland salinity is a human-induced salt problem that seems to be confined, for unknown reasons, to the semiarid lands of Australia, Canada, and the United States. Scalds are a salt-related phenomenon, also human induced, that occurs when duplex soils with a salty and/or a sodic subsoil have the sandy surface soil removed. They become impermeable to water. A review article on erosion and soil productivity was published by Dregne (1995).

According to Woods (1983), land degradation has been identified by a prime minister as the most important single issue on the Australian environmental scene. Degradation is said to affect large areas of the country and to be critically limiting sustainable developments. *Landcare* is an Australian grass roots movement organized by urban and rural citizens to achieve sustainable land and water systems (Francis, 2000). It is an influential nongovernmental organization.

A national assessment of land degradation was carried out in a Commonwealth/State collaborative study between 1975 and 1977 (Woods, 1983). The study concluded that of the 3,356,000km² of land in use in the drylands about 1,850,000km² need degradation control. Nearly 1,000,000km² suffer from vegetation degradation (rangelands, mainly) and about 900,000km² have combined vegetation and water and wind erosion. Thirty eight thousand km² are scalded and 4,200km² are affected by dryland salinity.

Mabbutt (1978) described an apparent unofficial response to Australian land degradation that involved a general movement to decrease areas of marginal cropland and to expand use of rangelands. There appears to be no question that there have been enormous advances over the last decades in recognition and treatment of land degradation in Australia (Aveyard, 1988; Conacher et al., 1995).

Europe

Most of the 65,000,000ha of drylands in Europe are found along the Mediterranean Sea. Spain has the largest dryland area. The European Community has financed the collaborative MEDALUS research program on desertification for many years. The results of those studies have been published in individual researchers' papers and in summary volumes (Perez-Trejo, 1994; Geeson & Thornes, 1996; Mairota et al., 1998; Burke & Thornes, 1998). MEDALUS research has focused nearly always on only one desertification process: water erosion. A little work has been done on salinization. With the emphasis on the role of vegetation in controlling water erosion, some analyses have been made on vegetation changes over time. Mairota et al. (1998) said that land degradation is an old problem and that nowhere in the region are there even vestiges of the "natural" vegetation. They added that the impacts of the last 50 years have been more profound, environmentally, than in the previous 5,000 years. Destruction of the native vegetation many centuries earlier lends support to the belief that water erosion, too, has a long history. It dates to at least 2,000 years ago when Plato is said to have beanoed the suspended sediment that darkened the sea at the mouths of Greek rivers and spoke of denuded hills. The MEDALUS atlas (Mairota et al., 1998) states that the project's erosion model indicates that below 300 mm rainfall decreases erosion, in general. Field tests appear to show that actual erosion is less than the model predicts.

A map of soil erosion in western Europe (the European Community) indicates that water erosion occurs in the uplands of all the Mediterranean countries (de Ploey, 1989). Little wind erosion is indicated. Chisci (1992) supported the conclusion about water erosion. Soil salinity is serious in the Ebro Valley of Spain. Spain is said to be one of four European countries experiencing severe water erosion (Bermudez et al., 1989). About 26% of Spain is severely eroded and another 28% is moderately eroded. Kosmas et al. (1977) found, contrary to the MEDALUS atlas, that there was a tendency for increased runoff and sediment loss with decreased rainfall in hilly Mediterranean shrublands. Fire is a major contributor to water erosion, in particular in forested lands (Rubio & Sanroque, 1990). As changing economic conditions have led to abandonment of marginal terraced land, the neglected terraces develop breaks in the terrace wall that become large gullies, as in Yemen and elsewhere.

Summary

As befits a region that has been populated for thousands of years, overgrazing, deforestation, and water erosion are old processes. Excessive soil salinity plagues the Ebro Valley in northern Spain and is locally important elsewhere in Spain. Wind erosion is a minor problem.

North America

North America here is meant to be Canada, the United States, Mexico, Central America, and the Caribbean countries. Drylands in those countries cover about 580,000,000ha.

