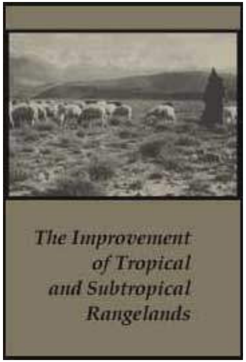
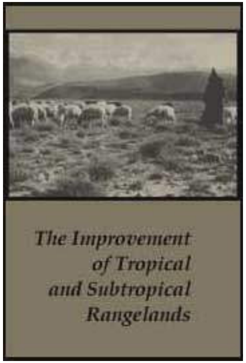


The Improvement of Tropical and Subtropical Rangelands (BOSTID)



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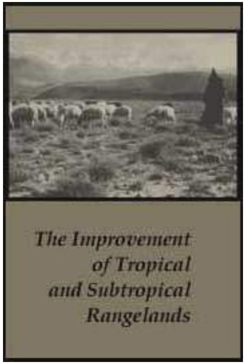

The Improvement of Tropical and Subtropical Rangelands (BOSTID)

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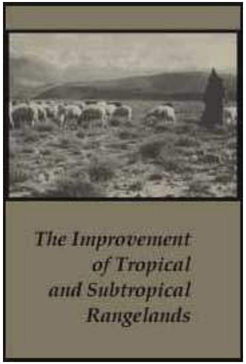

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NOTICE: The project that is the subject of this report was approved by the Governing Board of the National Research Council, whose members are drawn from the councils of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine. The members of the committee responsible for the report were chosen for their special competences and with regard for appropriate balance.

This report has been reviewed by a group other than the authors according to procedures approved by a Report Review Committee consisting of members of the National Academy of Sciences, the Nation al Academy of Engineering, and the Institute of Medicine.

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This report has been prepared by an ad hoc advisory panel of the Board on Science and Technology for International Development, Office of International Affairs, National Research Council. Staff support was funded by the Office of the Science Advisor, Agency for International Development under Grant No. DAN 5538-G-SS-1023-00/R.

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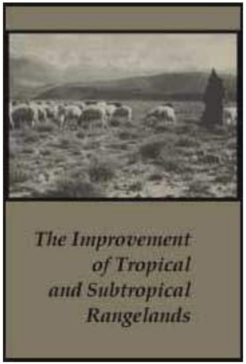

Panel on the improvement of tropical and subtropical rangelands

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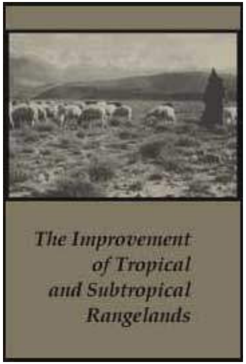

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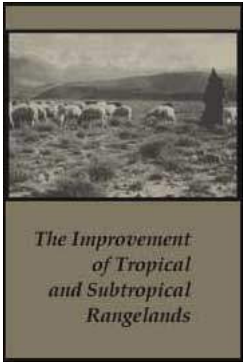
The Improvement of Tropical and Subtropical Rangelands (BOSTID)
- *(introduction...)*



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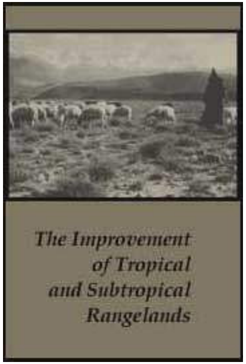


Preface

Overgrazing, fuelwood collection, uncontrolled burning, the unregulated exploitation of forest products, the growth of transportation networks, agricultural expansion into marginal areas, major social and economic changes are but some of the factors that have contributed to the degradation of tropical and subtropical rangelands. Periodic drought has intensified the impact of vegetation loss, and it appears that this loss may, in turn, prolong drought. Because rangelands comprise a substantial percentage of the earth's surface and support millions of human beings, it is critical to understand the complex causes of this cycle of drought and degradation, and to ensure that socially, economically, and scientifically appropriate measures be formulated and implemented to stem degradation and increase the productivity of rangelands.

The areas affected include some of the most vulnerable ecosystems in the world. For example, once disturbed, dryland ecosystems often require decades, or even centuries, to regain productivity. Nevertheless, there can be no moratorium on the use of such "fragile" lands; their products are vitally important. Although this report focuses upon problems of

range improvement in Africa and Asia, many of the observations and recommendations could be applied to the tropics and subtropics of Latin America as well.

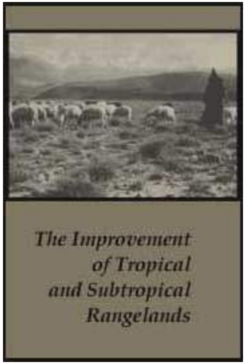
The panelists and other individuals responsible for preparing this report have no illusions regarding the case with which productivity can be restored to the world's rangelands. The areas are vast, and measures that could improve them are characteristically costly in terms of labor or capital. Rehabilitation efforts are further affected by social and political considerations.

This report takes a broad perspective. It focuses on the principles of range management by describing various indigenous adaptations to specific Old World ecosystems, and by discussing how experience elsewhere can complement indigenous knowledge. It also outlines techniques for assessing the condition of rangeland vegetation. Although the report to some extent draws upon North American experience, its authors fully acknowledge the limitations of this experience in addressing degradation problems in the tropics and subtropics. Nevertheless, this experience can usefully illustrate the application of basic principles, which the panel hopes will stimulate local research. What is needed is a basic appreciation of indigenous adaptations, a knowledge of local socioeconomic and environmental change over time, and innovation solidly based on an understanding of ecological principles.

Rangelands that are "common property" are particularly difficult to manage because of the frequent breakdown of organizations and institutions responsible for their welfare. Successfully managed rangelands characteristically benefit from some form of local control Therefore, case studies that describe successful approaches are also provided.

This report complements More Water for Arid Lands, published by the National Academy of Sciences in 1974, which describes littleknown, but promising, small-scale technologies for the use and conservation of scarce water supplies in arid areas. The Improvement of

Tropical and Subtropical Rangelands is the third report to appear in the series Resource Management for Arid and Semiarid Regions. Other titles include Environmental Change in the West African Sahel and Agroforestry in the West African Sahel.



The Improvement of Tropical and Subtropical Rangelands (BOSTID)

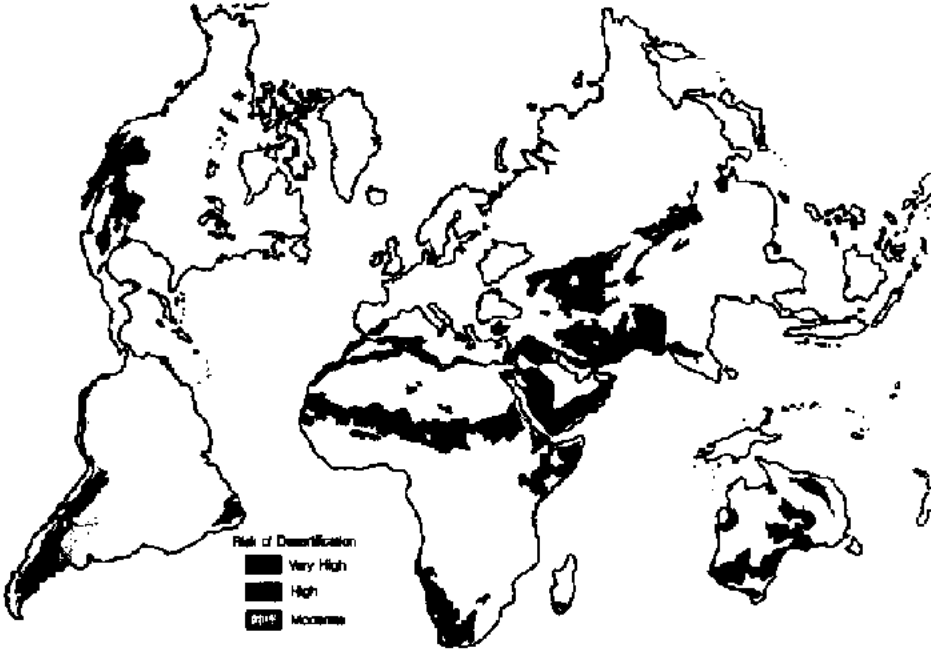
Overview: Dimensions of a worldwide environmental crisis

The geographical scope

Rangelands are one of the most important land use types in the world. Roughly 47 percent of the earth's land surface is rangeland, about 80 percent of which is at least moderately degraded. Substantially more than half of this area lies in tropical and subtropical areas. By contrast, less than 10 percent of the earth's surface is devoted to arable agriculture. In recent years, degradation has been increasing, and many of the world's major rangelands are at risk. The desertification hazards map, compiled by several United Nations agencies, shows are as that are at greatest risk of desertification because of a continuation of

factors such as low rainfall, terrain, soil and vegetation conditions, and high human and animal use. Identifying ways to arrest and reverse these trends is the central concern of this study.

Tropical and subtropical rangeland is usually characterized by rainfall so low or irregular that crop production is difficult unless irrigation systems, which require high capital investment, can be established. Typical vegetation types include grasslands, low-density forests (such as dry tropical thorn forests), and shrublands. The term desert is commonly applied to those rangelands that are the most arid and least productive of vegetation.



Areas at risk of desertification

Rangelands are used to support grazing of browsing livestock. The openrange system of livestock production is characteristically associated with the extensive use of sparse, scattered, and often seasonal or ephemeral natural vegetation. Most of the world's estimated 3 billion head of domesticated livestock are reared on tropical or subtropical rangelands, rather than on highly productive pastures or in feedlots. Most of the red meat consumed by humans is produced on rangelands. Some 135 million people, about 20 percent of the world's population, base their economies and societies on rangeland

resources.

The pastoralists' systems of livestock production characteristically require movement of herds and herders over large areas, on either a seasonal basis (transhumant pastoralism) or a basis of perpetual migration (nomadic pastoralism). Pastoral socioeconomic systems can be further distinguished by combinations of other activities with those of herding. Herding, along with some agricultural crop production is a frequent combination, creating what are known as agro-pastoral systems; herding and tree-crop production creates silvo-pastoralism. Important economic activities of other pastoralists involve conducting, supporting, or controlling long-distance overland trade routes.

Reduced vegetative cover is often the result of overstocking, uncontrolled or concentrated grazing, removing woody plants for fuel or shelter, and clearing natural vegetation. Destructive management practices are often related to colonial-period modifications of indigenous management systems: for example, highly regulated land-use systems, such as the herima system of Masina, were widely converted to open-access systems with the imposition of the European law of public domain; the ecological integrity of indigenous pastoral systems was frequently destroyed through the imposition of international boundaries; cattle-based livestock systems were promoted in marginal drylands at the expense of sustainable indigenous systems based on better-adapted forms of livestock; wells projects encouraged concentrated grazing around water supplies; and the new economic order stimulated herd increase and its attendant economic rewards. Population growth in pastoral societies, approximately 1.5-2.0 percent annually (National Research Council, 1983b), is regulated by the observance of restrictive mores and other mechanisms. Hence, internally generated population growth is seldom a problem in pastoral zones. Indeed, declining population, with a corresponding inability to manage large herds, is often a serious problem. Further, the higher annual rates of growth in agricultural societies, characteristically on the order of 2.5-3.0 percent, encourages agricultural expansion into rangelands and forces pastoralists to increase use pressure on

the remaining land base. Risks are highest in the more arid rangelands where rainfall is lowest, or least dependable, and where evaporation and transpiration rates are highest.

Soil erosion is another consequence of rangeland mismanagement. Generally, it is a natural and continuous process, but in undisturbed ecosystems with a protective cover of plants, the soil is usually regenerated at the same rate that it is lost. If soil and vegetative cover are not in balance, erosion is accelerated. Under natural conditions, it takes several hundred years to generate a few millimeters of topsoil, but it can be lost to erosion in minutes if no protective vegetation is present.

Rehabilitating rangelands requires a respite from their intensive use. This involves the elaboration of a program of land management or, as a last resort, a program of land preparation, seeding, and planting, followed by careful management of use by livestock. To bring about such a program, alternative supplies of water, fuel, food, and other services may have to be provided to local pastoralists while the improvement is taking place. It is often helpful to develop programs of range improvement with reference to precolonial indigenous adaptations, where applicable, and knowledge of the changes that have occurred in local systems of production through time. Employing local people in seeding and planting efforts must also be a part of the development program. Local people must participate fully in demonstration projects; their understanding and commitment is clearly necessary for success.

Protection of a large number of relatively small rangeland areas is especially valuable to reveal what species are present, to provide for seed production, and to demonstrate the potential for ecological recovery. Demonstrating benefits that can be obtained by restoring the full natural cover and productivity of the vegetation may be a means of persuading local people that relaxing pressure on grazing lands is essential. However, this alone does not mean that long-term viability will be established. Protected areas and other conservation measures may restrict access to fuel, food, forage, and other products. If

substitutes are not provided to compensate for the loss of these resources, the local community is likely to frustrate the conservation measures. Compensatory measures might include improving pasture quality, establishing fuelwood or animal fodder plantations, or providing credit, alternative food, supplemental animal feed, fuel, or fiber, as appropriate. If the measures concerned take time to yield results, they must be supplemented by measures that bring immediate benefits. For example, if a protected area or watershed forest is threatened by wood-cutting for fuel, it will be necessary to provide an alternative source of fuel that can be used immediately.

AN IGNORED RESOURCE

Dry grazing lands are largely ignored by governments and technical assistance agencies. Very little agricultural research funding goes to rangeland development. This stems partly from the limited political power of pastoralists or typical rangeland populations, and partly from the high cost of traditional land rehabilitation practices.

As a consequence of this neglect, opportunities have been lost to make vast marginal areas more productive for pastoral people and other rural populations. Further, deteriorating rangelands contribute to flooding; when precipitation interception and infiltration are reduced, runoff correspondingly increases. The problem is compounded by the downstream effects of flooding, variously including damage to crops and settlements. Insufficient research is aimed at finding ways to protect existing rangeland or identifying appropriate new crops that would complement livestock production. Agronomists the world over are taught the principles of agricultural land management, but are unfamiliar with special rangeland techniques. The uninformed conversion of rangeland to cropland has helped destroy rangelands. For example, the moldboard plow destroys the surface vegetation and exposes thin, dry soil to erosion by wind and water. Clearly, abuse of rangelands has accelerated erosion, at times rapidly, at times slowly. As soil erodes, sediments enter water courses and river bottoms, estuaries, and deltas, which have

become the sink for nutrient-laden sediments.

CAUSES OF ENVIRONMENTAL DEGRADATION

The causes of land degradation must be understood in developing a strategy for land rehabilitation. Before costly methods are applied to promote range improvement, existing degradation forces should be identified and countered. Although the role of specific social forces is frequently unclear, devegetation - the progressive disappearance of plants from the land - is generally the result of human activities: overexploitation by man and his animals.

Degradation can begin with the depauperization of woodlands adjacent to and within dry rangelands, the encroachment of agriculture, or drought. Improper grazing usually follows these events on constrained range resources. Continued high animal density accelerates the removal of palatable species and the lack of competition permits the growth of species that are less palatable or less capable of supporting livestock on a sustainable basis. In many areas of the tropics and subtropics, the pressure of heavy use has caused ecological deflections from predominantly perennial grasses to annuals, resulting in a sharp reduction of late dry season carrying capacity. Woody shrubs, whose roots compete for soil moisture with the remaining grasses, also increase in number. In many instances, the woody vegetation is cut for fuel and shelter, thereby limiting the fodder contributions of the vegetation. Wind and water assault the exposed soil, causing cyclical flooding and erosion, eventually leaving the land to become bare and sandy. The overuse of vegetation by man and his livestock reduces the possibility of natural reseeding. The complex mixture of native species that are palatable or desirable becomes locally simplified as species become "extinct." In naturally semiarid regions, this leads to what is becoming known commonly as desertification - the simplification of the ecosystem to the point where its biological productivity and diversity are reduced to a minimum, and it can no longer sustain man and his animals in more than a casual, seasonal, and very limited fashion.

In areas such as the West African Sahel, there has been speculation that a progressive ecological downturn in productivity may be occurring in a highly variable climatic region that until recently experienced unusually favorable rainfall when viewed on an annual basis. However, the consensus of informed opinion is that to date there is insufficient evidence for attributing recent droughts to a major climatic change. These climatic cycles are very long term, and reconstruction of paleoclimate is difficult in the absence of historical records of rainfall fluctuation. Climatic cycles are perhaps 400-500 years long, with internal shorter cycles on the order of 70 years, and phases of 25-40 years (National Research Council, 1983b).

On the other hand, there is short-term evidence that the relationship between land abuse by man and his livestock, resulting in ecological deterioration, is more direct and irreversible than is generally appreciated. There is also evidence of low soil fertility, which continues to keep productivity low when combined with low rainfall (Breman and deWit, 1983). Historical review of former levels of vegetation, productivity, and land-use indicators shows that much higher levels of biological productivity were maintained throughout similar past fluctuations in rainfall, until changes in land-use patterns occurred (National Research Council, 1983b). One of the most significant changes was the introduction of large-scale cattle husbandry in colonial Africa, and the subsequent control of the tsetse fly in some are as by insecticides and by removing the vegetation of the fly's habitats.

In the areas where this occurred (sub-Saharan West Africa, the Horn of Africa, Botswana in southern Africa), a previously complex ecosystem comprising trees, shrubs, and grasses, with a wide variety of wildlife and livestock (camels, goats, sheep, and cattle), has become progressively simplified. The remaining perennial browse trees and shrubs and grasses are subject to overgrazing.

The consequences of devegetation are most stark in arid and semiarid areas, where they

lead rapidly to erosion, elimination of many useful species, and a drastic drop in carrying capacity, resulting in death of animals and the drift of refugees to other areas. In wetter agricultural areas, environmental consequences may not be so dramatic, but the economic impact can be substantial because the erosion-droughtflood cycle interferes with cropping.

In recent years, an additional factor has been the rising cost of petroleum fuels, which has led to a growing use of fuelwood. Much of the fuelwood has been taken from areas surrounding agricultural regions for local domestic use. However, fuelwood and charcoal are increasingly being sold in towns to peripheral urban dwellers for cooking as well as to commercial establishments for various uses. Little of this additional demand has been met by increased planting of commercial or state fuelwood lots (National Research Council, 1983a). The impact of the deforestation is being felt as reduced moistureholding capacity and increased exposure of soil and crops to wind and rain cause lower yields of crops and loss of topsoil.

THE NEED FOR REHABILITATION

Rangelands are easy to destroy, but difficult to restore. However, because of their size and potential for increased productivity, their improvement can bring many benefits to developing countries. If left undisturbed, rangelands will, in most cases, regrow and reclothe themselves with vegetation, but it may take more than 50 years to return to a stable state. Opportunities should be seized that emphasize vegetation for useful forage and conservation of species.

Improving rangeland is generally a costly process because of low economic returns, relatively low productivity, fragility, site specificity, and often capricious precipitation. For privately owned land, it makes no sense to invest $50 to renovate a hectare of land worth $5. To halt the situation of dams, harbors, and rivers, and to slow the vast loss of topsoil

and avoid threat of devastating flash floods, in most cases will require programs that encompass large areas and are supported both by the government and by the local community structure.

To overcome future starvation and malnutrition, either marginal lands must produce more food or there must be a decrease in the human populations relying on such lands. Revegetation is the critical key to the renovation of many rangelands. A cover of vegetation keeps the soil and water in place and decreases evaporation and runoff. Vegetation creates a living barrier to runoff and erosion by increasing percolation and soil storage of rainfall. It shelters the soil from scouring and provides a barrier that slows runoff. Its leaf litter absorbs water and protects the soil surface from rain and wind. Roots and soil organisms help break up the soil, making it porous so that water can infiltrate.

Revegetation is possible both by such natural processes as seed dispersal by wind, birds, and other animals, or carried by seasonal streams and floodwaters; planting by human activity, deliberate or unplanned also promotes new growth. Planned revegetation has two components: (1) direct intervention by seeding or planting trees, shrubs and grasses, using a variety of techniques; and (2) management interventions that serve to strengthen the role of natural revegetation processes.

Strengthening natural regenerative systems, in addition to direct planting methods, can be achieved in several ways. The basic objective is to add extra genetic material adapted to the ecosystem to provide a greater range of material for multipurpose use, and to assist the system to regain its former productivity and resiliency. For example, existing distribution mechanisms can be used, such as planting a mixture of perennial legumes around degraded well-heads, from which animals will spread them naturally (National Research Council, 1981). Nomadic pastoralists supplied with seed will be able to replant fodder shrubs and improve oasis systems with windbreaks or living fences composed of fodder legumes.

Where grazing pressure can be reduced and regenerative mechanisms strengthened, substantial regrowth is likely. The usual way of approaching this objective is to encourage herders to control their grazing. However, herders are usually more sensitive to the management of their grazing resources than are outsiders, and if overgrazing occurs, it is because other conditions make misuse of resources necessary for survival.

Animals can be used to upgrade rangelands if their use is carefully managed. Cattle, sheep, goats, and other livestock prefer somewhat different forages, so they can be grazed together or selectively in sequence. Grazing animals may encourage the dominance of unpalatable species depending on how grazing occurs. This selectivity is especially notable with some trees and shrubs. Improved grazing management may not eliminate these unpalatable species; therefore, other methods for removing them must be found.

Demands of the urban areas also generate pressures on rangelands. For example, many countries encourage the development of crop production in marginal areas to increase the amount of food available to feed a burgeoning urban population. Ways should be found to raise the efficiency of food and fodder production in areas where high productivity is possible, rather than expanding into marginal are as where crop productivity is low but grazing is more appropriate and dependable.

This report addresses issues of socioeconomic context, regional assessment and site evaluation, approaches to management, and criteria for plant selection in intensive rehabilitative efforts. The case studies provide further information regarding these issues, as well as descriptions of projects that have succeeded as a result of broadbased analysis and sensitivity to environmental and social context.

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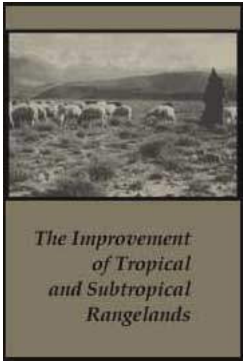

The Improvement of Tropical and Subtropical Rangelands (BOSTID)

Part I

Introduction

In this report, rangelands are defined as "land carrying natural or semi-natural vegetation which provides a habitat suitable for herds of wild or domestic ungulates" (Pratt, Greenway, and Gwynne, 1966). Rangelands typically possess characteristics that make them unsuitable for agriculture or intensive forestry: they are variously too dry, too steep, too rocky, poorly drained, or too remote. In Africa, the Near East, and southern Asia - the geographical focus of this report - rangelands occupy 2,666 million hectares, or 53 percent of the land surface (table 1).