Canada

Five major types of soil degradation are prevalent in Canada: water and wind erosion, salinization, compaction, loss of organic matter, and acidification. All but acidification are dryland problems, principally in the prairie provinces of Alberta, Saskatchewan, and Manitoba (Science Council, 1986). Wind erosion affects croplands in all of the prairie provinces. Dryland salinity is concentrated along the United States border. Water erosion is a modest problem. Soil compaction is common, but there are little data on its extent. Canada is one of the few countries that has made an estimate of income foregone due to soil degradation. For the prairie provinces, that figure is about U.S.\$700,000,000 annually. Wind erosion is the costliest, followed by organic matter loss and salinity. Compaction costs are believed to be low. Irrigation salinity is low.

United States of America

Of the major land degradation processes in United States drylands, wind erosion, vegetation degradation of rangelands, salinity, and water erosion have been the most studied in the 17 dry western states of the country. Research has made possible the transformation of what was once called the Great American Desert (the Great Plains). Research on water erosion in the Palouse wheatlands of the Pacific Northwest have helped to develop one of the most productive agricultural regions in the nation. The Palouse research is notable for using the 800,000ha of hills and valleys as a field experiment for developing a sustainable agriculture. After 50 years of continuous study of scientific, social, and economic factors affecting the economy and the environment, much has been accomplished and much remains to be done. Erosion rates are still too high.

The best national information sources for data on land degradation in the United States are the national resource inventories carried out every five years on

nonfederal land (USDA, 1994). These inventories emphasize water and wind erosion but do give information on vegetation degradation on rangelands and on salinization. They do not include federal land, which may constitute more than 30% of the 11 western states. Most of the federal land is rangeland or national forests administered by the federal Bureau of Land Management and the Forest Service.

In the 1992 inventory, nonfederal dry cropland amounted to approximately 50,000,000 ha in the 17 western states, rangeland to a little less than 160,000,000 ha, and irrigated land to 14,000,000 ha. The inventory estimated that 70% of the dry cropland needed conservation treatment to control water and wind erosion and dryland salinity. The detailed tables show the severity of erosion, by states. Erosion is estimated using the Universal Soil Loss Equation and the Wind Erosion Equation on nearly a million farm fields.

Rangelands, both federal and nonfederal, in the 17 western states come to 320,000,000 ha. In the most comprehensive determination ever made in the United States of rangeland condition (ARS, 1974), 28% of the total rangeland was believed to be in good condition, 49% in fair condition, and 23% in poor condition. The numbers probably are similar today or may show that land in good and fair condition has increased due to better management. An excellent description of dryland degradation in the United States is a booklet by Sheridan (1981). An analysis of the policy roots of rangeland degradation made by Hess and Holechek (1995) traces the development of the factors that brought about the degradation of what is called the arid grasslands but includes all lands west of the 100th meridian. Rangeland degradation began in earnest in the middle to late 1800s when southwestern cattle numbers increased explosively to meet the demands of the eastern states (Cox et al., 1982). The impact of water erosion is described well in a book by Follett and Stewart (1985).

Mexico

Vegetation degradation, principally deforestation, began in Mexico at the time of the Spanish Conquest (Roldan-Parrodi & Trueba-Davalos, 1978). At first, the wood was used for building construction and fuel. A little later, large amounts were needed to support mine tunnels and to smelt ore. Still later, railroads required wood for ties and to satisfy the high demand for fuel for the steam engines. Mining was a particularly significant contributor to forest and rangeland deterioration because many of the gold and silver mines were located in the dry north of Mexico. Northern grasslands provided the meat for Mexico City and other cities in central Mexico. In the arid and semiarid climatic zones of the Mexican altiplano, vegetation degradation of grazing lands in the eight northeastern states was very severe on 80% of the land (Berg et al., 1999). Water erosion was bad on 40% of the country, wind erosion on 90%, and salinity on 16% of the irrigated land (CONAZA, 1993). Wind erosion affects 80% of the national territory, mostly in the northern border lands. Irrigated land has become more than 20% salinized, also in the north. Overgrazing and tree cutting has become a major concern on 80% of the semiarid and dry subhumid drylands, also in the north. Humans are responsible for almost all of the degradation. The CONAZA book contains many useful and well-made small-scale maps.