In the areas considered, there are two general systems of rangeland utilization: systems that use the land to produce goods that are removed or exported from the land (ranches), and those that chiefly provide subsistence for people associated with livestock and wildlife populations (indigenous pastoral systems). Contrary to popular belief in industrial nations, pastoral systems are not necessarily less productive than ranching systems. African pastoral systems, for example, are often as productive as market-oriented ranching systems in comparable areas in terms of protein produced per unit of land utilized.

	Area of Permanent Pasture[a] 1955	1975	1983 (million hectares)	Permanent Pasture as Percent of Land Area 1983	Open Forests[b] 1980 (million hectares)	Other Land[c] 1983 (million hectares)	Estimated Total Area Range and Pasture[d] (million hectares)	Rangeland As Percent of Total Land Area
North America (United States and Canada)	277	265	265	14	275	746	913	50
Europe	83	88	86	18	22	91	153	33
USSR	124	374	373	17	137	702	861	39
Central America (inclusive and Caribbean)	79	94	95	32	0.3	99	145	48
South America	330	446	456	26	248	230	619	47
Africa	615	785	778	26	508	1,317	1,945	65
Asia (except China)	279	372	369	21	61	602	721	41
China	194	286	266	31	45	415	538	58
Oceania	377	472	460	55	76	182	627	75
World Total[e]	2,358	3,181	3,157	24	1,372	4,384	6,721	51

Notes:

a Includes permanent meadows and pastures and land that has been used for five years or more for the production of herbaceous forage crops, either cultivated or wild

b Includes wooded land with a grass understory beneath the open canopy. Livestock and wildlife browse on both the leaves and twigs of the trees and on the grasses

c "Other land" is a residual category defined by the United Nations Food and Agricultural Organization (FAO) in its *Production Yearbook*. About one third of this land is so dry it lacks plant cover. However, a significant percentage of this land may be grazed seasonally or in years of heavy rainfall. Half of this category is counted in the estimated total area of range and pasture

d Sum of areas of permanent pasture (1983), open forest (1980), and 50 percent of "other land" (1983)

e Numbers may not add up to totals because of rounding

Sources:

1 Data on "permanent pasture" and "other land" are from United Nations Food and Agriculture Organization (FAO), *1983 Production Yearbook* Vol. 38 (FAO, Rome, 1985), Table 1, pp. 47-48, and FAO, *1955 Production Yearbook* (FAO, Rome, 1955)

2 Data on open forests and other wooded land are from United Nations Food and Agriculture Organization (FAO)/Economic Commission for Europe (ECE), *Forest Resources 1980* (FAO/ECE, Rome, 1985)

Table 1 Distribution of the World's Pastures and Rangelands, 1955-83

Most ranches are privately owned, and characteristically use investments of capital and various management techniques on large areas of land to increase livestock production. Unlike pastoral systems, labor inputs are low. Hence, ranching often produces more protein per hour of labor than does pastoralism. On the other hand, ranching requires vastly greater inputs of energy, and expenses incurred in connection with fencing, water development, brush control, revegetation, grazing management, and selective breeding are substantial.

Pastoral systems represent the principal form of rangeland utilization in Africa and Asia.

They involve significant social adaptations to the movement of livestock or wildlife from one location to another in relation to the availability of forage and water. The rangelands utilized are seldom privately owned, and mechanical and chemical inputs are seldom prominent. The systems are labor intensive. It has been estimated that livestock and wildlife support some 30-40 million pastoralists, and the animals and animal products associated with pastoral systems are critical to millions of other individuals in settled communities (International Institute for Environment and Development and the World Resources Institute, 1987).

The importance of livestock in pastoral systems exceeds their value as sources of milk, meat, blood, and hides. Livestock often represent a means of accumulating capital and, in some societies, are associated with social status. They are assets that can reproduce and that can be liquidated should cash be required. In addition to supporting livestock, rangelands serve as sources of other significant economic products: bushmeat, fruits, berries, nuts, leaves, flowers, tubers, and other food for human populations, as well as medicinal plants, building materials, thatch, fencing, gums, tannin, incense, and other products important to the economies of rural populations (Sale, 1981; National Research Council, 1983; Malhotra, Khomne, and Gadgil, 1983).

The importance of rangelands as sources of bushmeat and vegetable foods for human populations deserves special attention. These foods are derived from species that are well adapted to the environmental peculiarities of the regions in which they are found. Hence, such foods are often available in the event of crop failure or substantial losses of livestock. Even during periods with average rainfall, satisfactory crop yields, and herd stability, such foods constituted a significant part of local diets. Indeed, in many societies, the offtake of wildlife from rangelands exceeds that of livestock in importance. In 1959, for example, the sedentary and pastoral peoples of the Senegal River Valley in West Africa relied upon fish and wildlife for over 85 percent of the meat that they consumed (Cremoux, 1963); native plants were of equal or greater importance. Since that time, widespread environmental

degradation has dramatically reduced the availability of the natural products associated with local coping strategies and has correspondingly increased the vulnerability of rural populations (National Research Council, 1983). In most instances, the degradation is a result of breakdowns in the traditional resource management systems that for centuries had maintained an equilibrium between environmental systems and human activity (National Research Council, 1986).

Number of Cattle (in thousands)

Country	1940	1968-1970	1974	1978	1982	1985
Senegal	440	2,615	2,318	2,500	2,300	2,200
Mauritania	850	2,100	1,175	1,200	1,500	1,350
Mali	1,174	5,300	3,640	3,800	5,300	5,800
Burkina	491	2,900	2,300	2,600	2,871	2,800
Niger	754	4,200	2,200	2,850	3,487	3,530
Total	3,709	17,115	11,633	12,950	15,458	15,680

SOURCES. Gallais, 1979; Africa South of the Sahara 1986 1985; and Africa South of the Sahara 1988 1987.

TABLE 2 Cattle Populations in the West African Sahel

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South of the Sahara 1988 1987.

Rangeland ecosystems, particularly those in arid and semiarid regions, are highly susceptible to degradation. In many regions, degradation is chiefly a result of changing herd composition and overstocking. Particularly noteworthy since the advent of the colonial period has been a proportional shift in herd inventories favoring cattle, a form of livestock poorly adapted to dryland ecosystems, at the expense of well-adapted and less environmentally destructive forms, such as camels, as the former were more marketable within the context of the new economic order (Chassey, 1978). In the West African Sahel, for example, colonial policy resulted in an almost fivefold increase in cattle populations between 1940 and 1968 (table 2).

Agricultural expansion has also contributed to the degradation of tropical and subtropical rangelands. In drylands, agricultural expansion results in increased pressure on rangelands because the conversion of the more productive forage reserves to crop land forces pastoralists to "overgraze" the remaining land base (Thomas, 1980).

Moreover, grain crops deplete soil nutrients at a rate thirty times greater than the rate of nutrient loss in a properly stocked range ecosystem (Heady, 1975). The cost of replacing the lost phosphorus, potassium, nitrogen, and other nutrients is generally prohibitive.

In many regions, high levels of sustained use pressure have eliminated the more palatable plant species (species referred to as "decreasers" in range science). In dryland

ecosystems, plant growth is relatively slow. When aerial biomass is consumed by foraging livestock, many plants respond by transferring nutrients from their roots in order to produce new leaves. This results in reduced rooting. Reduced rooting, in turn, reduces the ability of the plant to absorb moisture and nutrients even during rains. As the more palatable species are weakened, less palatable species ("increasers") become dominant. With continuing high levels of use pressure, increasers give way to undesirable shrubs, grasses, and forbs ("invaders"). As these species are overgrazed, the land surface is exposed to further, more severe, degradation. In the drylands of Africa and Asia, cattle have been particularly destructive. Unlike camels and goats and most native herbivores, which are predominantly browsers, cattle are grazers. Cattle therefore increase pressure upon perennial grasses and often eliminate them, causing ecological deflections toward ephemeral annual grasses and relatively unproductive trees and shrubs, such as Calotropis procera (Gaston and Dulieu, 1976).

The reduction or elimination of vegetative cover, in combination with trampling and the compaction of the surface by livestock, reduces infiltration and permits the mobilization of soil particles subject to transport by overland flow. This results in depressed groundwater tables and increased soil erosion. Surface exposure and the reduced organic content of soils also result in altered soil-water relationships and greater amplitude in soil temperatures. This altered soil ecology adversely affects important soil microorganisms, such as the rhizobial bacteria responsible for nitrogen fixation in acacias and other leguminous genera. This, in turn, affects nutrient regimes and results in a further loss of soil structure. Altered soil ecology directly eliminates additional plant species and frustrates regenerative processes in others. Further losses occur through disruptions in various biological dependency and affinity relationships. Environmental degradation both reduces range carrying capacity for livestock and affects wildlife populations through habitat modification. Rangeland conditions in selected countries of Africa, Asia, and Western Asia are described in tables 3, 4, and 5.

Location	Range Condition	Causes or Consequences
Cameroon		
Countrywide 8,300,000 hectares	Original perennial grassland and acacia types mostly replaced by annuals and unpalatable shrubs	Many years of heavy grazing and frequent burning; drought in 1975; severely degraded areas unlikely to recover without protection
Northern Sector 7 million hectares		
Sudano-Sahel region (acacia grasslands and steppes--Sahel; dry and moist woodlands--Sudanian types)	Almost denuded state in many areas	
Guinea-Congo region (south of Garoua)	Range in better condition than Sudano-Sahelian types	Use of range resources limited by tsetse fly infestations; pressure on open area grazing lands can be partially alleviated with tsetse control programs or livestock prophylaxis
Southern Sector		
Adamaoua Plateau and other localized areas About 1,300,000 hectares	Quality of range generally better than in northern sector	Rainfall higher, tsetse limited, and area probably stable; cattle increasing at 1-2%/year expected to cause degradation

Table 3 Rangelands Conditions in Selected African Countries

Sudan 56 million hectares (permanent pasture), 24 million hectares (grasslands)	Range deteriorating and desertification accelerating, apparently continuing downward trend; 75-80 million total hectares suitable for agriculture but only 24 million hectares currently grazed, 7 million farmed	Increase of 5-18 million head of cattle during last 30 years; cultivation of marginal lands; woodcutting and shrub uprooting for fuelwood
Somalia 29 million hectares	Overgrazed perennial grasses replaced by annuals and in some cases unpalatable shrubs; deterioration accelerating. The rangeland is the greatest natural resource of the country.	Overgrazing; increased demand for meat and livestock products
Kenya Rendille management area 13.249 square kilometers	3.9% range and 7.6% woodland are good-excellent; 77% and 70% are fair; predominance of fair and poor condition indicates a serious state of rangeland degradation	The cause for the degraded condition is not certain; it is projected that significant improvements can be realized

Table 3 Rangelands Conditions in Selected African Countries - continue 1

Location	Range Condition	Causes or Consequences
Uganda 5 million hectares		
Northeast region Entire Karamoja District 816,300 hectares	Perennial grasses replaced by plants with lower nutrient requirements and less value to animals; irreversible erosion	Majority of grazing land outside tsetse area; livestock populations increased rapidly; overgrazing (feeding and trampling)
Most of Acholi District Semiarid range	Reduction of ground cover Majority of grassland areas are four disclimax created by fire and grazing (would return to dry forest if these factors were eliminated)	
Morocco 12,141,000 hectares rangelands countrywide	Reduced forage production Expanding desertification	Overstocking; expanding dryland agriculture; uprooting of shrubs for fuel increase soil erosion; decline in natural grassland area
Tunisia 3,142,000 hectares	Degraded Rangelands estimated to be producing at 1/2 of potential (optimistic estimate); presumed to continue deteriorating	Uncontrolled grazing; fuelwood cutting; long history of misuse; stocking rates estimated to be 3-8 times higher than ideal

Table 3 Rangelands Conditions in Selected African Countries - continue 2

Zambia		
Countrywide, Upper Zambezi (Western Province), Kafue River locality Eastern Province 35 million hectares	Deteriorated; severe cover depletion; excessive stocking rates	Overgrazing--average stocking rate for entire country is 0.32-0.45 hectare/livestock unit (10-15 times higher than recommended)--not perceived as a problem by rural inhabitants; soil erosion widespread
Zimbabwe		
Tribal Trust Lands 16,161,000 hectares	Approximately 50% in very poor condition (1960 survey); deteriorating	Overgrazing from increased livestock population (+119% 1964-77) seriously deteriorated forage resource base
Buffalo Ranch Farm 20,000 hectares		Stocking rate management:
--Cattle Section 12,000 hectares	Good condition; apparently stable, possibly improving	8.5 hectares/livestock unit
--Game Section 8,000 hectares	Fair condition; apparently stable	8.0 hectares/livestock unit equivalent (455 kg)

SOURCE: Adapted from World Resources Institute and the International Institute for Environment and Development, 1986, p 76.

Table 3 Rangelands Conditions in Selected African Countries - continue 3

Location	Range Condition	Causes or Consequences
Syria		
Countrywide, 8,700,000 hectares (grasslands)	Overgrazed; trend either generally downward or stable at minimal productivity	Too many animals; most productive rangelands destroyed by plowing; uprooting of shrubs for fuel; establishment of water points (wells) without any grazing controls
Interior Steppes: arid deserts	Originial plant community virtually eradicated; replaced by species of little interest to humans or animals; long history of degradation	Overgrazing, especially by goats; development of wells permitted overuse of plant resources

Table 4 Rangeland Conditions in Selected Western Asian Countries

People's Democratic Republic of Yemen		
Countrywide, 9 million hectares (grassland), 2,500,000 hectares (scrub forest)	Degraded stage of retrogression; declining, or stable at minimal productivity	Grazing pressure; fuelwood collection
Yemen Arab Republic		
7 million hectares (pasture) 1,600,000 hectares (woodland)	Majority of "woodland" better classified as "rangeland"; depleted plant cover; severe sheet and gully erosion, decline in livestock numbers	Long history of degradation; overgrazing fuelwood cutting; World Bank believes range can be restored to some extent
Iraq		
Countrywide, 36,040,000 hectares (grazing land, i.e., uncultivated) 100,000 hectares (forage)	Low productivity; progressively downward trends	Uncontrolled grazing; conversion of some desert lands to dryland farming
Steppe Zone, 6,200,000 hectares	Predominance of unpalatable shrubs; disappearance of natural vegetation; historical downward trend; continuing loss of rangeland	Overgrazing, conversion to dryland farms
Mountain Range (forest and sub-alpine)	Palatable perennial grasses generally scarce; annuals predominate	Long history of overgrazing
Alpine Meadows	Good seasonal grazing (four months); apparently stable	Limited seasonal usage
Southwest Desert, 16,700,000 hectares	Apparently fair--but steady deterioration	Overgrazing, in past due to transhuming flocks from neighboring countries

Table 4 Rangeland Conditions in Selected Western Asian Countries - continue 1

Location	Range Condition	Causes or Consequences
Oman 1 million hectares (permanent pasture), 20,208,000 hectares (other land)		
Desert and Mountain	1975 little evidence of damage to plant communities; stable, perhaps improving	Herd size decreasing in nomadic regions
Sain Katnt and Batinah	Overused	Excessive woodcutting; heavy grazing and trampling by livestock
Settled Areas	Perhaps fair condition at present, possibly improving	Animals are concentrated in these areas, but heavy reliance on fodder crops
Jordan 6,316,253 hectares (grazing and/or uncultivated)	Loss of vegetation; degradation for hundreds of years, but utilization has become increasingly destructive in the past few decades; substantially increasing erosion with pavement-like soil	Overstocking, especially of goats (also affects reforestation) Lack of water more limiting than lack of feedstuffs; sedentarization concentrated animals in smaller areas for longer periods, human population increased sixfold over 55 years, increasing demand for red meat; long-term, continuing degradation

Table 4 Rangeland Conditions in Selected Western Asian Countries - continue 2

Saudi Arabia Countrywide 85 million hectares (pastureland) Arabian Shield-South 2,400,000 hectares, (9.5% of total country area)	Increase in biomass production since 1967 but species composition indicates degraded forage resource; poor, 40%, fair, 20%; good-excellent, 40%; human-caused destruction of rangeland has increased significantly	Widespread availability of trucks allows transport of animals and water to remote areas previously used infrequently; animal production units increased 1.8 times since 1967; rangelands are less suitable for sheep (grazing) and better suited for camel and goat (woody browse)
Iran Countrywide, 1,100,000 hectares (specified as pastureland)	Severe depletion of range; (disappearance of most preferred perennial species, e.g., Artemisia and Aristida) and continuing deterioration; serious soil erosion and flash runoffs	Heavy overstocking--estimated to exceed carrying capacity by 4 times; fuel gathering, widespread encroachment of dryland cultivation into traditional grazing areas; climatic fluctuations

SOURCE: Adapted from International Institute for Environment and Development and World Resources Institute, 1987, p. 68.

Table 4 Rangeland Conditions in Selected Western Asian Countries - continue 3

Location*	Range Condition	Causes or Consequences
India 11,850,000 hectares	Highly degraded; overgrazed; soil erosion and desertification, reduction in grazing land/animal ratio; gradual conversion of forests to savannahs and steppes	Overstocking of sheep and goats; agriculture expanded into marginal areas, government neglect; no management of fodder production or rangelands
Sri Lanka 439,000 hectares	Native grasses of low grazing value; area not reported to be degraded; gradual increase in livestock numbers	Grazing areas frequently affected by cyclones, heavy rains, and overflowing water tanks; religious objections limit range animal production
Nepal 1,978,000 hectares Rangelands are concentrated in mountainous areas	Degraded; overgrazed; soil erosion on steep slopes; deforestation	Excess unproductive livestock; closing of Tibetan border to livestock from Nepal causes overgrazing
Pakistan 5 million hectares Rangelands are concentrated in Baluchistan	Poor; most rangelands estimated to produce 10-15% of potential; the "former acacia savanna" of the Indus Valley alluvial plain is the important grazing area; dry; overgrazed; most areas completely devastated; entire species of edible plants eliminated, valley floors completely devastated; other areas, dry and heavily used; soil erosion; desertification; extensive damage to vegetation cover	Overstocking, estimated at three times the ideal; heavy nomadic use; fuelwood demand by city dwellers

Table 5 Rangeland conditions in selected Asian countries

Afghanistan 30 million hectares	Low mountains of the Hindukush north slope are good summer pasture; southern desert is good winter range; other areas are heavily overgrazed; the heavily grazed southeastern foothills of high mountains of Hazaradiat still have fair to good grazing; many rangelands have seriously declined, and this is continuing	Uncontrolled stocking, especially along major migration routes; fuelwood gathering; steady expansion of dryland cultivation
People's Republic of China 285,690,000 hectares	41% of total land used for grazing; 25% of grasslands deteriorated; erosion is "dangerously accelerated"; loss of productivity; desertification	Population pressure; 27% of desertification attributed to overgrazing; government heavily favored agriculture over rangelands during the 1950s; conversion of remaining thin forest and good grassland into cultivated fields
North China	Too arid; unproductive; poor grazing land; heavily overgrazed; badly eroded; low forage production; poor forage quality, soil erosion by wind and water; plant cover deterioration faster than rehabilitation	Removal of best grazing for agriculture; and urban development Increased pressure on remaining rangeland, formerly productive grassland are now sand dunes; poor management of grasses and fodder crops
South China	Poor pasture quality; restricted seasonal grazing time, low carrying capacity and poor cattle growth	

*Note: Size of Rangeland: Figures are those given by the United Nations Food and Agriculture Organization for Permanent Pasture, which underestimates total size of rangeland

SOURCE: Adapted from International Institute for Environment and Development and World Resources Institute, 1988-89, p 80.

Table 5 Rangeland conditions in selected Asian countries - continue 1

The effects of rangeland degradation often extend well beyond the rangelands themselves.

Dust originating in degraded rangelands is transported by dry-season winds to distant areas, causing annoyance, health hazards, and costly interruptions in air and ground traffic. The rapid release of runoff in degraded rangelands following rains contributes greatly to destructive flooding in downstream lowlands, and sediment entering drainage systems in degraded rangelands shortens the useful life of reservoirs and irrigation systems.

Less obvious effects would include the impact of rangeland devegetation on climatic regimes. For example, it is now widely believed that precipitation is strongly influenced by biogeophysical feedback mechanisms (Charney, 1975). According to this hypothesis, drought is reinforced through changes in vegetative cover. Large-scale losses of vegetation would increase surface albedo, which, in turn, would affect the atmospheric energy budget in such a way that the subsidence, which promotes aridity, would be intensified.

Further, it is now believed that levels of precipitation are strongly influenced by soil moisture locally released into the atmosphere through evapotranspiration. Hence, reduced vegetative cover and decreased soil moisture would result in reduced local precipitation. Finally, losses of vegetation affect surface roughness in the atmospheric boundary layer. Surface roughness contributes to the destabilization of moisture-laden air masses, thus encouraging precipitation. Devegetation also reduces carbon dioxide uptake in the planetary biomass. The greater concentration of carbon dioxide in the atmosphere contributes to global warming, causing changes in atmospheric circulation and rising sea levels through the melting of continental ice sheets (Study of Man's Impact on Climate, 1971; Woodwell, 1984).

The science of range management originated in North America, and North American approaches to range management are described in several wellknown volumes, such as A. W. Sampson (1952), Stoddart and Smith (1955), R. R. Humphrey (1962), and National

Research Council (1962, 1984). Historically, attempts to transfer experience gained in the management of North American or Europe an rangelands to the management of tropical and subtropical rangelands have been unsuccessful (Heady and Heady, 1982). In improving tropical and subtropical rangelands, it is important to carefully characterize the physical system being managed in order to better understand the biological potential of the system and assure that critical ecological processes are restored and maintained. It is equally important to relate efforts in range improvement to the needs,

knowledge, adaptations, and capabilities of local populations, as well as to the broader economic and political contexts of such efforts. The widespread belief that pastoral systems are simply artifacts of the past requires reexamination. The view that range improvement in the tropics and subtropics should focus narrowly upon the increased per unit productivity of selected forms of livestock, usually cattle, at the expense of the biological diversity basic to the maintenance of local coping strategies and economies should similarly be reexamined. This report describes tropical and subtropical rangelands, addresses issues of socioeconomic context, discusses approaches to regional assessment and site evaluation, explores management strategies, and provides criteria for plant selection in relation to efforts in range improvement. The case studies appended to the report provide further information regarding these issues. The Improvement of Tropical and Subtropical Rangelands is the third report to appear in the series, "Resource Management for Arid and Semiarid Regions." Other titles include Environmental Change in the West African Sahel (1983) and Agroforestry in the West African Sahel (1983).