Central America and the Caribbean

Water erosion is, by far, the major land degradation process in Central America (El Salvador and Guatemala) and the Caribbean (10 small countries) drylands. Steep slopes and volcanic ash soils contribute to the erosion problem. Haiti has the reputation of being one of the most eroded countries in the world but evidence is conflicting. Without question, though, there is severe erosion in parts of El Salvador, Guatemala, and Haiti.

South America

Information on land degradation in South America is scarce. Some data on soil degradation in the Andean countries and Brazil are available, with northeast Brazil probably the most studied region. According to Zachar (1982), severe erosion is found in northern South America (Colombia, Venezuela, Ecuador, all Andean countries) drylands. Erosion is said to increase with increasing climatic dryness in Brazil. The best-protected lands are the terraced fields constructed by the Incas. Terraces were built on very steep slopes, such as can be seen at Machu Picchu, an old Inca city in the remote mountains of Peru. Heavy sedimentation of the Parana River draining parts of Brazil, Paraguay, Uruguay, and Argentina bears witness to the severe erosion in its watershed. Wind erosion is severe in sandy areas of western Argentina and Patagonia. Salinity damages irrigated land in the 52 river valleys that drain the coastal plain of Peru. Salt is a continuing threat to cropping in northern Argentina. Overgrazing is widespread in cold and windy Patagonia, along with the wind erosion (del Valle et al., 1997; INTA, 1993). An unpublished map of soil degradation in Argentina was prepared at a small scale. It shows the location of water and wind erosion and salinized land. The issuing agency is unknown. A 1995 report on soil deterioration in Argentina says that 40% of the country is affected by water and wind erosion, salinization, and other processes (SAGyP, 1995).

A project to control widespread erosion on steep slopes in Ecuador by planting live fences of nopal was an apparently successful effort to use local experience to cope with water erosion (Casas-Castaneda & Matallo, 2000). It has the great merit of using a plant, *Opuntia ficus-indica*, with which the local people have long been familiar.

Water erosion is common in the Andean countries, particularly, and in dryland Brazil. Wind erosion does its greatest damage in Argentina and is locally important in the coastal plain of Peru and to a lesser extent in Chile. Salinization of irrigated land can be expected almost everywhere in the drylands but mostly in the south of the continent. Little is known about rangelands except in Patagonia, where overgrazing by sheep is a concern, along with soil salinity.

Discussion

Lack of good information on the extent and severity of land degradation in the global drylands severely hampers attempts to determine its significance in setting priorities for national spending. Various uninformed spectators of the scene may claim that land degradation threatens the survival of the human race, but others may protest that there is no problem worthy of serious attention. Certainly there are places in the world where extreme examples of erosion can be seen, such as the Loess Plateau of China, Lesotho, and Haiti. Still, those are unusual conditions. Most erosion is sheet erosion, unnoticed and untended until farmers become convinced that something must be done. Lack of attention does not mean that there is no problem. Perhaps it will take a crisis of some kind to generate action to assess the significance of land degradation.

When the United Nations was developing the international Convention to Combat Desertification, there was hope that assessing degradation in individual countries would be among the first programs of the Secretariat. That, unfortunately, never happened and none of the country delegates to the Conference of the Parties, the governing body for the Convention, appeared to object. Ignorance of the extent and cost of degradation in their own countries did not hinder the delegates who were preparing national plans of action to solve an undefined problem. A very few countries, such as Mexico, found the situation intolerable and determined to collect the available information on the extent, causes, and effects of land degradation in

their countries. Those countries are ready to make responsible decisions. There are not many.