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The nature of tropical and subtropical rangelands

This report focuses on areas of low and undependable precipitation within the tropics and subtropics. (1) Much of the area is occupied by savannahs and thorn-bushlands, often characterized by a rich diversity of grasses. The prominence of grasses in tropical rangelands in many instances reflects the repeated use of fire in hunting or range renewal (Sauer, 1952), as well as the coevolution of grasses and wild herbivores (Harris, 1969). Substantial tracts of forest are associated with tropical rangelands in some regions; in others, extensive swamps created by the seasonal overbank flooding of exotic rivers are features of considerable regional importance.

Tropical rangelands differ greatly from rangelands in temperate regions, and social adaptations to these differences are reflected in the management of range resources. Differences of climate (Trewartha, 1954), soils (Sanchez, 1975), vegetation (Davy, 1938; French, 1957), and other environmental factors are well documented and generally well understood. The management of tropical rangelands is further affected by the prevalence of livestock diseases. Rinderpest, foot-and-mouth disease, contagious bovine pleuro-pneumonia, anthrax, east-coast fever, trypanosomiasis, and sheep pox have historically

taken heavy tolls in the tropics (Pratt and Gwynne, 1977). Strategies to blunt the impact of disease include increasing livestock holdings to levels that assure the survival of a breeding nucleus. The relatively high levels of social, economic, and political differentiation within the tropics similarly affect the exploitation and management of range resources.

Range classification

Range management issues are usefully considered within the context of ecoclimatic zones. In this report, these zones are defined largely on the basis of land potential and moisture availability (Pratt and Gwynne, 1977). Within the tropics, five such zones can be distinguished:

1. Humid to dry subhumid (moisture index not less than -10).(2) This zone is characterized by forest and derived grasslands and bushlands, with or without natural glades. The grestest potential is for forestry (perhaps combined with wildlife and tourism), or intensive agriculture. The natural grasslands of this zone require intensive management for optimum production. Approximately 0.8 hectare is required per livestock unit, depending upon the related grassland association. (3) In this zone, approximately 2.5 livestock units are required to support one subsistence pastoralist; hence, 2 hectares are required to support each individual. The maximum population density per km² is about 50 pastoralists (see table 1-1).
2. Dry subhumid to semiarid (moisture index -10 to -80). The vegetation of this zone includes moist woodland, bushland, and savanna. Forestry potential is low. However, the agricultural potential is relatively high, soils and topography permitting, with emphasis on lea farming. Large areas are generally under range use and, with intensive management, can carry 1 livestock unit per 1.6 hectares. Approximately 3 livestock units are required to support 1 subsistence pastoralist. Thus, 4.8 hectares are required to support 1 individual. The maximum density of pastoralists would be approximately 21 per km². Regular burning

is an important management tool in this zone.

3. Semiarid (moisture index -30 to -42). These are areas with marginal agricultural potential, which in some regions is limited to rapidly maturing grains. The natural vegetation is characteristically dry woodland and savanna. This is potentially productive rangeland. Approximately 3.5 hectares are required per livestock unit, except where dry seasons exceed 6 months. The corresponding human carrying capability is 7 individuals per km². Animal husbandry is limited principally by the encroachment of woody vegetation and, in some locations, by leached soils. In many areas, particularly in Africa, the more open country with a high density of wildlife is a valuable tourist attraction.

	Ecoclimatic Zones				
	1	2	3	4	5
Hectares required per livestock unit	0.8	1.6	4.0	12.0	42.0
Livestock units required to support one head of population	2.5	3.0	3.5	4.0	4.5
Hectares required per head of population	2.0	4.0	14.8	48.0	189.0
Maximum population density per km²[a]	50.0	21.0	7.0	2.0	0.5

[a]These figures presume that all land is accessible and productive; if actual population density under subsistence pastoralism even approaches these estimates, overpopulation is indicated. Higher population can only be sustained if the pastoralists derive a substantial part of their subsistence from vegetable foods--collected, grown, or procured in exchange for livestock.

TABLE 1-1 Relationship between Ecological Zone, Livestock Carrying Capacity, and Maximum Population Density under Subsistence Pastoralism

TABLE 1-1 Relationship between Ecological Zone, Livestock Carrying Capacity, and Maximum Population Density under Subsistence Pastoralism

	Ecoclimatic Zones				
	1	**2**	**3**	**4**	**6**
Hectares required per livestock unit	0.8	1.6	4.0	12.0	42.0
Livestock units required to support one head of population	2.6	3.0	3.6	4.0	4.6
Hectares required per head of population	2.0	4.0	14.8	48.0	189.0
Maximum population density per km^2 [a]	60.0	21.0	7.0	2.0	0.6

[a] These figures presume that all land is accessible and productive; if actual population density under subsistence pastoralism even approaches these estimates, overpopulation is indicated. Higher population can only be sustained if the pastoralists derive a substantial part of their subsistence from vegetable foods--collected, grown, or procured in exchange for livestock.

SOURCE: Modified after Pratt, 1968.

4. Arid (moisture index -42 to -51). This zone is suitable for agriculture only where fertile soils coincide with a favorable distribution of precipitation, or where rainwater is concentrated in depressions. Many arid rangelands are dominated by species of Acacia or Prosopis. Perennial grasses, such as Cenchrus ciliaris, can be prominent, but succumb quickly to inadequate management. As many as 12 hectares may be required per livestock unit. Wildlife is important, particularly where dry thorn-bushland predominates. Burning requires caution but can be highly effective in range manipulation. Approximately 4 livestock units are required to support 1 subsistence pastoralist, and the maximum population density per km^2 is 2 individuals.

5. Very arid (moisture index -51 to -57). This zone supports rangeland with relatively low potential. The characteristic vegetation is shrub or grass steppe, with trees largely confined to water courses and seasonally inundated depressions. Perennial grasses, once dominant in many areas, are now localized within a predominantly annual grassland. Growth is confined largely to the seasonal flushes characteristic of summer therophyte vegetative communities, and grazing systems are generally based on pastoralism. Populations of both wild and domesticated animals are restricted by temperature, forage, and available moisture (Schmidt-Nielsen, 1964).

Systems of range classification should be regionally adjusted to include descriptions of the existing vegetation in physiognomic terms, with subdivisions by species composition.

Social system-ecosystem interactions

Most environmental systems are highly modified by human activity. Hence, an understanding of the biological and use potential of these systems benefits greatly from analyses of environmental change over time (National Research Council, 1981). Such analysis is also important in defining ecosystems and in identifying cause-effect relationships that have contributed to changes in the composition and productivity of these systems.

Indigenous social systems, through selection and adaptation, are functionally associated with local ecosystems through flows of energy, material, and information (4) (Rambo and Sajise, 1984). Changes in either the social or environmental system result in changes in the other. Hence, each system must be thoroughly understood if positive change is to be realized. In many, perhaps most, instances, highly disruptive changes are responses to external stimuli. Many examples could be cited. For example, the highly regulated land-use systems of many societies (see the discussion of the hema system in case study 9, Part II) were commonly transformed into open-access systems through the imposition of

European public-domain law often combined with land expropriation, a situation that, in many regions, has led to intense use pressure and severe environmental degradation. Similarly, colonial era introductions of cattle into inappropriate areas (such as Zone 5 of the above classificatory system) has led to severe degradation and zonal compression (National Research Council, 1983b). The fixing of boundaries, at national and sub-national levels, has reduced or eliminated strategies of mobility that are crucial to these areas. In addition, increasing market integration has converted highly conservative systems of land use into opportunistic systems that impose greater pressure on available resources. In some cases, this has destroyed the subsistence base that supported the coping strategies of local populations, and has reduced the range of economic options available to them. Wildlife, honey and beeswax, gums and resins, cordage, tannin, and medicinals are among the economic products lost through the de gradation of environmental systems in Africa and Asia.

Characteristically more subtle, but equally important, impacts on socioeconomic and environmental systems result from destructive modifications of indigenous systems of values, ideology, knowledge, and social organization. An unfortunate consequence of past efforts in international development is that so much attention was directed toward the transformation of what are now belatedly recognized to be critically important social adaptations, without corresponding effort being made to understand the context or consequences of the changes promoted.

In addressing issues of range management in the tropics and subtropics, many of the most important clues as to appropriate actions for governments and development agencies reside in the analysis of traditional adaptations to local environmental systems. Growing awareness of the importance of traditional adaptations is contributing to a shift of emphasis by governments and development agencies from open-field cultivation and plantation forestry to more biologically complex agroforestry or agro-sylvo-pastoral systems (National Research Council, 1983a). The growing interest in camel husbandry in

the drylands of Africa and Asia similarly reflects pre-colonial strategies of rangeland utilization. In West Africa, for example, camel-based livestock systems were commonly replaced by cattlebased systems by colonial administrators unfamiliar with the characteristics of the drylands of West Africa in relation to the requirements of cattle. By so doing, these administrators contributed greatly to the current environ mental emergency in Africa (National Research Council, 1983a). An overview of selected African and Asian pastoral adaptations is contained in Douglas Johnson's The Nature of Nomadism (1969).

NOTES

1. In this report, the terms "tropics" and “tropical” are expanded to include the subtropics (Tropical and Subtropical Steppe, Tropical and Subtropical Desert, Mediterranean or Dry Summer Subtropical, and Humid Subtropical climatic regions) as well.
2. Moisture indexes provide expressions of climate derived from monthly rainfafl and evaporation, with the estimate of evaporation based upon measures of radiation, temperature, saturation deficit, and wind speed, weighted for altitude and latitude. They are calculated on the basis of Thornthwaite's concept of moisture indexes (1948), combined with Penman's estimate of evaporation (1948) .
3. In many areas of the tropics, a livestock unit is taken to be a mature zebu cow with calf at Soot (averaging about 300 kg liveweight and having a daily dry matter requirement of 6.5 to 8.5 kg).
4. In an ecological context, information is simply organized or patterned energy or material that tells the observer something about the past, present, or probable future state of an ecosystem or its components. Human response to environmental information is unique compared with that of other organisms because it occurs largely at the cognitive level where cultural conditioning affects both perception and the selection of appropriate responses.

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The social context for rangeland improvement

The loss of desirable vegetative cover is a threat to world food supplies, to the quality of human life, and to the environment. Desertification, erosion, and the loss of useful plant species can be arrested through revegetation. However, revegetation efforts have often

ended in failure or have had limited impact. This has been particularly true in semiarid and marginal lands where the reestablishment of plants is a delicate process.

Revegetation often is required to correct the abuse of existing resources by people and their livestock. More often than not, the success or failure of revegetation schemes is also determined by human activities. Normally, adequate protection of an area is possible only if the people who use the land alter their behavior. If they are unwilling or unable to do so, revegetation efforts become more expensive or even impossible. Far too often, planners and conservationists ignore the human ecology of an area and fail to appreciate the importance of project lands for the survival of human populations. This chapter outlines the relationship between human activity and vegetative change.

In most instances, environmental degradation is a product of human activity. In the regions of Africa and Asia that are the focus of this study, overgrazing, the excessive cutting of fuelwood, and the cultivation of fragile lands - abuses often precipitated by the openaccess provisions of colonial public-domain law and subsequent lack of governmental management and control and economic differentiation associated with commercialization - have led to a loss of plant cover and required the development of government revegetation programs. To fully appreciate why this has occurred and how this process can be reversed, we must first understand how human beings have adapted to specific environmental settings.

Production systems in tropical and subtropical regions

The lands considered here are those in which permanent, sustainable crop production is not possible because of soil and climatic conditions. These regions have, however, supported substantial human populations for thousands of years. In these areas, people have developed production systems adapted to the low and variable productivity of these lands. In semiarid regions and marginal areas, one can find many kinds of production

systems - hunting and gathering, agricultural, pastoral, and agro-pastoral systems. Pastoralism and agro-pastoralism are probably the most common production systems in these regions; this is because domestic animals can convert vegetation on land unsuitable for agriculture into food and fiber. In Asia and Africa, agro-pastoral and pastoral societies take many forms. The exact organization of these production systems is influenced by local environmental factors, by history, by culture, by economic considerations, and by level of technology. In addition to these differences, there are similarities that must be understood if successful revegetation is to take place. Traditionally, people who live in semiarid and marginal lands have relied on two strategies - diversification and mobility - to cope with the erratic and generally low productivity of their lands. Mobility is perhaps the most important characteristic of these production systems. By moving about, one can take advantage of the spatial and seasonal variation of plant production. In crop production, systems of shifting and opportunistic cultivation are examples of strategies based on mobility. Land is cultivated for several years, and then it is abandoned to fallow and new land is cleared. The shifting nature of cultivation permitted natural revegetation processes to occur - provided that the fallow cycle was long enough.

Livestock are particularly mobile. Not only can they move about to "harvest" sparse vegetation, but they convert grasses and shrubs into useful products. They also can harvest perennial shrubs and plants that are less susceptible to annual variations in weather than are annual food crops.

Livestock herds in semiarid and marginal regions are rarely confined to the same pastures year-round. Seasonal movement is a common feature of livestock production even among sedentary groups (figure 2-1). A noteworthy difference between agro-pastoralists and pastoralists is that the former do not often move as complete families with their herds, whereas family members often accompany herds among pastoralists. The movement of animals may be as little as a few kilometers or as much as hundreds of kilometers. Movement, however, permits herds to take advantage of seasonally rich pastures, helps to

adjust to spatial variances in precipitation, and reduces the stress that is placed on vegetation through constant grazing and trampling (Wagner, 1983).

Mobility is probably the key production strategy for pastoral nomads. Strategies of mobility, such as nomadism and transhumance, are particularly prevalent in areas where the pattern of rainstorms is such that there can be wide differences between the amount of rain received by two plots a few kilometers apart (Gilles and Jamtgaard, 1981). Nomadism serves to reduce environmental stress and personal risk, but it is also more productive than settled livestock husbandry. In eastern Africa, in areas of Masai pastoralism, the grazing capacity of the land is increased 50 percent because of herd mobility (Western, 1982). In the important livestock-producing areas of Africa, comparisons of the productivity of mobile and sedentary herds have indicated the superiority of mobility. In Sudan, Haaland (1977) noted substantially higher mortality rates among sedentary herds than among mobile ones. Breman and de Wit (1983) studied the migratory system based in the Inland Delta of the Niger River in Mali, and found that its productivity often exceeds that of Australian and North American ranches.

Other studies in West Africa have indicated that a disproportionate number of sedentary cattle were lost in the 1968-1974 Sahelian drought. Losses of herds that quickly moved into rainier regions in response to the drought were minimal (Gallais, 1977; Sall, 1978). Not only were the impacts of drought less severe on mobile herds, but migrating herds caused less environmental degradation. Loss of vegetation around boreholes where herds permanently congregated was so severe that it could be easily recognized from satellite photos. Mobility is an important aspect of production systems in semiarid and marginal areas.

Mobility is just one way to cope with a harsh environment. Diversification of subsistence activities is another. For farmers, the ownership of livestock is one diversification strategy. Animals may survive even when grain yields are quite low, so livestock may

represent a store of capital that can be used in years of drought. Farmers may also grow a number of different crops to reduce the risk of crop failure. Wheat and barley or maize and sorghum may be grown together because one species tolerates drought better than another. Diversification goes beyond the diversification of agricultural enterprises. Farmers may also have secondary occupations, engage in trade, or in migrant labor to reduce their dependency on a fickle pastoral environment. In traditional subsistence-oriented societies, this diversification lessened the dependence on the immediate environment and lessened the probability of ecological disaster.

At first glance, traditional pastoralists would appear to have been a highly specialized group dependent solely on livestock production, but in reality these societies were highly diversified. First, multiple species of animals were raised (figure 2-2). Camels, cattle, sheep, and goats all have different water requirements, feed preferences, and reproductive rates. Browsers - camels and goats - are less affected by annual fluctuations in rainfall and in grass production than cattle and sheep. Small stock such as sheep and goats have high reproduction rates when they are well nourished. They can thus be used to build up herds rapidly after droughts or to take advantage of two or three consecutive wet years. Not only did traditional pastoralists diversify their herds, but they also had other sources of livelihood. Pastoralists in the Sahara, Asia, and the Andes were often heavily involved in long distance caravan trade, in the mining of salt, and/or in military pursuits. Often they ruled or exacted tribute from sedentary groups, which provided them with agricultural products. As a result, pastoralists, like agro-pastoralists, developed diversified sources of livelihood to prevent over-reliance on any particular aspect of the environment. One consequence of this diversification was to reduce the impact of man on any single ecological niche.

Societies living in marginal areas have many institutions to facilitate diversification and mobility. One important institution is the land-tenure system. In general, the private ownership of land in such regions is rare, except in those places where irrigation or other

conditions made permanent cultivation possible. Land ownership in these areas was, and still is to a large extent, collective. In areas of shifting cultivation, the cultivator had use rights to a piece of land as long as it was cultivated, but did not have an inalienable right to that land. Such rights belonged to a large group - a village, commune, clan, or tribe.

Rights to grazing lands and forest lands are also collective. However, in this case there are no user rights to individual pieces of land. Although an individual might habitually use a pasture or forest, mobility is essential to responding to fluctuations in precipitation and plant production, making exclusive assignments of land impractical. Often the boundaries between the territories of different pastoral groups are imprecisely defined, and relations of kinship and reciprocity exist that permit groups to temporarily use the pastures and forests of others. Collective ownership of pasture and forestlands is also more economical than individual tenure. The low and variable annual productivity of these lands makes the cost of maintaining fences and access roads to individual plots prohibitive. Under these conditions, if mobility is not impeded by private ownership of lands, all users of collective lands benefit from higher levels of production.
As the discussion above indicates, collective ownership of land facilitated both mobility and diversification. Therefore, a large proportion of range and forest lands remains today under the control of localities or as part of the public domain in Europe, Japan, and North America.

To say that lands are collectively owned does not imply completely open and unregulated access. That would lead to a "tragedy of the commons" situation such as that described by Hardin (1968), where individuals would each increase their herds or their use of the forests until the productive capacity of the resource was destroyed. Such unregulated exploitation of the environment ignores the fact that members of subsistence groups depend upon each other for their survival and are not individuals single-mindedly pursuing personal gain at all costs (Runge, 1981). Also, it is illogical to suggest that any group would stand by and let their subsistence base be destroyed.

The "tragedy" historically appears to occur where competition over land and its resources increases, and where differential access and market opportunities and political control reduce the effectiveness of prior regulatory procedures. Studies of traditional management systems indicate that in those areas where disease and warfare do not prevent overgrazing, a variety of institutions regulate the use of common resources. First, these lands are not open to all potential users, but are either used exclusively by certain groups, or at the very least, some groups are given priority over others. In the case of cropland, people usually need permission from local leaders or councils to use land. Even when access to pastures and woodland was technically open to all, controls over access to water, shelter, and minerals was controlled by localities or owned by individuals. For example, wells and springs are often "owned" by individuals or by small groups (Helland, 1982). Without access to water or to shelter, no one can use pastures, even if they are technically common resources.

Subsistence-oriented groups in semiarid lands do not necessarily live in harmony with nature. Pastoralists and agro-pastoralists often significantly alter the vegetation and fauna of the areas in which they live. Sometimes they do destroy the resources upon which they depend. If they do so, they quickly destroy their ability to survive and are either forced to move on or disappear. Direct dependency on the immediate environment for most subsistence needs is a strong incentive for the development of institutions to protect the environment. While most groups living in marginal areas have only rudimentary institutions, in some areas, such as southern Africa and the Atlas Mountains of Morocco, elaborate institutions evolved to regulate pasture use (Bourbouze, 1982; Gilles, 1982; and Odell, 1982). In recent years, many of the mechanisms that have traditionally served to protect vegetation have become less effective. The reasons for this decline are discussed below.

Context of environmental degradation

Typically, lands requiring revegetation have had their plant cover destroyed through improper farming methods, the extensive gathering of wood for fuel or construction purposes, or through overgrazing. In terms of destructive impact, cultivation and the gathering of woody species probably have had more impact on the environment than have grazing animals. Livestock are the primary cause of desertification only in areas where large numbers of grazing animals are concentrated, such as around boreholes. Overgrazing is, however, a major cause of vegetative change and often inhibits the restoration of plant cover.

Although these three actions of man are the main causes of environmental de gradation , the reasons for increased degradation are still debated. Four common reasons for environmental deterioration are climatic change, population growth, economic change, and human fallibility. Usually these factors interact. Over the past 30 years, the human and animal populations using semiarid and marginal lands have grown, thereby putting more pressure on the environment. Given the cycles of wet and drought years common to semiarid regions, such as the West African Sahel, this led to population growth that could only support the population in wet periods. The shortsightedness of governments and donor agencies also has contributed to environmental deterioration. In Africa in particular, ill-conceived water and livestock development projects contributed substantially to overgrazing (Bernus, 1971; Haaland, 1977). These factors have all contributed to the need for revegetation programs, but merely listing the mechanisms and factors leading to environmental problems does not explain the process by which this has occurred. Also, in many cases, destruction of plants in marginal areas has been occurring at a faster pace than have climatic or population changes. This has been due to factors that have reduced both the mobility and the diversity of traditional economies. These factors also undermined traditional mechanisms of environmental protection. The need for revegetation and conservation has been accelerated by the growth in government power, in modern economies, and in the use of improved technologies.

Changing political conditions have had severe impacts on many pastoral societies of Africa and Asia. In many cases, national boundaries were created in such a way that grazing lands used by one people were split between two or more nations. Over time, nations have incressingly restricted the movement of people and animals across frontiers . Such restrictions reduce the diversity of ecosystems available to herders and lead to herds spending longer periods of time in marginal areas than they had in the past. For example, it has been argued that the imposition of the frontier between Uganda and Kenya was the reason for overgrazing and the destruction of the pastoral economy of the Karamajong of Uganda (Quam, 1978). The imposition of national boundaries also had some impact on trading activities.

The growth of state authority has impinged on pastoral production systems in several other ways. To a large degree, governments have eliminated the raiding and warfare that often characterized the relationship between herders and their neighbors. While pacification is in itself quite desirable, it often had the effect of opening grazing lands to groups that previously did not have access to them. Often the state did not give title or the means to restrict access to grazing lands to anyone. This in effect made it impossible for communities to enforce local regulations designed to protect pastures or woodlands. Often government planners felt that local rules concerning pasture use prevented efficient meat production or impeded nation building (Sall, 1978; Cole, 1981). They wished to create a common pasture situation in which any individual who wished to raise livestock was free to do so, both to expand meat production and to combat tribalism. In many instances, these changes were accompanied by changes in herd composition. For example, cattle production increased dramatically in the northern Sahel at the expense of less destructive, better adapted forms of livestock, such as the camel (National Research Council, 1983).

The reduction of intergroup hostilities and the introduction of government land resource planning had additional impacts on the viability of traditional pastoral economies.