After an initial assessment, continued monitoring is essential to evaluate the rate of change in the desertification processes that affect each country. Longtime monitoring of environmental change is an unpopular endeavor in the minds of financial officers. Change usually is slow, and monitoring can be expensive. As with many natural processes, several years of observation may be needed to draw valid conclusions. Every year that goes by without monitoring further delays informed decision making. Choosing useful indicators is difficult but it can be done. Direct indicators of change, such as soil tests for salinity, are preferred over indirect indicators, but sometimes indirect indicators are the only ones that can be used.

Assessment of soil erosion frequently is done by using models such as the Universal Soil Loss Equation or the revised equation. Those are the methods used in the United States in the five-year national resource inventories. For almost any general survey of a large area, models are essential because plot experiments are costly and time consuming. Models do, though, have weaknesses, the greatest of which is that they must be validated anew when they are used under conditions that are different from that under which the model was developed. A thoughtful analysis of the use of the water erosion and wind erosion models in the United States, where they were developed and should be most accurate, revealed several weaknesses which bring into question their reliability (Trimble & Crosson, 2000). Reliability presumably could be lower when the models are employed in other countries. It should be noted, though, that no other models are believed to be as good as the Universal Soil Loss Equation. It is in wide use.

Land Degradation and Soil Productivity

It is logical to conclude that land degradation, if it is significant, should reduce soil productivity and crop yields (McCarthy & Clarke, 1985). That would seem to be obvious with water erosion: if erosion is high, yields should be reduced. What appears to be illogical is to have crop yields increase at the same time that erosion is removing the more fertile and productive topsoil. Yet, that may well be happening at the global, as well as national, level. The explanation for the seeming paradox (more erosion, higher yields) is demonstrated by data from the Palouse region of Washington, Idaho, and Oregon. Agricultural scientists, economists, and sociologists have been working for more than 50 years on an experimental area of 800,000 ha of wheatlands in the Palouse.

What the researchers have found is that water erosion, the principal degradation process in the hills and valleys of the Palouse region, has been and still is, causing a continuing loss of topsoil. But that loss of the best soil has been offset by technological inputs of fertilizers, pesticides, crop rotations, tractors adapted for use on the steep slopes, and a plant breeding program that developed a vastly superior dwarf wheat (Worldwatch, 2001). The result is that crop yields have increased even as erosion has increased. But, the records of the project clearly show that yields would have been 20% higher if there had been only slight erosion instead of the relatively high erosion that did occur. Erosion reduced the potential soil productivity but technology offset that degradation. If farmers had followed recommended conservation tillage practices, their yields would have been 20% higher with the same inputs they are making. Rising yields do not always mean that there is little erosion.

Farmers who have seen their own wheat yields increase steadily are not usually worried about continuing soil loss. Some time in the future, when erosion exposes denser subsoils, as has occurred on hilltops in the Palouse, yields can be expected to stop increasing. But that is in the future, and taking action to control erosion now is not likely (Steiner, 1987). Conservation now is good for the nation, but it may not be best for the farmer who must pay for it. It may be problematic for a farmer who has

deep soils but wise for one who has shallow soils. As Crosson and Stout (1983) stated, farmers everywhere are eminently rational in their decisions.

Natural versus Human-Induced Degradation

Natural (geologic) erosion is what laid down the rich agricultural lands of the Nile Delta, the Gangetic Plain, and the Mississippi Delta. Wind erosion brought airborne dust to form some of the most productive wheatlands in the world. Erosion is a natural process and also a human-induced process. How to separate the two is very difficult when they are going on simultaneously. Yet, an attempt must be made in order to know whether reclamation practices can be expected to be successful. If natural erosion is high, as it is in the Loess Plateau, for example, it can be overcome only at a very high cost, and then, probably, be futile in the long term. If the natural erosion is low, it may not be important, at least on site. Off-site damage is something else.

Land Degradation Cost

As noted earlier, Canada is the only country known to have calculated the costs of land degradation at the national level. One state in Australia has made estimates of soil degradation costs and one in the United States has calculated wind erosion damage costs. Some individual estimates have been made for a few of the land degradation costs but the record is spotty (Bishop & Allen, 1989). We still have only vague ideas of what degradation damage costs are for society. The very fact that so few efforts have been made by economists attests to the difficulty of doing so. Apparently, there is no agreement yet on how to evaluate natural resources. If facts about land degradation extent and severity are scarce, they are nearly non-existent for its costs. Yet, it is impossible to make informed decisions unless the costs of taking or not taking actions are known. This is an area of study that the Convention to Combat Desertification could pursue globally and country by country.

Land Degradation Control

Practices for control of land degradation in the drylands are widely available and, when properly employed, are effective (Stoddart et al., 1975; Troeh et al., 1980). Virtually all are site specific, though, and must be adapted to local conditions before being widely adopted. Even with that availability, there is much room for research to find simpler, cheaper, and more effective methods. It is time for a second Green Revolution focused on the drylands.

If degradation control practices are available so widely, why do farmers not adopt them? Crosson and Stout (1983) said that there could be two important reasons. The first is because farmers are ignorant of the damages. The second is that the cost of repairing or preventing the damage may exceed the benefits. In the authors' opinion, farmers make rational decisions. They know better than any outsider when crop yields are declining, so ignorance is not the problem. Being rational, they are unwilling to spend time or money, or both, to correct a problem if the cost of doing so exceeds the cost to the farmer of the expected productivity loss.

Conclusions

Land degradation in the drylands is an obvious problem in many places and a not-so-obvious one elsewhere. That uncertainty assures that there can be no rational decisions made on the priority that the land degradation threat poses at the national level. In the earlier stages of negotiations on the direction the United Nations