Governments have generally sided with agriculturalists in disputes between them and pastoralists. The cessation of raiding by pastoral groups led to projects to expand agricultural production, and population pressures have contributed to the expansion of cultivated are as - further reducing the mobility of traditional pastoralists. Generally, those lands that are occupied by farmers are marginal croplands but are among the best watered and most productive pastures (figure 2-3). They are generally those used during the dry season or in winter months when the productivity of other pastures is low. The loss of these lands to farmers forces animals to remain longer on more marginal lands and increases the likelihood of erosion and desertification due to overgrazing. Even where arrangements can be made for the pasturing of animals on stubble, as is the case of much of West Africa, mobility is reduced. Such arrangements can often be developed for regular seasonal usage of pastures but not usually for occasional or for emergency use.

While governments frequently have reduced pastoral groups' land rights, in some countries there have been attempts to protect pastoralists by adjudicating land rights. French colonial authorities in North Africa attempted to adjudicate tribal boundaries, and, in East Africa, post-independence governments have attempted to delimit group ranches and grazing blocks. These attempts have in some cases restricted the growth of herds and have probably reduced overgrazing, but they also can restrict mobility if strictly enforced. As mentioned earlier, the fluid, often vague, boundaries between the areas used by different pastoral groups facilitated mobility. Overly rigid enforcement of these rules can confine animals to too small an area or, if not enforced, boundaries may be ignored. If local groups still manage resources, the fluidity of boundaries may not be a problem, but if reforms have eliminated or modified the ability to control grazing, then once again the creation of a common resource may be required where one previously did not exist.
The growth of market economies, and the adoption of new technologies that this growth permits, have also reduced the viability of tradition al resource management strategies .
In a subsistence economy, one's survival is directly linked to the local environment. One exploits a wide variety of resources, but one's survival over time depends on the sustained

productivity of the immediate environment. The introduction of a market economy changes this. First, one can specialize in animal production or in the cutting of fuelwood. To do so means that one can increase one's standard of living by intensely exploiting a particular environmental niche. If one is selling for cash, the feedback loop between subsistence levels and environmental conditions is less effective. If demand for one's product is rising, price increases can more than cover the loss of productivity because of overexploitation of the environment. For example, as a pasture deteriorate, a subsistence herder may only have milk and meat to eat, while a commercial beef producer may for a long time experience stable or even rising income levels.. Free labor markets also reduce the risk of degradation for the individual. The destruction of the land may cause hardship, but the possibility of wage labor in the city always exists.

In the past, some form of "passive" management occurred when quantities of stock died as a result of drought. Today, in many parts of Asia and North Africa, herders can maintain herd numbers, even when pastures and water are totally exhausted, by trucking water and feed to their animals until rains restore pastures. The purchase of feed and the delivery of water, often subsidized by governments during droughts, leads to levels of overgrazing that would be impossible for traditional subsistence pastoralists. An unintended consequence of improving veterinary services and reducing disease is to remove this "natural" regulator of herd size. Another consequence of the growth of the market economy is that individuals enjoy increased economic independence. In traditional groups, each individual family is dependent on others for survival. In such a setting, social pressure and the threat of ostracism may be sufficient to prevent deviant behavior. The development of a market economy increases economic differentiation and may reduce consensus on resource management questions.

Modernization has also contributed to the degradation of the environment in some areas Improved medical and veterinary techniques have reduced the constraints that disease placed on human and herd numbers. The development of roads and the introduction of

motor transport have caused some nomads to become more dependent on herding as caravans have become less profitable and have probably encouraged the switch from camels to cattle. Roads and trucks have also made it profitable to cut fuelwood or produce charcoal at great distances from cities, and trucks make it possible to increase the use of remote or poorly watered pastures (Thalen, 1979). In many cases, mechanized plowing and sowing have made it profitable to plow up rangelands where rainfall is so erratic that only one year in three witnessed successful harvests. The introduction of new technologies often requires changes in traditional institutions, hence an unintended consequence may be a weakening of those institutions that have in the past protected the environment. In this light, publicly funded revegetation programs may be seen as attempts to correct some of the excesses of rapid social change.

As we can see, then, desertification and the destruction of plant cover have been caused by a number of factors. It is important to remember from these examples that environmental deterioration has been accelerated because the mechanisms that formerly helped people adapt to semiarid and marginal environments have been weakened. Diversification and mobility have been limited, and the feedback from man's use of the environment has been distorted. If revegetation efforts are to be successful, they must create a sustainable human ecology as well as stable, productive environmental systems. Too often, projects have undermined themselves by ignoring people, or by inadvertently accelerating the processes of declining diversity and mobility in production systems.

Successful revegetation requires changes in land use patterns so that the reestablishment of vegetation is encouraged. In the past, attempts have been made to control access to revegetated areas by changing land tenure arrangements. Nomads have been settled, private and group ranches have been created, and forest reserves have been legislated, all in attempts to control access to project lands by reducing animal movement and by restricting people to particular parcels of land. As previously mentioned, the reduction of mobility may threaten the viability of traditional subsistence systems. If their livelihood is

threatened, people may resist overtly or may passively resist by bribing forest guards or by grazing or cutting revegetated areas when they are not being properly guarded. Conflict between traditional users at the very least raises the cost of revegetation substantially, and may in many instances negate project efforts.

In some cases, the failure to understand the importance of mobility can mean disaster even when project goals are attained. Boreholes are examples of efforts to increase available pastures that, in fact, led to local desertification and to heavy livestock losses during droughts (figure 2-4). At other times, the success of programs in one area may lead to larger levels of environmental deterioration outside a project are a . Herds that are required to leave the are a of a range or reforestation project must go somewhere, hence the revegetation projects may accelerate the processes that they are intended to reverse. The settlement of nomads may increase overgrazing, as we saw in the Sudanese example (Haaland, 1977). The creation of private ranches or group ranches may improve the conditions of ranges in their boundaries, as it has in some parts of Kenya (Hopcraft, 1981; and case study 10). If ranchers are not excluded from common pastures they may use their individual pastures as reserves, which permits them to exploit other lands more intensively (Little, 1983). In a similar vein, people may preemptively destroy an area rather than have it come under the control of a public range or forestry program. Pascon (1980) cites the example of herders in Morocco who, when presented with the successful establishment of wheat grass on overgrazed plain, chose to plow up the entire region and plant wheat rather than give up control of their resources to a range management scheme. These examples, though perhaps more graphic than most, are typical of many attempts at revegetation.

Those who plan revegetation efforts often face a dilemma. Successful programs may require the use of coercion and force, which, in turn, raises the cost of revegetation, reduces the extent of the area that can be treated, and reduces cooperation. This is one part of the dilemma - coercion reduces the program area. On the other hand, success in a

limited area may be illusory; vegetation may be protected at the cost of widespread environmental destruction in adjacent areas. This is a cruel dilemma.

In part, this difficulty can be overcome if rehabilitation efforts are carefully reconciled with local systems of production. If one understands how a revegetation program will impact on an area, one may be able to make adjustments in other parts of the local production system to compensate for disturbances caused by a program. Instead of paying money for guards, it may be possible to plant highly valued, multiple-use species that would strengthen and diversify the local economy, thereby justifying protection by local populations. Approaches can be developed that enhance the advantages of mobility and diversity for production systems in these areas. The creation of new jobs or economic activities may have a greater impact on the environment than the creation of forest or grazing reserves.

Given sufficient time and money, it is possible for planners to characterize a production system and to design appropriate revegetation programs. An easier approach may be to reduce technical input, but to work closely with local populations to identify appropriate types of interventions and to monitor the program. Such an effort may succeed in areas where government policies have often undermined local institutions.

It is of particular importance that environmental rehabilitation projects yield multiple benefits. Multiple uses of vegetation should be encouraged. Local involvement should reduce management costs through increased self-enforcement of conservation rules. Finally, the project should help reestablish a local sustainable resource system that is not dependent on the vagaries of public funding and political will. There may often be some trade-offs between the efficiency of revegetation and local involvement. There may be more efficient and more effective ways of conserving and protecting plant cover than those acceptable to local populations. For example, the policies developed by ranchers and the Grazing Service in the United States under the Taylor Grazing Act did not satisfy many

conservationists, but they could be implemented effectively and did lead to improved range conditions in the western United States (Foss, 1960; U.S. Forest Service, 1979). The goal of any revegetation program should be to create a viable environment for plants, animals, and people. This can be done only by placing revegetation efforts within the context of local and regional production systems.

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The economic context

The previous chapter dealt with the behavioral characteristics of groups of people living

on, or using, arid and semiarid lands. This chapter focuses on the economic behavior of the individual or the individual household.

Economic analysis of pastoral management practices has proved difficult for several reasons. First, many analysts have a tendency to consider the household as one homogeneous decision-making unit, with the "head" of the household as the decision-making director. In fact, households are heterogeneous and not always clearly defined, and decision-making is generally delegated to a large number of individual household members who may not share the same interests. Surveys that used the (male) family head as the sampling or observation unit have therefore yielded incomplete or biased data, leading to biased conclusions.

Second, many studies have limited the focus of the analysis to one aspect of household activities - only land management or only animal performance, for example. These single-commodity approaches fail to incorporate interactions among various household enterprises. Therefore, the predictive value of the analysis for household behavior is low.

Third, any economic analysis is based upon the identification of determinants and their impact. Even when successful in identifying important factors, allocating values ("impact") to these factors has proved extremely difficult. In resource-poor environments such as arid rangelands, the assessment of values is highly time- and location specific. Not only do values vary over time and space, but also among individuals, households, tribes, and generations. The cost (negative value) of soil degradation will be felt more by future generations than by present ones (who might be causing the degradation).

Fourth, and related to the third point, is the difficulty in assessing the social costs and benefits (as opposed to the private values). Communal grazing is believed to occur with virtually no cost to the herders, but with possible social costs (in the case of overgrazing) to the society as a whole. In the same vein, the long-term costs are not necessarily the

same as the short-term costs. This problem is aggravated by the fact that the life span of range management projects is generally limited to 10 years or less, even in projects that attempt to deal with long-term problems, such as desertification and erosion. Another example of social costs is the negative effect that a project might have on resources or persons outside the project are a . For example , the development of a pocket of highly productive rangeland for crop cultivation might have a negative impact on the usefulness of the surrounding low-quality rangeland because during a drought period cattle would not have access to a highly productive forage source (Sanford, 1983). Other social costs or benefits include the impact of interventions on employment and equity.

Finally, we cannot overlook the fact that many projects have failed for reasons other than inadequate economic analysis. For example, biological scientists and technicians have often provided projects with short-term, single-commodity technical input-output relationships that have contributed to illusionary expectations of possible changes in management behavior.

For some time, pastoralists have therefore been labeled "irrational," but this allegation has been refuted by a growing number of case studies. Cattle portfolio models developed in industrial countries have found useful applications in pastoral situations (Jarvis, 1980; Ariza-Nino and Shapiro, 1984), and elements of African and Asian range management systems are finding application in industrialized countries (National Research Council, 1984).

Range systems

A range system is the arrangement of soils, water, crops, livestock, labor, and other resources that the manager works according to personal preferences, capabilities, and available technologies. The major factors that influence productivity are determined by the characteristics and interactions of (1) the physical environment, (2) the economic

environment, and (3) the social environment. Subsystems can be recognized within range systems. Interdependencies and interactions among resources (land, labor, crops, livestock, capital, water, wood), environment (climate, topography, soil, market), and humans (family members, relatives, friends, enemies) are essential components of the analysis.

The tools for the economic analysis of range systems are essentially the same as those for conventional farm management studies: budget analysis by gross margins or partial budgeting, linear programming, and discount procedures. However, when these methods are applied to a range system, the results have become more reliable, essentially because previously unidentified factors (inputs as well as outputs) are taken into account.

Little (1984), however, recommending the systems approach, also points to two major limitations: the assumption that the household is the proper unit of analysis, and the lack of focus on macro and micro linkages in problem solving. He therefore recommends a combination of household production and regional analysis.

Rangeland management systems have been divided into two major systems: nomadic and transhumant. Another distinction is based on land ownership - that is, pastoral nomadic, open-range ranching, and fenced ranching (Behke, 1984; Lawry et al., 1984). This distinction is addressed in a later section of this chapter.

Rangeland Farming Systems

Within the framework of range systems analysis, relatively little work has been done on livestock-related issues. Several reasons account for this neglect:

· Most of the research is done by crop-oriented agronomists and social scientists, neither of whom are familiar with livestock and therefore tend to overlook their role.
· Most of the livestock have multiple outputs (such as draft power, meat, milk, manure,

hides, status) and non-cash inputs (especially for ruminants).
· A substantial part of these outputs is used within the household (for example, draft, manure), and therefore only indirectly contributes to the cash income of the pastoralist.
· The cash income from livestock activities often occurs at irregular intervals and on special occasions; it is easily if not intentionally overlooked during household surveys (Sabrani and Knipscheer, 1982). Even if scientists have explicitly focused on the livestock component of the range system, they have encountered a number of additional problems. Table 3-1 compares livestock-oriented farming systems research with crop-oriented farming systems. Factors such as genetic variability, differences in age and productivity, and problems with farmer cooperation, measurement of effects of input and output, and representativeness of prices have constrained the researcher in conducting on-farm trials (Amir et al., 1985). Consequently, rangeland research has proved to be time-consuming, logistically difficult, and expensive.

Major Features of Nomadic Systems

Nomadic systems are based on livestock, and the main source of income is derived from meat and animal by-products. Typical for nomadic systems is the annual migration of livestock and managers, for example, from highlands in the summer to plains in the winter, as in the arid and semiarid region of Asia. The influence of climate as well as culture is large, as families or tribes or both travel together, following the opportunities that the climate offers. In this kind of culture, crop farming is held in low regard. The crop component in nomadic production systems is virtually nonexistent. The linkages between livestock and other household activities are found in household processing (for example, wool and weaving) and fuel supply. Land use is characterized by grazing and collection of fuelwood, while the manure of the animals returns some of the nutrients to the soil. Although nomads generally are believed to be unconcerned with improvement of feed resources, it is also known that they are aware of the importance of future pasture availability and, therefore, are careful in their grazing practices (Camoens et al., 1985).

Major Features of Transhumant Systems

The critical difference between nomads and transhumants is the existence of a substantial crop-producing activity in the household system. Transhumants migrate seasonally with their flocks but have a permanent residence area. The crop enterprise is generally for subsistence, while the livestock component is geared for the market.

Situation with respect to:

Factor	Crops	Livestock	Implications
Mobility	Stationary	Mobile	Difficult to measure and control non-experimental factors
Life cycle	Generally less than 4 months	Generally over one year	Increases costs likelihood of losing experimental units
Life cycle	All units synchronized	Units seldom synchronized	Difficult to find comparable units
Multiple	Only grain and/or tuber and residue	Multiple ouputs, meat, hides, milk manure, power	Difficult to measure or evaluate treatment effect
Nonmarket	Few	Many	Difficult to evaluate input or outputs
Experimental unit size	Small divisible	Large nondivisible	Increases cost, risk to cooperate
Producer attitude towards product	Impersonal	Personal taboos	Difficult to cull, castrate
Management variability	Low	High	Difficult to isolate treatment effect
Observation units	Many	Few	Large statistical variability

TABLE 3-1 Comparison of Characteristics of Crops and Livestock and Implications for On-

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Nonmarket	Few	Many	Difficult to evaluate input or outputs
Experimental unit size	Small divisible	Large nondivisible	Increases cost risk to cooperate
Producer attitude	Impersonal taboos	Personal cull, castrate towards	Difficult to product
Management variability	Low	High	Difficult to isolate treatment effect
Observation units	Many	Few	Large statistical variability

SOURCE: Bernsten et al., 1983.

Climate and culture play dominant roles in transhumant systems, comparable to those of the nomadic systems. Because of the crop activities, some of the land is privately owned (or rented). Some of the large ruminants are used for draft purposes, but the application of manure provides a linkage between the livestock and the crop component of this farming system.

The common feature of both the nomadic and the transhumant farming systems is the mobility of the households. This strategy to meet the variability in the physical environment is associated with unstable control of resources, notably land and water, and difficulties of planning herd size and herd movements.

Ownership

The three types of land ownership are communal, modified communal, and exclusive (Lawry et al., 1984). Exclusive land tenure (private ownership or lease) has been seen by some as a solution to overgrazing. Overgrazing in turn is believed to find its economic rationale in the "tragedy of the commons": the individual herdsman has no economic incentive to reduce the number of animals as long as there is free access to communal land and water. Although assignment of grazing rights is advocated as a solution (Doran et al., 1974; Jarvis, 1980), experience has not yet shown that tenure reform is an effective policy instrument (Lawry et al., 1984, p. 247). One of the problems is that stock limitations specified in leases are almost never enforced. There is also growing evidence that pastoralists are very aware of the need for rangeland conservation and will act accordingly (National Research Council, 1986).

Narrowly related to the issue of land ownership is that of access to water. Because moisture is the overriding limiting factor in pastoral management, access to water is crucial. In many cases, control of water supply implies de facto control of land use. Water

sources can be classified according to ownership in a similar way. Other classifications are made according to the technical operations (including boreholes, dams, wells) or size.

The basis of range economics

Economics may be defined as the science dealing with the allocation of scarce resources among various competing uses, with the objective of maximizing utility or maximizing satisfaction of human wants. For range projects, scarce resources include:

· Land. In the broadest sense, land includes all natural resources such as air, minerals, soils, natural vegetation, and water.
· Labor and management. These are the resources furnished directly by humans.
· Capital. This refers to the intermediate products (inputs) created from land, labor, and funds used in further production. Capital is both the money used to pay for inputs, and the buildings, machinery, livestock, and purchased inputs that can be valued in dollars or local currency.

Organizations must conscientiously attempt to guide the allocation of their physical, financial, and administrative resources among sectors and competing programs to further national objectives (figure 3-1). This is true whether the resources committed are being invested by the government directly or by individuals within the economy.

The concept of economic rationality is a central consideration of economic theory and the definition given above. A rational economic person, or consumer, is one who seeks to maximize utility or satisfaction. There is often a close identification between farmers' or pastoralists' consumption and their production decisions.

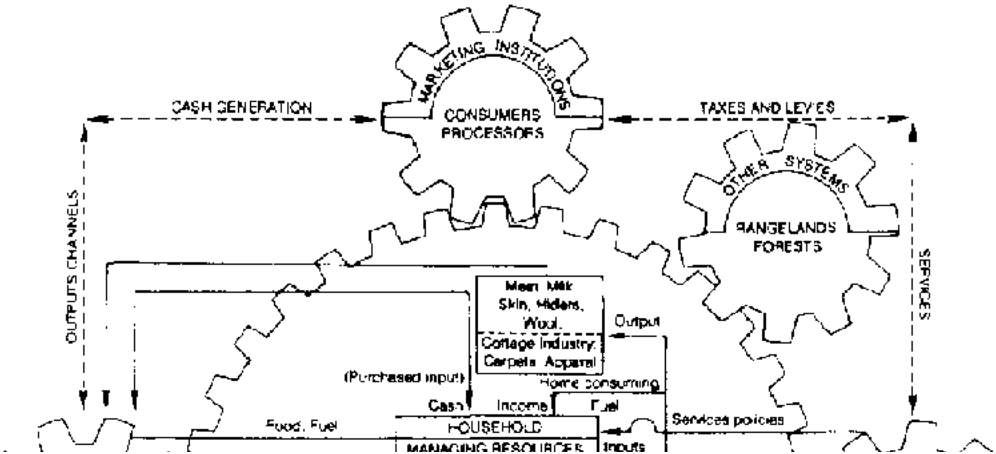
Personal preferences also affect decisions within the agricultural or natural resource development sphere. Some decisions may be made to enhance prestige or status with a peer group. Some may reflect consumption rather than production expenditures.

As mentioned previously, however, nonrational behavior may be difficult to judge, in particular by those outside the culture. What seems nonrational to an urban dweller from the industrilized world may be quite rational when examined in the correct cultural context. Therefore, in determining proper economic behavior, what outsiders consider maximum utility may not be in the best long-term interest of pastoralists. Clearly, before a rational economic strategy can be formulated, the culture and traditional economic behavior must be understood.

Project analysis

Agricultural or natural resource developments might best be defined, explained, analyzed, and understood as "projects." Projected cash flows over a period of time are required for comparisons among alternative development projects or other investment decisions.

In defining a project, Gittinger (1982) said:



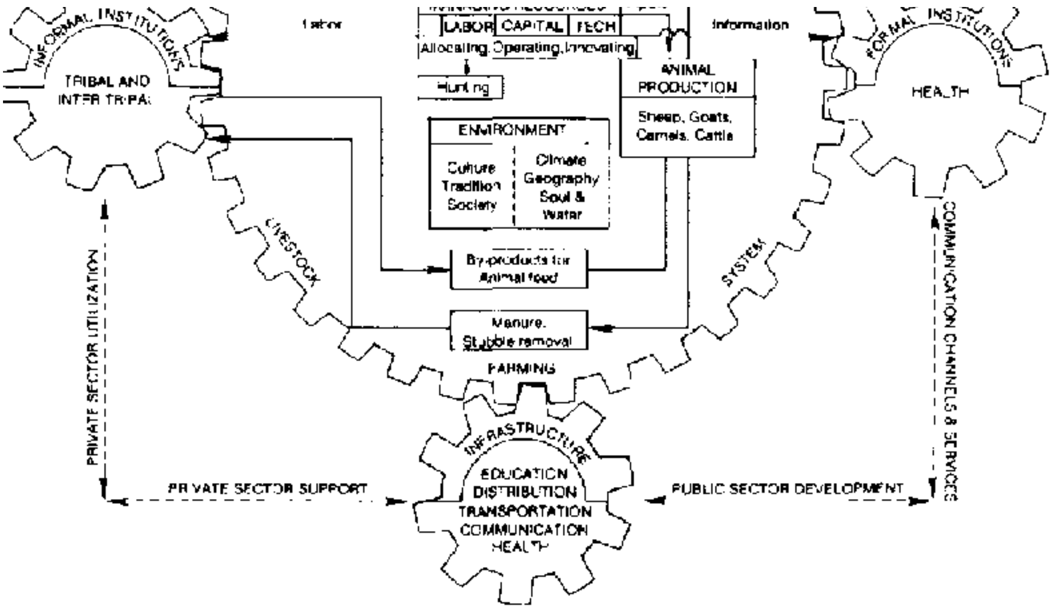


FIGURE 3-1 Pastoral Economies.

We generally think of an agricultural project as an investment activity in which financial resources are expended to create capital assets that produce benefits over an extended period of time. In some projects, however, costs are incurred for production expenses or maintenance from which benefits can normally be expected quickly, usually within about a year.

Range or marginal land development projects (such as seeding) can be viewed in the same terms as an agricultural project, although the investments, costs, and returns may be substantially different in substance and in timing of flows. For example, the returns on

a rehabilitation project may take several years to realize depending on the starting conditions and project management. These returns, however, may be in the form of higher stocking rates, which may have caused the problem in the first place.

An alternative approach is to examine potential losses that are avoided through rehabilitation. This approach is similar to determining the benefits of flood control projects. If degradation is not halted, then adjacent agricultural land may be placed at risk.

Gittinger also distinguishes between a project that may be relatively small, or perhaps quite large, but is of a nature that it can be analyzed, evaluated, developed, and administered as a unit. A "program" would typically be larger than a single project, and encompass multiple projects or aspects of development that are beyond the project definition and boundaries.

A project should contain relatively homogeneous resources so that investment requirements, costs, and returns from different parts within the project can be accurately represented. If a project becomes large enough to become heterogeneous, then a part of the project - which may in fact be uneconomical or unfeasible - may be hidden or masked and carried by other parts of the project that are worthy of development. When dealing with scarce resources, the concept of homogeneity within a project is important. Past experience has shown that in many instances projects have failed because of lack of social homogeneity; that is, within the target group of pastoralists, subgroups with contrary interests existed (see, for example, Sanford, 1983).

Economic and Financial Analyses

By definition, the economic analysis compares all returns and costs associated with a project during its useful life. Costs include initial and recurring annual expenditures, whereas the revenues include returns as a result of the project over and above what they

would have been without it.

Financial or cash flow analysis is the determination of the project's cash flow positions over the period of the project. This shows whether the project is self-supporting or whether deficits are likely to develop. It is simply to compare revenues and expenditures, including debt service on an annual cash basis. The objective of financial analysis is to consider and make estimates of the effects the flow of project costs and returns will have on people participating directly in the project, including families or community groups that make direct use of the project and the primary users. Financial analyses also must consider administration, management, and taxes of the project and costs to the government and donors for those activities.

In financial analyses, market prices, if available, are used to reflect the value of production. Project returns may also include a very significant contribution in the form of food or fuel consumed directly in the household. If subsidies are paid by the government in association with the development of a project, then that also becomes part of the income to the direct beneficiaries from the standpoint of financial analysis. Financial analysis also considers revenue to the goveronment (taxes) for project administration, which have been considered in the costs of the primary beneficiaries (users).

The "economic" aspects of project analyses and evaluation, in contrast to financial aspects, considers the project from the standpoint of the affected society and economy as a whole. Financial and economic analyses differ in three significant ways:

1. Taxes that are treated as costs to primary project participants in financial analyses are viewed by government and society as revenues, not costs.
2. In economic analysis, market prices may be adjusted and become "shadow" or "accounting" prices or “social costs/benefits" to reflect more accurately the economic values to society.

3. In economic analysis, interest on capital and repayment of borrowed capital are not treated as project costs. Although interest is a cost to the project, it is a return to society and the economy as a whole, if actually earned, and hence becomes a "wash" item in economic analysis and accounting for the project. Similarly, the repayment of borrowed capital, although a requirement for the project, neither increases nor decreases net national product.

Comparison Without and With a Project

The purpose of project analysis is to identify and estimate benefits and costs that will arise "without" the project and compare them with benefits and costs "with" the proposed project. The difference between them is the incremental or marginal net benefit arising from the project.

The results of the without-with comparisons may be the same as comparing a particular project situation "before" and "after." Often, however, the comparisons are not the same and may be greatly different because productivity may improve (increase) even without a project. Hence, the projection of the without situation would reflect higher productivity and returns than the current or before project situation. The benefits from a project designed to improve productivity at a more rapid rate than would occur without the project would be overstated by a before and after comparison, because improvements without the project are ignored.

Conversely, a different, perhaps more common, and certainly more serious situation could be one of rapid deterioration in productivity and resource or environmental conditions without a project. A project could be designed with the aim of ameliorating or reversing the deterioration; improved productivity could be a distinct bonus. It may therefore be difficult to compare or economically justify such a project when it may only retard the rate of degradation and keep the returns constant. Intangible benefits must then be considered

such as the quality of the environment and the costs associated with people moving to urban centers to escape declining land productivity.

Decision Making

A decision needs to be taken that leads to implementation, modification, or cancellation of the project. Certain costs and benefits (payoffs) are associated with any of these decisions. The decision may be to endorse the project and proceed with implementation based on a degree of uncertainty.

Problems and sources of uncertainty are classified in five categories:

1. Price structures and changes (values)
2. Production methods and responses, including weather effects and other natural phenomena (technical input/output coefficients)
3. Prospective technological developments
4. The behavior and capacities of people associated with the project
5. The economic, political, and social contexts in which a range improvement project exists.

All these sources of uncertainty affect the analysis of projects and are factors to be reckoned with in implementation and evaluation of results.

The basic principle for carrying out an economic analysis is to compare alternatives on an equivalent basis, such as a fixed output, time frame, and constant dollar values. In the analysis, the quantifiable assumptions must first be established as follows:

· All baseline project assumptions, such as the period of analysis, discount rate, cost of capital, and other economic and financial variables must be determined.
· Estimates must be made of project costs including capital costs, onetime costs such as

permits, annual operating and maintenance costs, and provisions for renewals and replacements. Estimates of fees, construction, labor and materials, and legal fees must all be determined and placed within the desired schedule.

· Project benefits, principally the increased production, must be ascertained.

· The source of financing and the specific terms of the loan must be defined.

· An appropriate economic analysis methodology must be chosen, and economic and financial feasibility must be established.

· A sensitivity analysis must be performed to determine how costs and benefits react to variations in such factors as discount rate, financing, and productivity.

· The persons or groups of persons who gain and who lose by the introduction of the project must be identified; there are always some losers.

The common approach to economic analyses has been to compare costs and revenues over a consistent time period on a ratio basis or net positive benefit basis. Several measures using discounted cash flow techniques can be employed: internal rate of return, benefit-cost ratio, net present value, and life-cycle costs. Each technique has its advantages, disadvantages, and appropriate applications.

Discount Rate

The discount rate is used for determining economic feasibility, whereas the interest rate is used to ascertain financial feasibility. The proper rate to use for testing economic feasibility is the opportunity cost of capital to society. This is the rate of return that could be earned by investing the capital cost of the project in a venture of similar risk or an alternative marginal project.

Discounted Cash Flow

One of the basic tools for determining economic feasibility is discounted cash flow. All cash expenditures are tabulated for comparison during the chosen period each year. The

total cash expenditure for each year is then discounted to the present and cumulatively added to a single sum. This sum is then compared with similar sums of discounted expenditures for alternatives. The alternative with the smallest sum is clearly the least costly. A similar comparison is made with cash revenues or receipts for the same period. The ratio between the sum of the discounted receipts and the sum of the discounted expenditures yields the benefit-cost ratio.

Certain rules must be followed in making discounted cash flow analyses:

· The same period of years must be used for each alternative set of cash expenditures and each alternative set of cash receipts.
· The alternatives must have the same production and capacity. In some cases, this may require adjustments to the costs of the lowest cost alternative.
· Cash expenditures will include renewals and replacements; however, if the years in which these will be made cannot be accurately predicted, an estimated average annual cash expenditure for renewals and replacements as well as an accelerated depreciation schedule can be used, since those costs will occur far in the future.

Discounting transforms all future costs and revenues into the present time frame so they can be compared on a current monetary basis. These sums are simply called the present worth or present value. All future expenditures and revenues are modified or discounted by a factor that provides escalation arising from opportunity costs and resource depletion.

The benefit-cost ratio technique is perhaps the most commonly applied in analyzing capital projects. The method compares the current worth of costs and benefits on a ratio basis. Projects with a ratio of less than one are generally discarded.

Determining costs and benefits

Computing costs and benefits involves use of simple without with comparisons. Specific

allowances are not made for time lags, except for charging interest for use of capital. Budgeting in such a static framework, or without-with project-context comparisons, can give a first indication of feasibility or nonfeasibility of a rangeresource-improvement project. Simple comparisons ignore time lags in phasing different stages into production and can overlook or ignore costs of capital through the developmental stages, exaggerate returns and feasibility, and underestimate problems that can arise. Budgeting year-to-year estimated changes through the transition period, though complicated, will aid in anticipating some of those problems. If the project resources are suitable and the project is successful, changes in physical production responses on a year-to-year basis may be predictable with some degree of certainty. Price changes often are unpredictable. Evaluations can be based on longer term average prices with year-to-year changes in production. Discounting procedures can be used to allow for valid comparisons of alternatives through time.

Benefits that might accrue from and be attributed to range-improvement projects may include increases in both the quality and quantity of outputs, depending on factors previously mentioned. When considering a resource improvement project that produces an intermediate product, such as forage, then improvement in quality of output may still be important but is of a somewhat different form. These are called intrinsic benefits. For example, improvement in forage quality has one or a combination of the following characteristics:

· Higher protein content
· Lower fiber content
· Higher total digestible nutrient (TDN) content
· Greater palatability to some species of animals consuming the forage.

While some of these characteristics are being improved during the periods of active plant growth, and on through the periods of maturity, an added bonus of residual plant biomass

during periods of plant dormancy is also useful for soil conservation. A second benefit could be simply an increased quantity of output.

Marketable output is the benefit most commonly expected from range projects. The increased physical production may result from: (1) improving the productivity of the native resource; (2) expanding the land area in production by conversion of native range, woodland, or jungle land to cropland or improved forage; (3) extending complete or supplemental irrigation water to arid or semiarid lands; or, (4) improving seasonal water supplies, even in more humid areas. Production may also be increased without increasing land area when projects use genetically superior seed, hybridization, fertilizers, or pesticides for control of weeds, insects, or disease. Increased production may result in marketing of the larger amount of products for the benefit of society or may allow greater consumption for the family or the social unit directly involved in the project.

When a resource development project involves forage production and livestock, then increases in forage production can be followed by increases in the number of livestock on the land and a greater yield of consumable or marketable livestock and products. This would produce one kind of effect on flow of returns, as the requirement for increased animals requires a savings (or investment) in addition to the resource development costs. It is also important to recognize that benefits in livestock production may be reflected in increased production of calves, lambs, kids, or young camels without larger numbers of the basic breeding herd.

Overstocking of rangeland is detrimental to livestock production. Increased production of livestock, therefore, can only be considered in light of long-term efforts to improve the range resource. Increased forage supply used only to ameliorate overutilization of rangelands can result in improvement in percent age of calf or lamb crops , in increased gains of growing animals, and probably in reduced mortality of both breeding stock and growing animals. Special use pastures or pastures to fill particular seasonal needs may

produce these effects also. Benefits of these types may well be associated with very high returns on resource development costs. Output may also be increased by a simple increase in forage production and expansion of livestock output. Increased forage also makes it possible to increase the number of breeding herd animals; even if they are producing at the same level as without the project, output will increase.

Resource evaluation

Evaluating the quality and adequacy of various resources for possible alternative uses is the first step in project planning. The climate and characteristics of land and soils, water supply (whether for irrigation, livestock, or domestic use), and incidence of weedy types of vegetation, insect pests, and plant or animal diseases should all be considered. The objectives of the evaluation process are to determine the forage and livestock enterprises that may be feasible and whether some alternatives can be ruled infeasible without further evaluation. These factors are described in more detail in chapters 4 and 5.

Location of the project and access to markets both for sale of products and for purchase of necessary supplies is another key consideration for determining feasibility. The location, climate, land, and water supply factors are often fixed. It is impossible, or at least difficult and often costly, to modify these factors. Water supply can sometimes be augmented by drilling wells or creating storage; however, the ecological consequences must be considered.

Human resources are the most difficult to assess. Most projects rely on organizations of pastoralists. Important questions to address are the following: Will the existing organizations be used, or will a new organization be established? What should be the size of the organization? How complex will be the functional specialization and what type of membership (inclusive versus exclusive, voluntary versus forced) is expected?

A new organization can only be established at a cost. Because of low population densities

associated with arid rangeland, communication between members is difficult. Difficulties in decision making, therefore, increase as group size increases. For the same reason (lack of opportunity to communicate), there are limits to functional specialization.

Sanford (1983) emphasizes that the "costs" of project organization are often underestimated if not overlooked altogether. A first step to the evaluation of human resources is a good understanding of the existing social organization.

Data Needs and Sources

Data required for cost and benefit evaluation, frequently called "input-output" data, include: herbage or animal production or possible alternatives; physical quantities of inputs used, whether a product is produced or purchased; prices for inputs; and prices for output to be sold.

The principal sources of physical input-output data for projects may include well-trained professionals with technical expertise in the area, data from other projects of a similar type and under similar conditions, people from the locality with good knowledge of the area and what might be expected, and data from controlled experiments.

Preliminary experiments are very important sources of data for technical specialists who must make judgments about the productivity of resources in new projects. The preliminary experiments do not yield perfect or reproducible results, particularly when applied to international projects of an agricultural nature where factors such as weather, variability in inputs, and the performance of the field crew typically are incompletely controlled. Situations in developing countries lead to what might be called “the experimental gap" between the yields that are obtained on the experimental plots and those likely to be achieved on projects. The technical specialists must attempt to estimate the extent of experimental gap and the extent of adjustment or correction. Farming systems research is attempting to narrow this gap.

In general, local data are most useful for ascertaining the response to different treatments or the change in output resulting from a change in level of the inputs.

Farmers or pastoralists may be the best source of information on crop or vegetation and animal performance, requirements for labor, materials, machinery use, feed requirements, and so on. Information collected locally by survey procedures can be used to establish benchmarks for current enterprise combinations and production practices, and to obtain crop and livestock labor requirements and machine use levels for operations of different sizes.

Market price determination

A number of problems confound the establishment of prices for use in project planning. Obtaining satisfactory price information is usually not a difficult problem in the United States. Merchants, dealers, and farm operators can usually provide satisfactory information on current levels of prices paid and received and wage rates. In developing countries, however, specific price information may be more difficult to obtain, and short-term price fluctuations are likely.

To the extent that markets exist and market price information is available, market prices should be used, but a few caveats must be considered. First, if market prices are generated from a location remote from the project area, then it would be necessary to make adjustments to account for differences from the project area because of transportation costs, any losses due to waste, spoilage, shrinkage, or death loss, and for transaction costs at the marketplace.

If prices tend to fluctuate in a completely irregular or random fashion or in a cyclical fashion, an average price or expected value may have to be used through a series of years.

Prices are one of the crucial assumptions in planning, and the importance of good price

forecasting cannot be overemphasized. However, it is possible to become too fearful and exaggerate the consequences of errors. The effects of different prices can be ascertained quite easily by "sensitivity analysis" after the major budgets have been prepared. This may be desirable, both to test the stability of a particular budgeted solution against variations in prices, and also to ascertain the amount of possible loss if the price assumptions are in error. The probability of different occurrences may also be assessed.

In project planning, the determination of prices is a problem if satisfactory market or price reporting systems do not exist. Often the only valid way to place a value on forage is indirectly, by determining its value through the livestock production process. In that case, the costs of producing the forage as an intermediate product could be used. Placing a price on the forage directly is unnecessary.

As mentioned earlier in the chapter, valuation problems are very difficult for the so-called non market or social considerations involved in improvement and rehabilitation practices. For instance, it is very difficult to place values on such things as enhanced erosion or flood control, dune stabilization, or enhanced wildlife production. However, damage mitigation analysis (as used in water resource projects) can be applied. In such a situation, the before analysis would overstate the without analysis and the before-after comparisons would understate the benefits of the proposed project compared with the without-with comparison.

The analyses based on the without-with approach to projections is generally more complicated because it does require projections of two situations. The current before situation can only be taken as a data base or benchmark and guideline information. A before-after type comparison is based on the current situation as one projection and only one projection is required for the relatively unknown after situation.

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Regional resource assessment

The purpose of a regional assesement is to develop a general overview of the project region that will be used in planning. Assessment includes describing the physical and biological character of the land and its historical and current uses. With this information,

one can estimate economic opportunities or the capability of the lands within the region, and identify potential problems that might be encountered under different management regimes or land use practices.

This chapter deals with the more detailed, site-specific evaluation that is necessary before any range improvement project can be implemented. The first part of the chapter examines the types of information required for a resource assessment and how they are used. The second part describes techniques for acquiring this information, with special emphasis on remote sensing.

Information needs

The objectives of the resource assessment, which are to provide information for general planning, are:

· To determine the general nature and condition of the resource base in the project region;
· To identify the areas within the region that are of special concern;
· To establish the relative importance of each area according to the objectives of the project; and
· To develop a realistic plan of action based on the assessment.

Maps and supplementary reports are the products of the resource assessment. The maps show the location and extent of different types of land in relation to other lands. Because a general overview is required, map scales are commonly smaller than 1:100,000.

In the mapping phase of a resource assessment, the region is surveyed and divided into areas that are relatively homogeneous in some property such as vegetation, soil, or land use. At the scales considered here, however, only broad patterns can be mapped. Mapping units will be somewhat heterogeneous and will contain a number of different site types. An important purpose of the report is to relate this diversity by describing the nature and

composition of the mapping units.

Mapping units are not necessarily predefined and may be designed to meet the needs of a project. These mapping units will become the physical units around which the study project is organized and probably will become the units used for many future land management decisions. Thus, criteria used to define basic mapping units must be carefully selected. In a resource assessment for range improvement, units should contain areas that (1) have about the same capacity to sustain one or a set of land uses, and (2) require similar kinds of management. This characteristic of land is generally called "land capability" and is determined by a number of factors, such as climate, vegetation, wildlife, and soil.

Climate

Climate is perhaps the most important factor in determining land capability because of its direct impact on the immediate resource, such as forage, and its role in determining the types of vegetation and soil found in a region.

The climatic data required for a resource assessment are those that influence the development of soil and the distribution of vegetation. Average annual temperature, seasonal extremes, frost-free period, evaporation, and precipitation amounts and their seasonal distribution are the most important considerations because they help determine soil type, water availability, vegetation type, and potential plant productivity.

Although climate is important in determining land capability, only broad generalizations are expected at the resource assessment level. The purpose is to identify relatively homogeneous climatic zones that could support one or a limited set of vegetation types.

Vegetation

Since climate cannot be observed directly, vegetation patterns often are mapped and interpreted as indicators of climate. Many assessments produce a composite map of climate and vegetation. Intended to serve as an indicator of climate, it is also an important management tool. An examination of the environmental history of the region and previous resource assessments, as well as an interpretation of the information generated during the mapping phases of the resource assessment, allows the development of a profile of the type of vegetation that might be found in different parts of the region under "natural" conditions. This model of potential or climax vegetation ultimately may serve as a guide for range improvement by suggesting what might be achieved.

It is also necessary to inventory actual vegetation patterns currently found within the region. A vegetation inventory includes maps and descriptions of associations, at a minimum, and could also include information on cover, production, and numbers of plants. Special attention should be given to determining the value of component species for forage, fuel, and other uses.

At this level of study, the goal is to provide information on the distribution of resources and, by comparing the results with the estimate of potential or climax vegetation, to identify areas where there are opportunities for range improvement, and to indicate areas where problems exist. Perhaps most important, the inventory of actual vegetation provides a picture of conditions at the beginning of the project that can serve as a benchmark for measuring general progress during the course of the project.

Geology

At the resource assessment level, geology is described in general terms. Primary consideration is given to identifying rock type and structure within the region. Geologic information provides a structural framework for the region and also is used to help form a general understanding of regional hydrology and the evolution of landforms and soils by

providing clues to the origin, age, and mineralogical composition of surface materials.

Landform

Landform is the feature commonly used to unify or provide a framework for the mapping aspects of the resource assessment. In most cases, landform is the most readily mapped feature of the landscape, and it is frequently correlated with other, less easily observed features, such as hydrology or soil. Not surprisingly, some vegetation types within the region may be consistently associated with a particular soil. Thus, an understanding of regional landform-soil-vegetation relationships is a powerful and necessary tool in developing the physical base of a resource assessment. An analysis of information on landform provides a general framework for survey while indicating some of the areas that might be especially susceptible to erosion. These areas would warrant special attention in a range improvement project.

Soils

Along with climate, soil type ultimately determines land capability. At the resource assessment level, however, only general soil information is gathered. This includes soil texture, soil morphology (that is, depth and presence of limiting horizons), general soil chemistry, and susceptibility to flooding or erosion. Ideally, many soil properties can be inferred from climate, landform, slope, and existing land use.

Soil types are not mapped at the resource assessment level unless the environment of the region is very simple. More typically, natural groupings of soil types, such as soil associations, are mapped. Although soil types are not mapped, descriptions of them are acquired to portray the range of conditions that will be found within the broader mapping unit.

Water

Delineation of watershed boundaries, major drainage lines, and other hydrologic features (for example, dry lakes) can help develop a general hydrologic framework of the region; it can also help facilitate the interpretation of landforms and soils, and can provide a general view of the likely distribution of water resources.

In most arid and semiarid regions, the distribution and quality of surface and near-surface water in an area will restrict the number of options for range improvement and subsequent management, and will have a major influence on the course of the project. Thus, a resource assessment must locate sources of surface water such as springs, streams, lakes, ponds, impoundments, and irrigation works, as well as average seasonal flows or volumes. Proven subsurface resources also must be reported by noting the location, depth, and yield of wells.

Current and Historical Land Use

Descriptions of land use are important for at least three reasons. First, one of the primary purposes of the resource assessment is to provide an overview of the mix of regional land uses. A comprehensive description of land uses will provide a general reference and may suggest functional economic linkages between land uses, such as irrigated agriculture and animal grazing systems. Any range improvement project must consider the relationships that exist between adjacent land uses.

Second, the land uses and management practices found within a region give some indication of variations in land capability. For example, pastures that are used only seasonally may be limited in their productivity because of cold winters or spring flooding. Such lands would require special consideration.

Third, some range improvement problems are associated with specific land uses, such as urban developments and woodcutting in many places, and should be identified for special treatment.

Like climate, some land uses are difficult to observe. Because of the ambiguous distinctions between some types of vegetation and land use (rangeland, for example), they are sometimes mapped together. A common compromise is to map "land cover," which includes all observable features that cover the land surface, such as vegetation, surface water, and various land uses (urban development or agriculture, for example).

Information on current land use should include maps and descriptions of all land uses, settlements, infrastructure (roads, canals, rail lines, fences, wells, and other watering points), and population estimates. Descriptions of regional land tenure practices may also be useful in explaining some land use patterns and management problems.

The patterns observed now may not be directly attributed to current land use practices. Historical events or land uses that are no longer observable may have left profound impacts on the land.