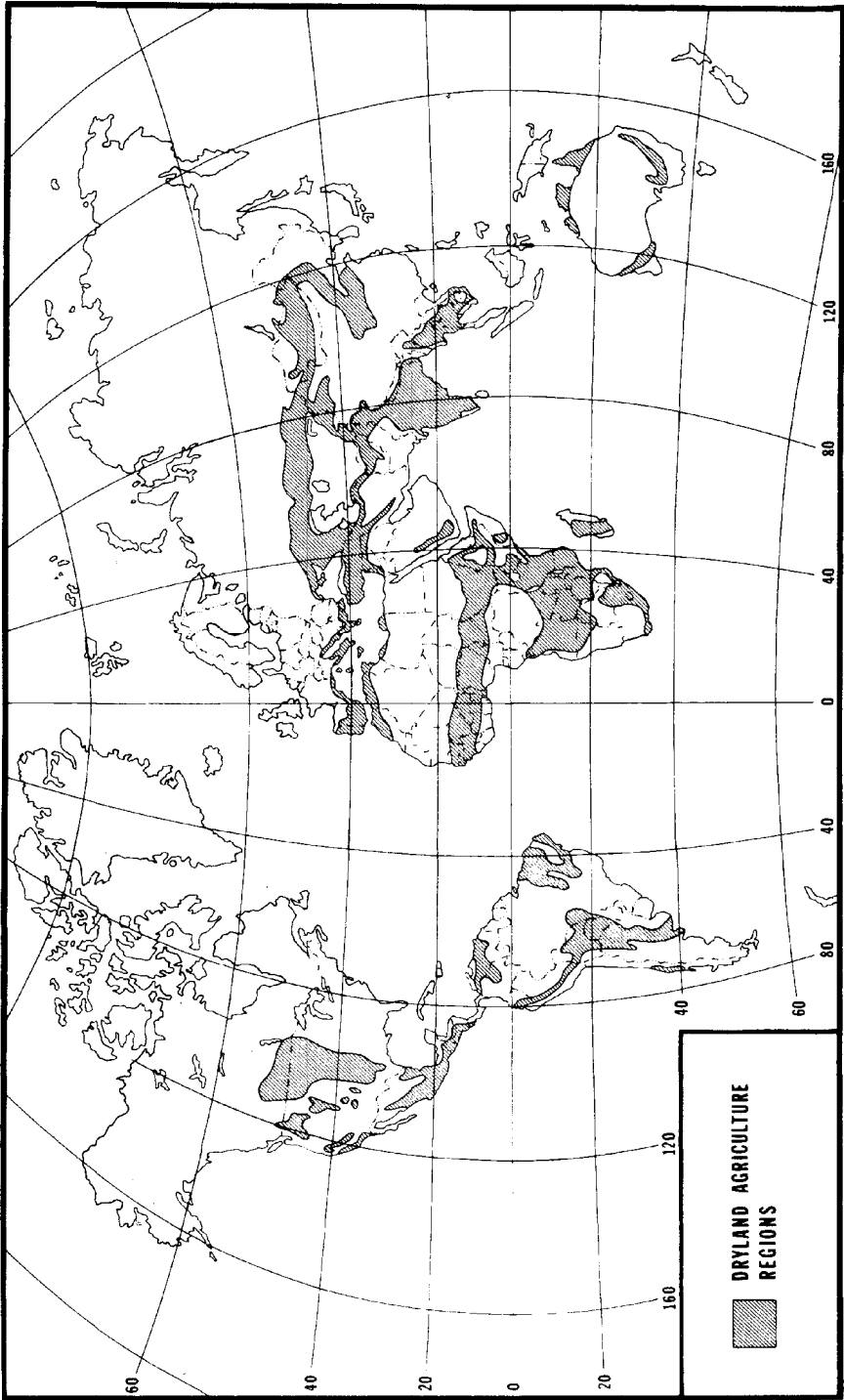


FIGURE 1 Dryland agriculture regions of the world.

Convention to Combat Desertification (CCD) would take, there was hope that a high priority would be assigned to assessing and monitoring desertification. The hope has disappeared. The CCD had a unique opportunity to initiate research on the status of land degradation, coordinate data collection procedures, and achieve international cooperation on the process. The tragic shortage of data continues, for the most part.

Based on the relatively little information available, it appears that dryland degradation is widespread in both developing and developed countries. Rangeland degradation is a centuries old problem in Africa, Asia, and the Mediterranean zone of Europe. It also seems clear that restoring degraded rangelands to good condition will not happen in the drier zones because the costs of doing so exceed benefits to pastoralists. Salinization affects about 25 to 30% of the irrigated land. It is one degradation process that can be corrected in a relatively short time (one or two years) and for which reclamation can be immediately profitable, in the majority of cases. Dryland salinity is a local problem in Australia, Canada, and the United States. It also is reversible.

Wind erosion occurs in practically all of the drylands. There is a real question about the magnitude of on-site and off-site damages. The little data available indicate that on-site damage is modest and off-site damage may be quite high. Water erosion, in the main, is worse in the semiarid and dry subhumid climatic zones than in the drier regions. It is a rainfed cropland problem, by and large, and seems to be common wherever sloping land is cropped, either as sheet or gully erosion or a combination. Most estimates of the relative damage done on-site or off-site have off-site costs being twice or more than on-site costs (Clark et al., 1985). In places where soils are deep, off-site damage is many times worse than on site damage. On-site damage can frequently be neutralized with greater technological inputs but the lost soil cannot be restored by natural processes in a human lifetime. Soil formation is too slow to do that.

Soil compaction undoubtedly reduces crop yields from their potential maximum in a large part of the dry cropland. Nobody knows, though, just how bad it is. One of the good things about the process is that it can be reduced or eliminated rather easily by changing plow depth.

There is an urgent need for accelerated research on dryland crop production to fight poverty and to increase food production in developing countries. Now there are about 450,000,000ha of dry cropland (Figure 1) that almost certainly are not producing at anywhere near their potential. The challenge of lower than optimum rainfall is truly daunting but no concerted effort to increase the effectiveness of rain, to explore the potential of water harvesting, and to develop better crop and soil management practices has ever been made. Improved utilization of the better dryland cropping areas will allow climatically marginal cropland to be returned to good grazing land. Dryland research has always been an orphan in national and international agricultural research agencies. It needs a dryland Green Revolution approach.

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