For example, highly saline rangelands may have been irrigated at one time and later abandoned because of salt accumulation. Thus, a general description of previous land uses, land use practices, and their locations may be useful in understanding current problems. Moreover, the successes and failures of the past may provide good evidence of what might be expected and how changes in management alternatives might be developed during the project.

Livestock and Wildlife

At the resource assessment level, it is necessary to produce a general census of animal herds within the region. Information gathered might include herd location, size, composition, general condition, and seasonal movement. In addition, the forage preferences and consumption patterns of the largest groups and their place in the local economy should be noted. With this information, range resources can be described in terms of forage demand, and the general economic and social impacts of alternative

animal management plans can be projected.

Information acquisition

Decisions concerning how the survey and other information gathering activities will be performed should be made at the outset of the resource assessment. Although this will not affect the type of information that is collected, it will determine, in part, how it is collected and organized.

Survey Approaches

Resource assessment might be approached in two ways: the component approach, in which each land characteristic is mapped individually, and the landscape or land systems approach, in which land is viewed as an integrated whole and the units that are mapped are more or less homogeneous. In both approaches, land characteristics are analyzed together to derive an estimate of land capability.

Component Approach

In much of the world, including the United States, agencies have been established to study individual resources (for example, climate and soils) within the country, or have been assigned to manage specific types of land use (for example, forest and rangeland). Both types of agencies conduct their own mapping activities. Thus, in a range improvement project, it is common to find that one or more land characteristics (for example, geology) have been mapped already for much of the project area. With this pattern established, a project will likely continue mapping land characteristics individually in the interests of consistency and economy. Moreover, project mapping may be carried out by several groups on a component basis because of the distribution or resource responsibilities among participating agencies.

Because it is difficult to map certain land characteristics individually, some characteristics often will be combined in one map (for example, climate and vegetation; vegetation and land use/land cover). Because of the constraints of scale, mapping units will tend to be somewhat heterogeneous, but will be designed around naturally linked groupings of land characteristics (for example, associations of soil or vegetation).

Landscape Approach
The need to adopt a systems approach during most phases of a range improvement project is emphasized throughout this volume. Two considerations argue for the systems approach at the resource assessment level. First, as noted above, the region should be understood in terms of its differences in land capability. This quality of the land is derived from physical and biological characteristics such as climate, soils, and vegetation. Although these characteristics may be surveyed individually, they must be considered together to determine land capability. Moreover, the units of land that are mapped function more or less like systems and not simply as a collection of independent components. Change in any one of the components will affect or be affected by other components in varying degrees. Thus, at the resource assessment level, it is desirable to consider the units of land to be managed as integrated "landscapes" with a distinct set of related characteristics.

Second, from a practical standpoint, significant economies of effort and improvements in product quality can be achieved by combining related or complementary aspects of the resource assessment. For instance, in a landscape approach, an interdisciplinary team (perhaps a soil scientist, geomorphologist, and plant ecologist) performs the mapping and analysis tasks as a group, rather than producing a set of individual maps and reports. Field expenses are reduced by combining activities, and mapping consistency and analysis quality are improved by complementary collaboration.

The landscape or land systems approach to resource assessment was developed and

applied first in Australia after World War II. The problems faced there were not unusual: large areas of the country had to be surveyed quickly and accurately to determine their agricultural potential. This highly successful approach is still used in Australia. Comparable approaches have been developed by other countries in many parts of the world for agricultural, military, and engineering purposes. In the following discussions, the Australian terminology is employed.

The land systems approach has a hierarchical structure of units (figure 4-1). The smallest unit of land recognized is the land element. It is defined primarily by slope, and is essentially homogeneous in all properties, corresponding to the concept of "site." Because of its limited extent, it is never mapped at the resource assessment level, but rather is the primary focus of site evaluation, as described in the following chapter. The next largest unit of land is the land facet, which consists of a set of related land elements, commonly on the same landform. It is seldom mapped in a resource assessment. The land system is the largest unit, and consists of geomorphologically and geographically associated patterns of land facets. The land system is the most commonly used mapping unit in this approach and is well suited to the general purposes of the resource assessment.

Information Acquisition Methods

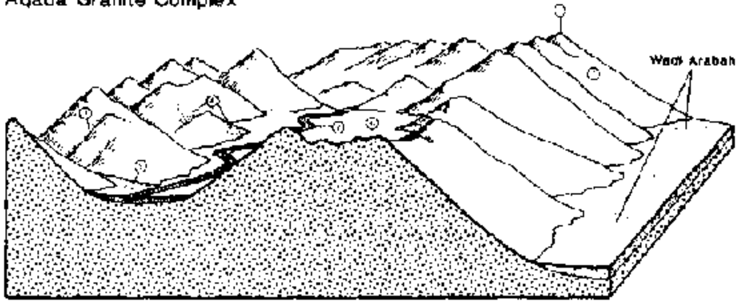
Archival Research

A search of archival sources of information is done at the beginning of the project to gather the work that has been done to map and describe land characteristics of the region. This avoids a duplication of previous work, and builds on the experience and insights of other workers in the region.

Published information on land characteristics exists for essentially all parts of the world. The types of information that can be found include maps and descriptions of climate, soil, and vegetation. Most of this information is extremely small in scale (for instance, world or

regional maps produced by the United Nations Food and Agriculture Organization). Although continental-scale maps are not suitable for a final assessment, they are a useful starting point.

Aqaba Granite Complex



AQABA GRANITE COMPLEX

Climate: Desert

Physiography: Dissected granite hills

Geology: Includes acid and basic igneous rock. Porphyry and narrow dolerite dikes locally prominent

Land facets:

No	Form	Soils	Vegetation
1	Crest bare rock	Lithosols	V. thin scrub
2	Bare rock slopes, including porphyry and dolerite dikes		(8a)
3	Wadis	Bouldery, stony and sandy regosols	Rather sparse scrub. *Acacia* spp., *Retama raetam* (4bb 4s, or 10b)

4	Steep screes and coarse block fans	Boulders	Sparse deep-rooted chenopods and shrubs (6n, 4h)
5	Gravel fans (smaller stones than 4)	Gravel	Sparse *Haloxylon salicornicum* (4n)
6	Desert flats, including small wadis	Stony and sandy regosols	ND*
7	Mud flats	Salt and clay, saline	Almost bare

* ND- No data

FIGURE 4-1 An example of land systems mapped in Jordan. (Mitchell and Howard, 1979)

Moreover, general reports usually contain extensive bibliographies that may lead to more specific studies for the project region.

Many papers are published in professional journals as a product of scientific studies conducted in a region. Commonly, these papers will describe one particular aspect of the region, such as overgrazing and erosion, that will not be critical to the total resource assessment, but may provide some insight into a particular problem in one part of the region. Descriptions of these papers can be found in science indexes and abstract journals, either by topic or by geographical location.

As noted above, maps and reports describing various land characteristics in a region are produced by regional, national, and international agencies. Because these materials may not be widely distributed, and their existence may not be generally known, inquiries must be made at all levels to find what work may have been done within any one region. Finally, some types of information, such as land ownership or census data, may be available only from local or regional archives.

All of the information needed for a resource assessment probably will not exist in a usable form at the start of a project. For example, vegetation maps are relatively uncommon, and

any existing maps for a region may have been done for a purpose that is not compatible with the objectives of the project (for example, a map of forest resources will be quite detailed for forested areas but may describe non forested lands only as "rangeland"). In other instances, existing maps or data may be out of date. Thus, in most resource assessments a good deal of map and supporting information must be gathered and compiled independently during the project. Some of the more commonly used techniques for generating this information are discussed below.

Interviews

Discussions with local administrators, researchers, and especially land managers can be conducted to gather information on those characteristics that cannot be directly observed and that are probably not recorded, such as land use, land management practices, animal management practices, general management issues, economic conditions, land capability, local perceptions of resources, and any other information that may support specific project objectives.

As suggested above, background information can be extremely

important in estimating land capability in terms of indigenous practices. It also should provide some clues about the acceptability of proposed changes in management practices.

Interviews may be conducted formally, and may rely on the use of questionnaires if the objectives of the project call for a quantitative description of some features of local culture. However, informal interviews are done more easily and may serve equally well.

Ground Sampling

Much of the information required for the resource assessment can be gathered only through direct observation. This information may be used to develop maps, to develop

estimates of the magnitude of other characteristics that are not ordinarily mapped (for example, population), or to describe the composition of mapping units (for example, vegetation species and cover, and soil type and depth) that have been recognized by other means (see the following section on remote sensing).

Maps and estimates of land characteristics may be developed in two ways. First, ground samples may be gathered in a sampling pattern such as a grid. Reasonable maps or estimates may be developed from such data. However, the accuracy of this approach is dependent upon the complexity of the region and the density of sample points. At the resource assessment level, it is unlikely that a project could afford the expense of allocating enough samples to characterize a large region. Thus, systematic ground sampling is used only for very intensive studies, such as irrigation soil surveys, or where the features of interest are assumed to be poorly correlated with other observable features, such as archaeological sites.

A second approach employs stratified sampling and is used where it is possible to assume a reasonable correlation between two or more characteristics. For example, in a landscape approach to survey, it is possible to stratify an area according to landform and elevation if good topographic maps of a region exist. Ground samples are allocated to each stratum, according to its importance or complexity. Maps and estimates developed in this way are reasonably accurate and more efficient than a systematic approach. However, dynamic land characteristics, such as land use and vegetation, may be inadequately sampled because of their high variability. For example, major changes in vegetation resulting from clearing or fire may be missed because they are not necessarily correlated with landform.

Remote Sensing

Although maps and estimates of land characteristics can be produced by ground sampling alone, it is seldom done for a resource assessment because of the expense and the

likelihood of missing important features.

Remote sensing is the most commonly used tool for gathering information for large areas As defined here, remote sensing includes the uses of aerial photography and satellite imagery to study the earth's surface. Remote sensing data are unique because they (1) provide a comprehensive picture and permanent record of surface conditions at one point in time and (2) present a vertical perspective in which all features are represented, essentially in their true geometric relationship with all other features. There is no ideal remote sensing system. Thus, a primary task in remote sensing is to select a system that best meets the needs of the project.

Principles of Remote Sensing Remote sensing exploits the differences that can be detected among surface features on an image of the earth. The ability to distinguish among features is conditioned by several factors. Foremost in many applications is the feature's tone or color. Earth materials reflect or emit electromagnetic radiation, including light, in different ways (figure 4-2). For example, vegetation has a unique pattern of reflectance, with moderate reflectance in the green part of the spectrum, low reflectance in the red part of the spectrum, and very high reflectance in the infrared part of the spectrum that is just beyond what is visible to the human eye. Second are those inherent properties of a feature that determine how it appears, or what is sometimes called a feature's "signature" or "response." The characteristic shape of a surface feature when viewed from above (for example, a folded geologic structure) or its relative size (such as tree versus shrub) are two such properties. Other important characteristics are less obvious, such as a feature's “texture" on an image (say the difference between the smooth texture of a meadow and the rough texture of a forest canopy), or the association of one feature with others (such as pine forests on steep north-facing mountain slopes).

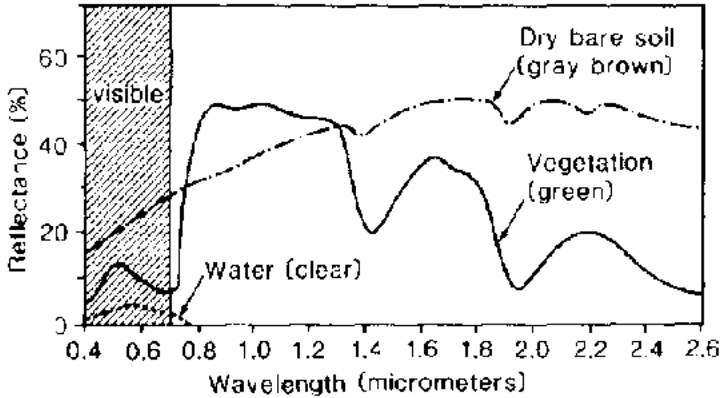


FIGURE 4-2 Spectral characteristics of different earth materials.

The type of remote sensing system used also affects the ability to distinguish among earth features Scale - the relationship between the size of the image and the area on the ground it portrays - largely determines what can be seen, especially if geometric properties such as size, shape, and even texture are noted. Other important characteristics of remote sensing systems have to do with system resolution, or its "sharpness" in several dimensions - spatial, temporal, and spectral.

Spatial resolution broadly describes the quality of the system that determines the smallest feature that might be detected. Thus, spatial resolution influences the ability to detect features based upon geometric characteristics. For example, to determine tree densities in savannah vegetation, relatively high-resolution images would be required to see individual trees, while simply to map the boundary between forest and savanna, low-resolution images might be preferred to enhance differences in total tree cover rather than the location of individual trees.

Temporal resolution describes how often a system acquires images for a single point. Although not usually a consideration for aerial photography, temporal resolution is an important characteristic of satellite systems because they operate continuously. For example, mapping forests in a large area and also distinguishing between evergreen and deciduous types would require a system that acquires images frequently enough to assure at least one cloud-free image from both summer and winter.

Spectral resolution describes the location and width of the parts (bands) of the spectrum in which the system records. Earth materials reflect and emit electromagnetic radiation in different ways. To improve the ability to discriminate features it can be useful to employ a "multispectral" approach by examining several different parts of the spectrum. The value of this approach is easily appreciated when comparing a black-and-white panchromatic photograph with a color photograph. Color photography provides much more information than black-and-white, but it tends to have poorer spatial resolution, is more expensive, and is difficult to process in some parts of the world because of the lack of proper equipment.

There is much information outside the visible spectrum that would be useful for studying vegetation (table 4-1). Photographic films have been developed that are sensitive to infrared radiation that is just beyond the visible part of the spectrum. Color infrared (CIR) film is the most common type. To record infrared energy using conventional photographic technology, colors from the natural environment are assigned to other colors on the CIR film. Thus, the final product is sometimes called a false color image: blue is filtered out, green is recorded as blue, red is recorded as green, and infrared is recorded as red. Because plants reflect more infrared light than green light, green vegetation appears as various shades of red or pink. Red soils are yellowish-green, and urban areas are bluish-gray. CIR photography is especially effective for mapping vegetation, but is expensive and sometimes difficult to expose and process.

Nonphotographic sensing systems can be carried by aircraft and spacecraft and provide similar kinds of spectral information. Nonphotographic systems have a number of advantages. For example, parts of the spectrum that are critical in some applications and that are beyond the capability of photographic systems, such as the thermal and microwave (radar), can be sampled. Also, many nonphotographic systems record images digitally, which allows several processing options (see below). With the exception of Landsat satellite data, however, nonphotographic imaging systems will be used in few resource assessments because of the expense of processing and the need for special computer facilities.

Satellite Systems Since 1972, satellite imagery suitable for land resource assessments has been produced continuously for most parts of the world. Landsat was the first satellite to provide regular and universal image data and continues to be the most widely used system.

	Landsat Multispectral Scanner (MSS)	Landsat Thematic Mapper (TM)	NOAA Advanced High Resolution Radiometer (AVHRR)
Cycle	18 days (Landsats 1, 2, and 3)		Daily
	16 days (Landsats 4 and 5)	16 days	
Swath width (kilometers)	185	185	2,600
IFOV/ resolution* (meters)	80	30	1,100
Spectral band nos. and corresponding wavelengths (micrometers)	1) 0.5 - 0.6 2) 0.6 - 0.7 3) 0.7 - 0.8 4) 0.8 - 1.1	1) 0.45 - 0.52 2) 0.52 - 0.60 3) 0.63 - 0.74 4) 0.76 - 0.90 5) 1.55 - 1.75 7) 2.08 - 2.35 6) 10.04 - 12.50	1) 0.58 - 0.68 2) 0.72 - 1.10 3) 3.55 - 3.93 4) 10.30 - 11.30 5) 11.50 - 12.50

* Instantaneous Field-of-View Resolution

Table 4-1 Comparison of Landsat MSS, TM, and NOAA AVHRR System Characteristics

Table 4-1 Comparison of Landsat MSS, TM, and NOAA AVHRR System Characteristics

	Landsat (MSS) Multispectral	Landsat	NOAA Advanced High

	Landsat (MSS) Multispectral Scanner	Landsat Thematic Mapper (TM)	NOAA Advanced High Resolution Radiometer (AVHRR)
Cycle	18 days (Landsats 1, 2, and 3) 16 days (Landsats 4 and 5)	16 days	Daily
Swath width (kilometers)	185	185	2,600
IFOV/ resolution* (meters)	80	30	1,100
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band nos..	1) 0.5 - 0.6	2) 0.52 - 0.60	1) 0.58 - 0.68
and correspond-	2) 0.6 - 0.7	3) 0.63 - 0.74	2) 0.72 - 1.10
ing wavelengths	3) 0.7 - 0.8	4) 0.76 - 0.90	
(micrometers)	4) 0.8- 1.1		
		5) 1.65 - 1.75	
		7) 2.08 - 2.35	
			3) 3.65 - 3.93
		6) 10.04-12.50	4)10.30-11.30
			5)11.50 -12.60

*** Instantaneous Field-of-View Resolution**

SOURCE: Adapted from the Final Report of the Panel on the National Oceanic and Atmospheric Administration Climate Impact Assignment Program for Africa, BOSTID, National Research Council, Washington, D.C., January 1987.

The primary instrument on Landsat is the Multispectral Scanner (MSS), which records images of the earth in four spectral bands (see table 41). Images are recorded digitally but are produced in both digital and photographic formats. The MSS creates an image by recording the relative brightness of each element or cell of a large array. Each picture element (pixel) equals an area on the ground of approximately 0.5 hectares (60 m x 80 m). An image is created for each band in the green, red, and two infrared parts of the spectrum. Images from each band may be combined to create an image that is similar in color renditions to a conventional CIR photograph, and may be interpreted manually. Because they exist in digital form as well, images may be processed statistically using a computer. Although spatial resolution is relatively low, the MSS is well suited to resource assessment because a single image covers a large area and, as suggested above, it is desirable sometimes to avoid the confusion introduced by detailed data.

The most recent series of the National Oceanic and Atmospheric Administration (NOAA) weather satellites has carried the Advanced Very High Resolution Radiometer (AVHRR) instrument. The AVHRR has low resolution (see table 4-1) because it was intended to complement conventional very-low-resolution weather satellite systems by acquiring data that could be used to describe general land surface conditions. Although AVHRR has been used mainly for monitoring studies, it might provide useful information for exceptionally large regions.

Aerial Photography Aerial photographs are the most widely used form of remote sensing data. They are routinely acquired in most parts of the world for a variety of purposes, including geophysical surveys and the production of topographic maps.

The principal advantages of aerial photography are its high quality (conventional image format is about 23 cm x 23 cm) and the ability to schedule photographic missions at the proper time and appropriate scale using the desired films and filters. Moreover, aerial photography firms can be contracted to fly missions over almost any area in the world. The primary disadvantage of conventional aerial photography is its relatively high cost.

To counter the high costs of conventional aerial photography, increased use has been made of 35 mm cameras for aerial photography (figure 4-3a and 4-3b). Because the film format is so small, most 35 mm photography has been acquired at very large scales from low flying light aircraft. Images from these systems are of somewhat lower quality than conventional aerial photography and they must be used with some care. The advantages in cost and flexibility, however, seem to offset most other considerations when the 35 mm system is used for resource assessment.

Use of Remote Sensing Data

Aerial Photograph Interpretation Satellite images or aerial photographs can be interpreted manually by a trained analyst who is familiar with the study region (figure 4-4). As in any mapping exercise, the objective is to recognize areas that are more or less homogeneous in one or several properties. Using knowledge of the region and the image characteristics, the analyst examines the image and manually delineates areas judged to be homogeneous. areas or mapping units that appear to be related (for example, sandy alluvial fans) are labeled accordingly. These mapping units can serve as strata for subsequent sampling. Boundaries are determined, and mapping unit descriptions are generated by examining large-scale aerial photographs or by analyzing ground samples.

Single images are rarely used in remote sensing. The preferred approach is to examine a number of images at scales larger than that of the base map; larger-scale images are used to refine or label mapping units defined at higher levels Ultimate verification is provided by ground sampling This multiple strata sampling scheme is called the multistage

approach to remote sensing (figure 4-5). The multistage approach is used with all types of remote sensing data but is especially effective when satellite images are being used.

Photo Sampling Several other types of information must be gathered during the resource assessment that are not normally mapped by remote sensing (including human population, herd sizes and composition, and detailed land use). Although much of this information might be gathered through ground sampling or interviews, other techniques have been developed for using large-scale (larger than 1:1,000) 35 mm photography as a supplement for ground sampling. For example, a rich methodology has evolved for the use of low-level photography for studying rangeland and large animals in East Africa (International Livestock Centre for Africa, 1981). These systems use the aerial photograph as a sample point in a systematic sampling scheme. Detailed interpretations of the photographs are used to develop accurate estimates of the sizes of domestic and wild animal herds, human populations, crops, and land use at the ranch level for very large regions at comparatively low costs.

Digital Processing Satellite images are available in digital format. These data may be selectively enhanced to produce images that are more easily interpreted by the analyst. For example, if the project is located in a region dominated by bright sandy soils, the contrast at the brighter end of the tonal range can be increased at the expense of the darker. This type of enhancement would bring out subtle differences in brightness that otherwise might be overlooked (figure 46).

Applicability and Availability of Remote Sensing Data Remote sensing may be the only way to acquire information about basic land resources in many parts of the world. Maps of natural resources and land use are relatively rare in many nonindustrialized countries. In fact, adequate base maps that describe topography, roads, and cultural features may not exist for many areas.

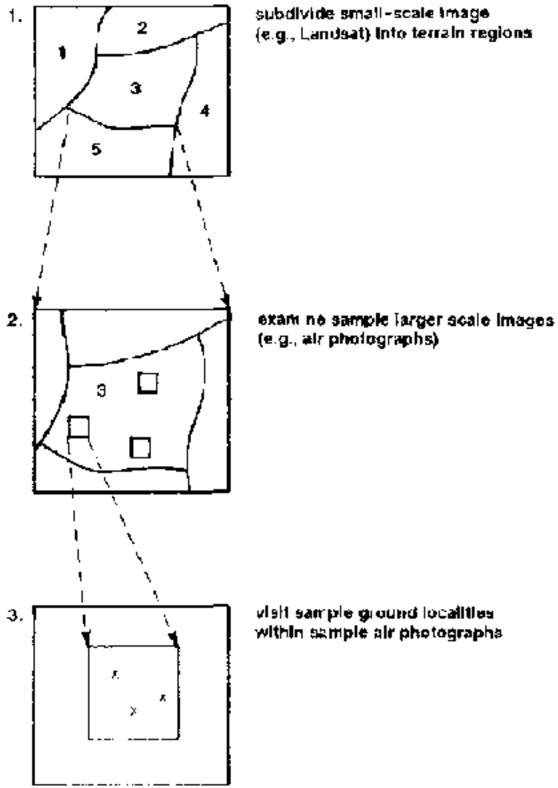
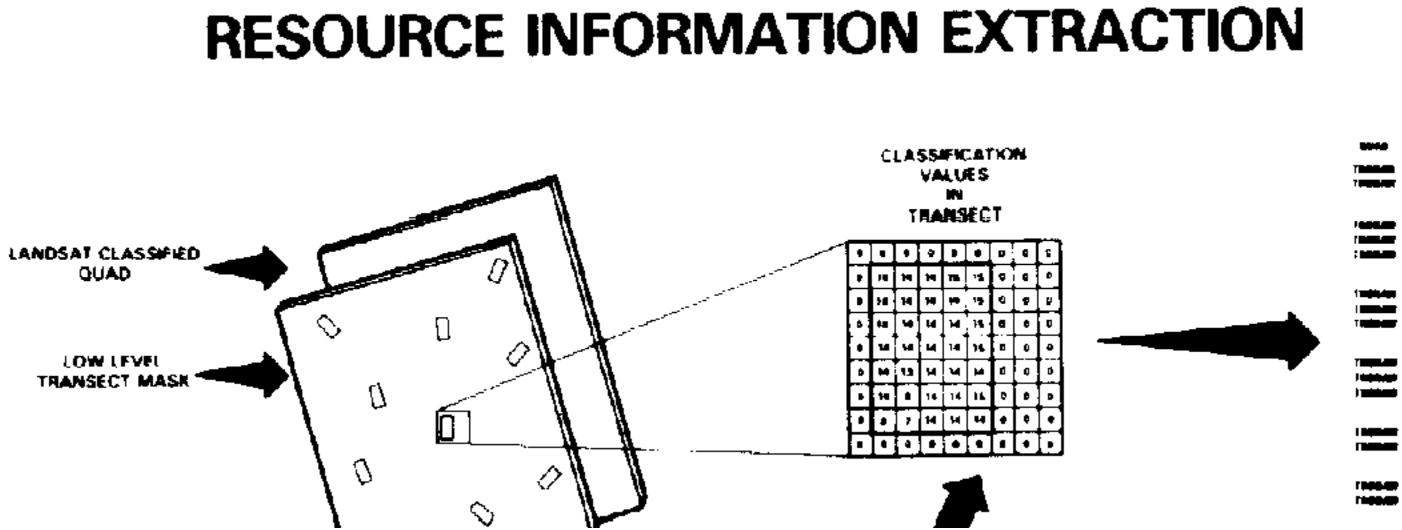


FIGURE 4-5 The multistage approach to sampling as applied in remote sensing (after Townshend, 1981).

Conventional aerial photography is usually the preferred source of information for mapping land resources. As previously noted, however, existing aerial photography may

be quite old and thus of relatively little value for mapping current conditions. Even current aerial photography, though, may present difficulties. Because of the great amount of detailed information they contain, conventional aerial photographs are commonly perceived to have considerable intelligence value. As a result, their distribution is sometimes controlled by military authorities and thus may not be available.

If the project is large enough, acquisition of aerial photography may be a major activity and warrant special attention. A large number of private firms provide aerial photography services. Their names and addressses can be found in the telephone books of major cities or in directories of the journals of major professional societies, such as Photogrammetric Engineering and Remote Sensing, the journal of the American Society of Photogrammetry and Remote Sensing.



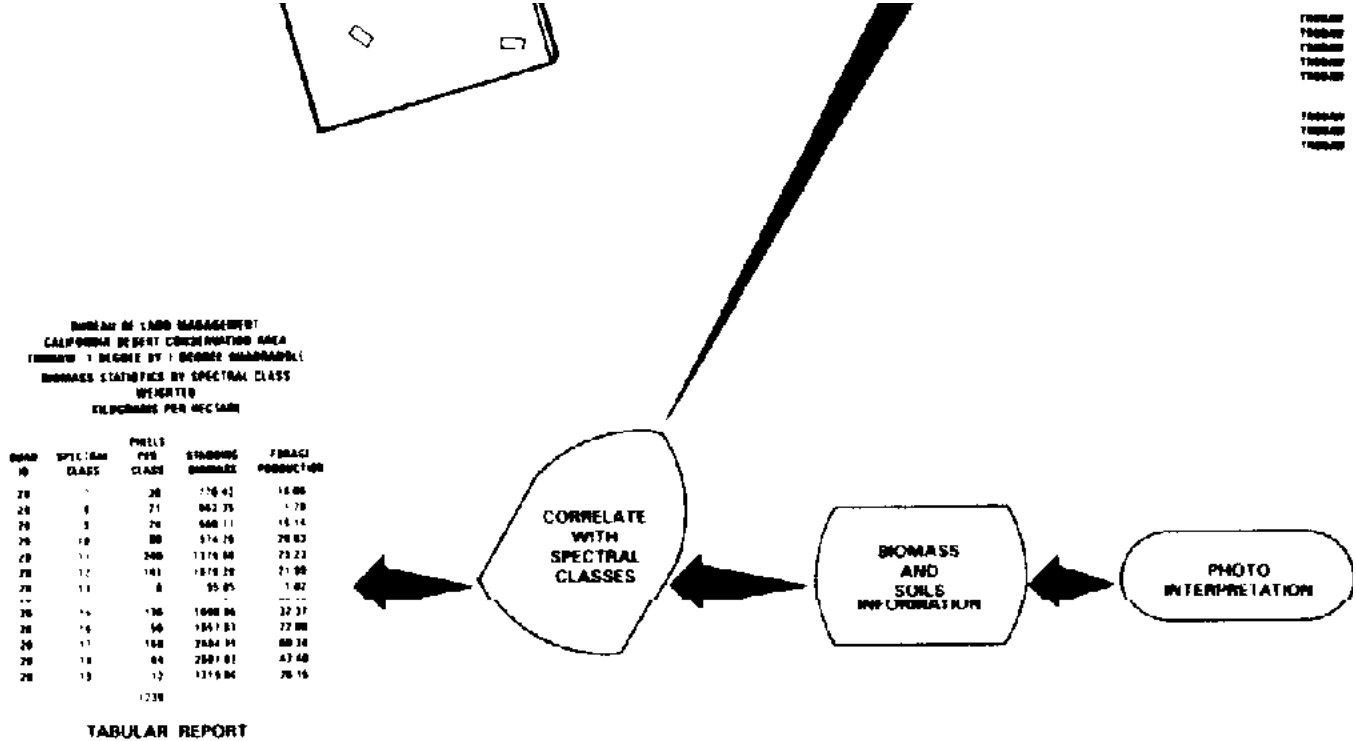


FIGURE 4-6 A method for using digital classification of Landsat imagery for vegetation inventory. Low-level, large-scale aerial photographs were acquired along randomly selected transects. The photographs were used to estimate biomass and soil condition along the sample transects. These values were correlated with the various Landsat spectral classes along each transect. Summary values then were calculated by multiplying the area of each spectral class by the vegetation and soil values derived from the sample

transect data for the entire study area. (Courtesy of Jet Propulsion Laboratory, California Institute of Technology, Pasadena, California, McLeod and Johnson, 1981)

Landsat Data Distribution Centers	
NORTH AMERICA	ASIA
National Oceanic and Atmospheric Administration Customer Services EROS Data Center Sioux Falls SD 57198 USA	National Remote Sensing Agency Balanagar Hyderabad - 500 037 Andhra Pradesh India Remote Sensing Division National Research Council
Canadian Center for Remote Sensing User Assistance and Marketing Unit 717 Belfast Road Ottawa Ontario KIA 0Y7 Canada	196 Phahonyothin Road Bangkok 10900 Thailand
	Chairman
SOUTH AMERICA Instituto de Pesquisas Espaciais Departamento de Produ�ao de Imagens ATUS-Banco de Imagens Terrestres Rodovia Presidenta Dutra Km 210 Cachoeira Paulista-CEP 12.630 Sao Paulo Brazil	Indonesian National Institute of Aeronautics and Space JLN Pemuda Persil No. 1 P. O. Box 3048 Djakarta Indonesia Remote Sensing Technology Center of Japan Uni-Roppongi Bldg. 7-15-17 Roppongi Minato-ku Tokyo 106 Japan
Comision Nacional de Investigaciones Centro de Procesamiento Dorrego 4010 (1425) Buenos Aires Argentina	Academia Sinica Landsat Ground Station Peoples Republic of China
EUROPE	
EAS - ESRIN Earthneat User Services Via Galileo Galilei 000 44 Frascati Italy	AUSTRALIA Australia Landsat Station 14-16 Oatley Court P. O. Box 28 Belconnen A.C.T.

	2616 Australia
AFRICA National Institute for Telecommunications Research ATTN: Satellite Remote Sensing Centre P.O. Box 3718 Johannesburg 2000 South Africa	

The United States has maintained an "open skies" policy in the acquisition and distribution of data from the Landsat satellites. Since the initiation of the Landsat program, ground-receiving stations have been established in a number of countries around the world (see list below). Images from these stations are available at a modest cost and cover most parts of the earth (see table 4-1).

Where large areas are studied and extensive ground sampling poses a problem, large-scale aerial photography may be required to supplement satellite data and conventional aerial photography. This is particularly true when the efficient multistage sampling approach is employed. Nonconventional systems have been developed (see figures 4 3a and 4-3b) that provide excellent data at low cost for large areas (International Livestock Centre for Africa, 1981). Where budget presents no problem, conventional aerial photography can be purchased from a service.

The variety of remote sensing systems currently available ensures that basic information on land resources can be produced quickly at reasonable cost for almost any country. Should training or re-training be necessary to benefit from these systems, practical training courses are available at most major agricultural universities, and at many remote-sensing centers. Aside from short-term courses (less than one month duration), university training is generally part of a longerterm advanced-degree program. However, a variety of variable-duration, comprehensive training programs in all aspects of remote sensing are available under Unesco auspices through the International Institute for Aerial Survey and Earth Sciences (ITC), 350 Boulevard 1945, P.O. Box 6, AA Enschede, The Netherlands.

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Site evaluation

One of the key elements of a range improvement program is the proper selection of sites for demonstration projects. To ensure success, a site must be carefully chosen and must be typical of the particular ecosystem being considered for an extensive program.

The types of information that are needed at the larger scale, more extensive planning level, and the methods by which this information might be gathered and subsequently used, have been described in the preceding chapter. Analysis of this information should help identify specific areas for potential improvement. In many instances, however, a more detailed site evaluation is required before initiating activities. A preliminary site evaluation can be achieved, in part, through an intensive search of the literature. On-site surveys and observations may still be necessary to complete the site assessment and fully

evaluate the site's potential for improvement.

An ecosystem perspective

A site for a proposed range improvement project or program is a microcosm of a larger ecosystem. Regardless of how it is delineated, an ecosystem is the basic unit of ecology, typically a complex system, comprising the physical setting, plants, animals, and its human population. Compounding this complexity is the fact that an ecosystem is almost always changing, even in semiarid and arid rangelands.

The natural process of change in the composition of an ecosystem is referred to as succession. Successional changes take place in response to natural or man-made influences in the environment. So-called primary succession happens on newly exposed areas, such as landslides or sand dunes, whereas secondary succession occurs after the previous vegetation has been destroyed or disturbed by fire or agricultural practices, for example. In many areas of Africa and Asia, a disclimax (a climax maintained through disturbance) has been established through savanna burning and heavy use pressure by livestock. In any case, natural ecosystems evolve from essentially bare areas to more or less stabilized types of dominant vegetation through a series of successional stages.

The current successional stage of a site being considered for improvement should be characterized. Some individual plant species grow better when in competition with existing vegetation on sites in the early stages of succession. Other plant species survive and grow with existing vegetation on sites in later stages of succession. Through recognition of the current successional stage, the species to be planted and managed can be better matched with the successional condition of the site, thereby enhancing the probability of continued growth.

Knowledge of successional patterns is gained, in general, from analyses of systematic, long-term observations of cyclical processes by astute ecologists. These analyses are

difficult where successional change is orderly, and they are next to impossible where the changes are erratic. Nevertheless, the potential for the improvement of a site is put in a proper ecological perspective when analyses provide approximations of the current successional condition with respect to the range of successional stages that characterize a site.

A systems approach to site evaluation

A systems approach should be adapted in a site evaluation for assessing potentials for range improvements. Otherwise, the effort might simply be a collection of discrete, often incomplete, and generally unrelated exercises in measurement.

A systems approach to problem solving, regardless of its nature, generally involves a holistic study of the interacting elements that function simultaneously for an explicit purpose, emphasizing the connections among the various parts that constitute this whole. The interacting elements of concern function in "driving" the ecosystem processes. By its very nature, a systems approach to designing a comprehensive site evaluation involves several disciplines, including meteorology, soil sciences, and biology.

It may be impractical (or unnecessary) to measure all of the parts of an ecosystem in a particular site evaluation because, in many instances, only a relatively small number of limiting components may be related to the success of the range improvements. With a systems approach, however, the probability of overlooking important, possibly constraining, attributes will be greatly lessened.

Evaluation of abiotic and biotic components

A site evaluation focuses upon two broad sets of components: nonliving (abiotic) components and living (biotic) components. Climate, soil, landform and relief, and water resource are abiotic components; plants and animals of all forms, including humans, are

biotic components. The objectives of the proposed range improvement project or program, the complexity of the ecosystem being evaluated, and the completeness of the available relevant knowledge will largely determine the intensity of the effort to be undertaken in evaluating these abiotic and biotic components. Details of measurement and sampling techniques may be found in Avery (1975), Bell and Atterbury (1983), Brown (1954), Cain and de Oliveira (1959), Carmean (1975), Child et al. (1984), Conant et al. (1983), Jones (1969), Lund et al. (1978), Lund et al. (1981), National Research Council (1962) Schemnitz (1980), and Soil Resources Inventory Group (1981).

Abiotic Components

Reasons for evaluating specific abiotic components of a site are discussed below. Techniques commonly used to quantify these components are briefly described.

Climate

Climate can be defined as the total complex of weather conditions and its average characteristics and range of variation over an appreciable area of the earth's surface. Conditions over an extended period of time are usually taken into consideration. weather in turn, comprises a set of atmospheric conditions at a specified point in time and, therefore, refers to events. Climate is basic to an ecosystem because of its significance in soil development and plant productivity.

Climate is difficult to characterize, owing to frequent deficiencies in the length and consistency of necessary meteorological records.

The climate of a site is most easily described from records of the United Nations World Meteorological Organization or from data collected by national weather offices. Unfortunately, many weather stations from which this information is obtained are often poorly distributed, especially in semiarid and arid lands of developing countries.

Precipitation Patterns The amount and distribution of rainfall is important because of its role as a source of soil moisture. Survival and subsequent growth of plants is, of course, closely tied to the availability of water in the soil mantle. Rainfall, in itself, is usually of little direct significance to plants, although there can be some absorption of water through the leaves and, occasionally, the bark.

Although soil moisture is mostly derived from rain, not all of the precipitation that falls on a site is equally effective in raising the soil moisture content. The slower, more gentle a rainfall event, the greater the penetration, or percolation, of water into the soil. However, a series of precipitation events that totals only several millimeters may add little to the soil moisture content, because the individual events are too widely separated and too gentle to have a cumulative effect. The more severe a drought, especially in dry climates, the greater the quantity of rain required subsequently to alleviate the drought.

Reliable measurements of rainfall are most commonly acquired from networks of rain gauges. There are many types (for example, standard, recording, and totalizer), and dimensions of rain gauges, but they all consist essentially of a funnel with a vertical collar that delivers water to a collecting reservoir. Only precipitation records obtained from gauges located away from eddies caused by physical obstructions should be used in a site evaluation. As a general rule, obstructions overhead should be no closer to the gauge than twice the height (from the ground) of the receiver funnel.

Temperature Regimes Heat from solar radiation controls the temperature regimes near the surface of the earth. The temperature at a site is influenced by incoming solar radiation that, in turn, is modified by secondary heat transfers from terrestrial radiation and air movements. Temperatures of either high or low extremes can be detrimental to the establishment and growth of plants. Hot temperatures, in combination with drying winds, can be damaging to recently emerged plants, especially under conditions of minimal soil moisture. Conversely, cold temperatures can delay seed germination and subsequent early

growth, placing the survival of plants in jeopardy. Following establishment, temperatures of either extremes can reduce the overall growth performance of most plant species.

For best growth, many plants require nighttime temperatures that are considerably cooler than daytime temperatures. This difference between nighttime and daytime temperatures, termed thermoperiod, is important in the flowering and setting of fruit. In general, plants will become adjusted to regular diurnal fluctuations in temperatures and, as a result, may not exhibit "normal behavior" when grown in foreign environments. Therefore, individual plant species should be selected on the basis of their adaptation to temperature regimes (including mean, maximum, and minimum temperatures) at a site.

Reliable air temperature data are gathered from simple thermometers (for instantaneous determinations), maximum-minimum thermometers (to measure temperature extremes), and thermographs (for a continuous record of temperatures). Thermometers are generally housed in shelters with louvered sides to permit air to circulate freely. The shelters should be located at a distance at least two-thirds the height of any obstructions. Temperature will vary if obtained on steep slopes or in hollow areas.

The air within plant leaves is usually saturated with moisture under growing conditions, and vapor therefore will move from the leaves into the surrounding atmosphere, cooling the atmosphere in the process; this is transpiration. The rate of transpiration in plants depends in part on the amount of atmospheric moisture present; the drier the atmosphere, the higher the rate of water loss. Transpiration is the dominant process in the water balance of plants and can cause water deficits to occur. Under conditions of limited soil moisture, these water deficits may be responsible for growth reductions or death.

To characterize atmospheric moisture at a site in a given period of time, relative humidity is often measured. With summaries of relative humidity regimes over a growing season, it may be possible to determine the changes of transpiration in plants resulting in water

deficits. Because certain plant species are better able to withstand the stresses of water deficits, this knowledge can be useful in evaluating the value of plant species for revegetative purposes at a particular site.

Instantaneous measures of relative humidity are obtained from manual observations of dry- and wet-bulb thermometers on a sling psychrometer. Hydrographs, of which several types exist, are used to record relative humidity on a continuous basis. These instruments should be housed in the shelters containing thermometers.

Wind The effect of wind on evapotranspiration, the total moisture loss from soil by evaporation and plants by transpiration, can be critical, particularly in dry climates. When a plant is exposed to drying winds and hot temperatures, water deficits in its leaves are likely to occur; this situation is compounded under minimum soil moisture conditions. The desiccating impact of wind on plants is demonstrated by low survival rates, stunted growth, and frequently death in many plant communities of semiarid and arid lands.

Data on wind patterns (prevailing direction, velocities, and seasonal fluctuations, for example), characterizing a particular site, are uncommon in many nonindustrialized countries . When this information is available, it has generally been obtained by using an anemometer during short-term site visits.

Light Another climatic factor that affects the growth of plants - an important factor that is seldom measured extensively - is light. Solar radiation in the visible bands of the spectrum controls photosynthesis. At very low light intensities, photosynthesis may take place at such a slow rate that all of the carbon dioxide evolved by respiration is not used; with these conditions, carbon dioxide is given off by the plant, not absorbed by the plant from the atmosphere. On the other hand, high light intensities promote rapid transpiration, which can often have detrimental effects. In general, individual plant species differ in their relative tolerances to either low or high intensities of light.

The photoperiodism of plants also differs among species. Some plants require long photoperiods (that is, length of day) to grow and develop, while other plants do better with shorter photoperiods. Photoperiods can be easily measured by the length of daylight at a site.

Soil

The word soil refers, in general, to the natural surface layer of the earth's crust in which plants grow. It is a porous medium, comprising minerals and organic materials. Living organisms, water, and gases are other constituents of soil. Whether climate or soil is more important in governing plant growth is immaterial, since both are necessary.

A site evaluation is normally incomplete without some kind of soil inventory, classification, or assessment. The evaluation of soil resources is conducted to determine the capacity of a particular site for a prescribed range improvement project or program, specifically in terms of supporting individual plant species or groups of plant species. More general information may be available from in-country files and experiment stations. Some international organizations, such as the Food and Agriculture Organization of the United Nations, can also provide general information (Dudal, 1970).

Evaluations of soil resources are made to provide adequate information for decision makers. Herein, the decision makers are concerned principally with the improvement of semiarid and arid rangelands. The kinds of decisions that these individuals will make must be known before a soil survey begins. Specific needs will largely determine which soil parameters should be measured and the procedures to be used in evaluating the soil resources.

It is beyond the scope of this report to describe the many techniques of conducting a soil evaluation. This information is available in numerous references; see, for example, Conant et al. (1983), Lutz and Chandler (1946), and the Soil Resources Inventory Group (1981).

Instead, a "checklist" has been prepared to indicate many of the attributes that may be included in an evaluation of the soil resources on a site; each item is briefly discussed below. Obviously, the factors that are ultimately included in a particular soil survey must be those that relate to decisions made relevant to the particular range improvement project or program. Emphasis should be placed upon those factors that are "limiting" to the growth and development of the plant species.

Parent Material The underlying parent material from which soil develops has an important influence on the type of plants that a site will support. When the growth of an individual plant species is good on one site but poor on an adjacent site, investigation will often disclose that the two sites are characterized by geologic material of differing mineralogical composition and origin. In general, the soil is derived from the underlying rock. In some instances, however, the parent material may have been transported to the site by gravity, water, or wind.

Parent material, a descriptive parameter, is usually determined by field observations by a competent soil scientist. Geologic maps, if available, are also helpful in delineating the extent of soil that has been developed from a parent material.

Depth If soil depth is limited, the development of roots can be restricted. Soil depth is measured by exposing the soil profile and measuring the thickness of the separate layers. Many basic soil properties are characterized by horizon. The number of soil profiles taken at a site depends largely on the inherent variabilities of the individual properties.

Texture and Structure Two important physical properties of soil that greatly influence plant growth and development are texture and structure. Texture refers to the size and distribution of the soil particles (sand, silt, clay, and mixtures of them in various proportions); structure refers to the grouping of these particles into aggregates. Texture can affect and may restrict the development of roots, primarily through its influence on

nutrient retention and aeration. Structure, which is most important in soils high in silt and clay particles, affects the percolation of water and air. The success of individual plant species in revegetation is dictated, in many respects, by texture and structure of the soil at a site.

Both texture and structure are descriptive measures, most commonly taken by horizon in the soil profile. Care must be exercised to ensure that samples are representative of the site.

Soil pH Different species of plants generally exhibit a preference for a degree of acidity or alcalinity in the soil, and have their own optimum pH values. Because pH may vary from one site to another, it should be included in a soil survey to maximize the returns from revegetative efforts. The pH of soil can be determined by using inexpensive but accurate field colorimetric sets.

Water-Holding Capacity As mentioned above, the survival and growth of plants is dependent on the availability of water in the soil. Waterholding capacity is a soil parameter of considerable utility. After saturated soil has been drained of gravitational water, it is (by definition) at field capacity. Field capacity is often determined in the laboratory, although approximations can also be made in the field by using a tensiometer. If desired, field capacity can be measured by horizon.

Organic Material The accumulation of dead organic material on a soil surface is significant to the "well-being" of plants in various ways. Organic material is, in time, a primary source of mineral nutrients. The organic increment of a soil profile is also a source of food for soil organisms that, in turn, are the chief causes of decay of the organic material; this process is critical in the nutrient cycles of a site. Organic material is colloidal, and thus, its waterholding capacity is relatively high.

Organic material content is minimal on many semiarid and arid lands. The sparse

vegetation and year-round high temperatures favorable for rapid decomposition do not allow the accumulation of organic matter in appreciative amounts. The water-holding capacity of these soils is also frequently low. In general, the presence of organic litter may be quantified through visual inspection at a site, but differentiation into other compounds may not be possible except under laboratory conditions.

Salinity Salinity is often a constraint in revegetative activities. Saline and alkaline soils are commonly found in the valley bottoms of semiarid and arid lands. These soils create specific difficulties in selecting appropriate species for planting, and only plant species that are adapted to these sites should be used. Also, high levels of saline in soil reduces the amount of water available to plants and, therefore, can accentuate physiological drought.

Soil salinity is frequently measured with the aid of a Wheatstone bridge (an electrical device which measures conductivity). However, as is the case in surveying many soil attributes, these measurements are based on "point samples," which limit their extrapolation because of site variability.

Fertility Individual plant species have their own nutrient requirements for growth and development. When the soil lacks these nutrients, certain plant species may not be suitable for revegetation. In that case, it may be necessary to apply a fertilizer, although this practice may be uneconomical in an extensive revegetation project or program except for establishment. To the extent possible, the natural fertility of soil should be ascertained by chemical analyses. A practical approach to "measuring" soil fertility is to employ native plants as indicators of fertility ranges. Knowledge of the ecosystem and successional cycles of a site is necessary for this technique, however. Quantitative expressions of soil fertility are obtained with soil-testing kits.

Soil Classification The classification of soil is an attempt to group soils into categories

that, in general, are useful in understanding the dynamics of an ecosystem. It is based, regardless of the system, on an examination of the "typical" soils in an area. In the process of classification, a number of soil attributes may be considered, including (but not exclusively) many of those described above. Soil classification is time-consuming and generally expensive, but it can provide decision makers with necessary information for the effective planning of range improvement activities. Fortunately, many countries have soil survey departments that can furnish technical assistance for this purpose.

The selection of a soil classification system to be used in a resource evaluation program is an important consideration. For instance, the needs of a project with one objective may be met by a specificpurpose, site-specific soil classification, whereas an integrated rural development program requires the use of a general purpose soil classification. An example of the former is an irrigation project aimed at increasing the production of bananas. In this case, soil properties important to water management considerations must be used as differentiating criteria in the development of a specific purpose soil classification. On the other hand, a multifaceted rural development program requires a general-purpose soil classification to assess the suitability of soils for a variety of uses. In this case, soil classes must be defined by attributes relevant to a wide spectrum of management goals.

Several general-purpose soil classification schemes have been developed by different countries to meet their needs. As Smith (1963) noted, a soil classification scheme developed in a particular country is biased by the accidents of geology, climate, and the evolution of life in that country. Its application in other countries can be problematic.

The FAO/Unesco soil-classification system (Dudal, 1968) and the U.S Comprehensive Soil Classification System (Soil Survey Staff, 1975) are now used in many nonindustrialized countries (Conant et al., 1983). The FAO/Unesco system attempts to group the soils of the world. Because of the wide spectrum of soil-forming environments, groups in this system include considerable variability. On the other hand, soil taxonomy was developed to

facilitate soil survey in the United States (Smith, 1963). To avoid ambiguity, soil classes are precisely delimited by chemical and morphological properties. The rigidity of class boundaries and the need for laboratory analysis hamper the successful application of soil taxonomy in nonindustrialized countries. Furthermore, since the current version of soil taxonomy was based primarily on soils from temperate regions, its use in tropical areas may be problematic.

In addition to the FAO/Unesco soil grouping and soil taxonomy, several other soil classification schemes are in use in nonindustrialized countries. The relationships and main features of several of these are outlined by Beinroth (1975), Buol et al. (1980), Butler (1980), Camargo and Palmieri (1979), Conant et al. (1983), Jacomine (1979), and The Soil Survey Staff (1975).

Landform and Relief

Characterizations of landform and relief are necessary to the evaluation of a site because of their influence on climate and soil conditions. In many instances, the relation of plant survival to landform and relief is very close. At a minimum, general landform and relief should be quantified at a macro level.

In general, an area should be divided into "warm" and "cool" sites on the basis of aspect and slope combinations. So-called warm sites in the northern hemisphere are oriented, in a clockwise direction, from southeast to northwest, while "cool" sites are oriented from northwest to southeast. Of course, this situation is reversed in the southern hemisphere. Within a particular aspect class at a given latitude, slope is important when orienting a site to the sun. More gradual and steeper slopes receive less intensive sunlight than do "intermediate" slopes; the hottest and often the driest sites are those that most directly face the sun on a summer day. The amount of solar radiation received on a site is closely related to other factors (for example, precipitation, temperature, and soil moisture) that,

individually or collectively, influence the choice of species, establishment, and the growth of plants.

The position of a site on a slope can also determine the growth potential of an individual plant species. High, convex surfaces, which are frequently subject to wind erosion and weathering, tend to be drier and (in dry climates) warmer than is average for an area. Conversely, low, concave surfaces, on which soil tends to accumulate rather than erode, are generally moister and cooler than average. Midslopes are typically intermediate in these characteristics.

Knowledge of the terrain of a site may be helpful in selecting the most appropriate method of revegetation. For example, level to gently rolling lands are preferred in many instances because ground preparation, if necessary, can be more effectively accomplished with machinery at less cost. Investigation has shown that the cost of ground preparation rises sharply on slopes that exceed 20 percent and is generally uneconomical.

Measures of landform and relief of a site can be obtained from topographic maps, if they are available. On site, aspect is normally determined with a compass, and slope is measured with an Abney hand level (or pocket altimeter). Aspect and slope can be "integrated" into a single measure of site orientation through use of daily solar radiation values for explicit combinations of aspect, slope, and latitude (Buffo et al., 1972; Frank and Lee, 1966).

Water Resources

Range improvement projects or programs on semiarid and arid lands are highly dependent on the distribution and availability of water to me et the water requirements of individual plant and animal species. The seasonal availability of surface water resources must be inventoried in terms of surface flows and impoundments, and seeps and springs. Locations of existing wells and promising groundwater aquifers (for subsequent development)

should also be studied. In general, estimates of potential yields and (as mentioned below) quality of water resources may be necessary in comprehensive range improvement.

Water quality, both physical and chemical, must be considered in the evaluation of a site if, as part of a revegetation effort, artificial watering is required. Individual plant species possess their own "tolerance" to the physical and chemical properties of water. Therefore, when water is to be applied, these properties should be known to maximize the benefits and minimize the detriments of the watering.

Sampling and analytical techniques of assessing water quality are numerous. However, to ensure high-quality results, a prerequisite to the extrapolation of water quality information, only "standardized" methods should be employed. These methods are detailed in Conant et al. (1983), Dunne and Leopold (1978), and Wisler and Brater (1965).

Biotic Components

Plants, animals, and humans comprise the biotic components of a site. The importance of these components and ways of measuring them are discussed below.

Plants

The native plants that are growing on a site, if any, can be helpful in describing the inherent productivity of the site and, from this knowledge, the chances for a successful range improvement activity. The occurrence of “key" plants can often be used to indicate site quality. Also, knowledge of the productivity levels of native plants can “index" levels of production that might be expected from subsequent range improvement activities. Observations of plants that can be important in the evaluation of a site include, but are not limited to, identification of the individual plant species (taxonomy), properties of the individual plant species (for example, chemical composition and particularly, the traditional uses of the plants which indicate important properties), groupings of the

individual plant species into communities, and vegetation-soil-terrain relations.

Of course, interpretations of individual plants and communities of plants must be undertaken in light of the on-site land-use patterns. Use of plant resources as described above can be hampered by land management practices that result in excessive utilization of the plants on a site. Because previous and current land uses may tend to cloud the picture, the ecological impacts of these previous or existing land use patterns on the plant resources must be well known and thoroughly understood.

Plant Indicators Various key plants may be useful in analyzing the capacity of a site for range improvement. To a large extent, the presence, abundance, and size of these plants will often reflect the nature of the ecosystem of which they are a part and, therefore, may serve as indicators of site quality. However, the correlations between "key" plants and associated site quality, which are generally based on detailed ecological investigation, may not always be apparent. Effects of competition among individual plant species, events in the history of plant development (such as drought, fire, and outbreaks of insects), and land management practices can weaken a plant association to the point that it has little predictive value. Nevertheless, in many situations, site quality is sufficiently reflected by plant indicators to make use of the latter in an evaluation of a site for range improvement.

Sometimes, the occurrence of plant indicators is combined with abiotic components of the environment (for example, climate, soil, and topography) in an attempt to describe more accurately the quality of a site. The more factors that are taken into consideration, the better is the estimate of site quality and, consequently, the understanding of the potential of a site for improvement practices. Comprehensive reviews and comparisons of site evaluation, including its history, methods, and applications, have been prepared by Jones (1969) and Carmean (1975).

Productivity Levels Knowledge of the productivity levels (that is, amounts of plant

material present) of plants growing on a site can provide insight into what might be expected from any range improvement practice. Information regarding the total production of all herbaceous plants, taking into account the loss of plant material to utilization, is often used as a "threshold" productivity value. In other words, improvement should be expected to exceed the existing productivity levels. If excessive utilization of the plants has occurred, the measures of existing production may be biased downward.

Volumetric measurements of plants are seldom made to quantify productivity levels. Instead, weights are used to measure the biomass of the plant material present. The weights of plants are most precisely obtained by the clipping of sample plots. But, since clipping is time-consuming and costly, a double sampling procedure is frequently employed to measure productivity on an extensive basis; weights of plants are estimated on all plots, with only a few plots clipped to derive a factor to correct the estimates, if necessary.

Whenever feasible, productivity levels should be obtained on the basis of individual plant species to allow subsequent groupings into plantform categories or grazing value classes for decision-making purposes.

Plant Cover In addition to the productivity or biomass available for utilization, the ability of the plant community to stabilize the site and arrest the soil erosion process should also be determined. Productivity information alone does not provide the manager with this knowledge. The percentage of the soil surface that is covered by plants, either only by the base of the plant (basal cover) or by all above-ground plant parts when viewed from above the canopy (canopy cover), indicates both the susceptibility of the site to erosion and the established dominance of one plant species over another.

Plant Number A plant community might be dominated, in terms of productivity and cover, by one or two plant species, the individuals of which are old and decadent. As these

individuals die, they will be replaced by the same or new species. Data on number of plants of each species may give the land manager an indication of the health (vigor) and reproductive status of species in the community and, therefore, insight as to which species are likely to increase or decrease. Knowledge of this sort will guide the selection of the appropriate range improvement practice.

For more detailed information concerning techniques for vegetation analyses, the reader is referred to Conant et al. (1983), a publication prepared specifically for efforts in nonindustrialized countries.

Other Measurements and Observations To help in the selection of individual plant species for revegetation projects and programs, there may well be other kinds of on-site surveys or observations of plant resources that should be taken. Depending on the goals of the improvement practice, these may include growth forms and plant community structures (that is, vertical layerings); seasonal growth, development, and maturity patterns, including the differences among grasses and forbs, shrubs, and trees; and ecological conditions and trends (Pratt and Gwynne, 1977), as these parameters are influenced by successional cycles and degree of site deterioration.

Animals

Individually and collectively, animals have a major impact on the physical environments and the plant communities with which they are associated, and, as a result, can affect range improvement activities in diverse ways. Depending on the activity, these impacts can be beneficial, detrimental, or both. Some animals greatly influence the ecosystem processes that are basic requirements for plant growth and development, such as nutrient and water cycling. Successional patterns are affected by other animals, by regulating competition, development, and productivity among individual plant species and communities of plants.

A major influence on the success of range improvement activities is the grazing activity of larger ruminant herbivores. However, both the positive and the negative roles that animals play in an ecosystem should be considered in a site evaluation.

Many semiarid and arid lands furnish habitats for wild animals and domestic livestock. Therefore, knowledge of animal types that occur on a site, their distribution and routes of migration, and their ownership or legal status can dictate, to some degree, the options for range improvement.

Animal Types All types of avian and terrestrial fauna (including soil biota) are part of an ecosystem. Difficulties arise, however, in defining the geographic boundaries when more-mobile animals are evaluated. In practice, ecosystems are commonly based on plant communities, soil classification units, or other abiotic features, or combinations thereof, and animals are then "incorporated" into the delineated ecosystems as consumers and secondary users. Mobile animals generally roam over several ecosystems.

Wild animals have varying effects on the ecosystem. Earthworms, arthropods, and ground-dwelling mammals play major roles in the decomposition of organic material. In their absence, the nutrient cycles of a site can be adversely disrupted. Birds are important agents of seed dispersal for many individual plant species. This dispersal activity can be beneficial or harmful to reproductive strategies. Mammals, especially rodents, can also be important agents of seed dispersal in many plant communities.

The grazing activities of the larger ruminant herbivores, both wild species and domestic livestock, have already been mentioned, and are covered in more detail in chapter 6. Grazing is commonly considered destructive, although it can benefit the desired vegetation on a site by removing competitive plants that otherwise may use limiting water and nutrient resources. Grazing activities also prevent the buildup of coarse, unpalatable plant parts and stimulate the growth and tillering of more plant materials.

Techniques of enumerating animal types and their respective numbers, including the censusing or sampling of animal populations, are described in Child et al. (1984), Conant et al. (1983), and Schemnitz (1980).

Distribution and Migration Patterns In addition to knowing what types of animals occur, knowledge of their distribution and patterns of migration can also be important in site evaluation. Uniformly distributed animal populations generally tend to exert uniform effects on a site. On the other hand, a population of animals that is unevenly distributed will frequently have uneven effects upon a site (for example, animals clustered around a wellhead). The distribution of animals is also influenced by their migratory patterns. In general, migration (whether seasonal, yearly, or indeterminate in response to unknown stimuli) can result in cycles of impacts that should be known when planning a range improvement program.

Information regarding the distribution of animals can often be obtained while their kind and number are being enumerated. Migratory patterns, which are descriptive measures, can be determined only through repeated observations of the animals on a site.

Ownership Status The ownership of animals can be important to a range improvement activity, particularly in situations in which the control of the animals is necessary to the success of the venture. In general, the ownership of wild animals, if specified by law, lies with the state, which may assume responsibility for their regulation. However, domestic livestock are often privately owned by individuals or groups of individuals that operate in a cooperative. The ownership of animals must be established, and the responsible parties contacted and their cooperation obtained, if manipulation of the animal populations is considered necessary to ensure the success of an improvement project or program.

Humans

It is necessary to assemble and analyze what is known about the human users of the land

and, of equal importance, what values people attach to the natural resources that will be affected by a range improvement activity. Deficiencies of information in this area can, and in most cases do, constrain the effectiveness of a project or program. Serious conflicts often exist between traditional land management practices and what might be proposed in a range improvement plan. Therefore, it is imperative that proponents of range improvement understand the people who will be affected, and the reasons why the people do what they do (see National Research Council, 1986).

Information regarding human activities, land use in the area of concern, population densities and community structures, and the migration of families and family groups is a minimum baseline for the evaluation of humans. Rural sociologists, ethnologists, cultural geographers, and ethnic botanists, all working at the local level, should be involved in this work.

Integrated evaluations

Two basic approaches are employed in the evaluation of a site, regardless of the purpose: an integrated approach and a component approach, as explained in chapter 4. Abiotic components and biotic components that are important in evaluating a site for range improvement have been discussed in the preceding sections, component by component. Most on-site surveys and observations of natural resources are based on a component approach, although the individual components being evaluated are not necessarily considered in isolation. Within a systems framework, the components that are related to the improvement of a site must be evaluated in an integrated manner. By doing so, all of the elements of an ecosystem, both abiotic and biotic, will be studied to form as complete a picture as possible of a site being considered for improvement.

One final point: many site evaluations fail to include a provision to monitor the changes in an ecosystem that could, subsequently, have an influence on the success of a range

improvement effort. Therefore, to the extent possible, monitoring should be provided to be sure that temporal changes, both positive and negative, are recorded and identified for possible changes in past project management as well as for use in future project planning.

In the preceding pages, much has been said about the various factors that need to be measured and evaluated. How these components are used in evaluation has not been discussed. A computer model is not generally the answer. Some limits may be needed to delineate the range of acceptable conditions.

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Grazing management

In recent years, there has been renewed interest in indigenous management systems, such as the hema system of the Near East (see case study 9). Such systems represented highly sophisticated adaptations to the peculiarities of particular environmental settings. The breakdown of these systems, often as a result of disorienting socioeconomic change during the colonial era, has resulted in widespread environmental degradation. While the principles upon which these systems were based are still valid, changing environmental, socioeconomic, and political conditions present new challenges. In many areas of the world, the most promising approach to rangeland improvement is to complement the adaptations of local populations with relevant experience from analogous areas elsewhere. This chapter discusses grazing management from a Western, technical perspective.

To meet the needs of forage-fed livestock and provide the other products and services from rangelands, these lands must be managed wisely. If they are mismanaged to the extent that plants fail to provide sufficient soil cover, the species composition of the plant communities changes, reducing productivity and increasing soil erosion. Continued abuses can result in severe soil degradation. As indicated in the previous chapter, this does not imply, however, that all grazing is destructive. Some native plant communities have evolved over thousands of years under grazing by native animals.

Not all major plant species have evolved under grazing pressure.

Species that are not adapted climatically should not be considered important components of the range ecosystems. Plants must be adapted for grazing or browsing by animals and for soil protection. The value of all plants growing in an area must be considered. Even small populations of a few species may contribute much to animal performance during a brief but critical part of the year.

Range management involves both range improvement and grazing management practices.

Range improvement generally has greater potential than grazing management for increasing production. Such practices as brush management, revegetation, and fertilization can increase range forage yields as much as tenfold. Manipulation of grazing time and intensity, on the other hand, usually results in relatively minor changes in range productivity.

Rangeland revegetation by livestock manipulation alone is not as dramatic as mechanical revegetation, and it may take more time. On the other hand, it will likely be much less expensive and may be more in harmony with local cultures. Livestock manipulation may involve protection of areas from grazing, deferred grazing, seasonal grazing, rotation grazing, stocking rates, or intensity of grazing, or various combinations of these approaches.

Grazing management concepts

The application of ecological principles to range science often means maintaining or improving native stands of vegetation through grazing management. In addition, range managers may use a combination of extensive and intensive practices; for example, brush management combined with a grazing system, or revegetation and fertilization combined with a grazing system. A range manager can select the degree of intensity for a unit of rangeland depending on the potential of the sites within that unit; economic, social, and political factors; and available technology. Rangelands can be managed for various objectives, attempting to achieve a balance among management and social, economic, and environmental concerns.

Range managers must be flexible and innovative when planning operations on a range unit. Practices successful on one range unit may be less so on the next, or even unsuccessful on a unit nearby. No grazing scheme will eliminate the need to practice all economically appropriate range management techniques. No practice will produce the

desired results if the range manager does not understand and believe in the principles involved, monitor the performance of units and animals, and adjust schedules and livestock numbers to changing conditions.

Forage production on rangelands, though controlled to a large extent by range site characteristics, is critically tied to the health of the root system in perennial forages and to seed production in annual forages. Consequently, grazing strategies must be developed to maintain a healthy root system in perennial forages and an optimal seed yield in annual forages. Specific grazing practices to maintain productivity will necessarily vary with the limitations of the site an d weather during the growing season. Roots can successfully grow and support a forage crop under grazing when the intensity and time of use is properly controlled. Individual plants need to grow, to photosynthesize, and to replace damaged or senescent tissue every year. This can be accomplished by closing an area to grazing during the growing season, by stocking lightly enough that the livestock remove forage at a rate slower than the growth rate of the forage, or by rotating use so that forages are ungrazed during critical periods of the growing season. Any of these approaches can be successful when the specific growth patterns of the forages are known or can be estimated.

Since most rangelands are made up of a complex of species, grazing must consider availability and palatability of the vegetation produced each year. Livestock will not graze all individual plant species uniformly unless the pasture is overgrazed or grazing is carefully designed to produce a uniform pattern of grazing that provides for sufficient vigor to produce the next crop. Within a given site, different plant species will maximize their growth at different times of the growing season. As the plant community develops, there is a continual change in relative proportions of different plants and, therefore, a continually changing availability of forages. Along with the changes in availability, there are changes in palatability among species or changes in palatability related to the growth stages of the constituent plants.

If grazing is unmanaged or managed without consideration of the dynamic nature of the plant community, some forages will be used heavily while others are lightly used or not used at all during the period when interspecific competition is critical. Desirable forages that consistently are at a disadvantage because of differential grazing will lose to the more competitive plants. This will change, and usually reduce, the productivity of the range site. If grazing is designed to take advantage of the natural community dynamics of a range site,

the loss of desirable forages can be prevented by manipulation of the time and intensity of grazing. Grazing may need to be varied within the growing season in some cases, among sequential growing seasons in other cases, or in a combination to most effectively match the livestock with the forage.

Rangeland productivity may decline with grazing unless the practices that reflect certain principles are followed. One of the main principles of grazing management concerns the duration of time that animals are allowed to graze a given area and the timing of this grazing to critical stages of vegetation growth. A second considers the degree of uniformity of use that plants receive as influenced by an even distribution of grazing animals across a given area. A third involves the type of livestock grazed as a means of manipulating plant communities. The most sensitive, and thus the last, main principle that should be addressed, particularly on communal grazing lands, relates to the numbers of animals grazing an area. All of these principles must be applied to one degree or another when prescribing a grazing management scheme.

Time of grazing

The primary purpose of range management is to prevent excessive grazing. This is especially important during the growing season in order to increase the vigor and productivity of existing plants and, eventually, to improve species composition. An

alternative to heavy grazing to obtain use of less desirable plants is to graze a unit during that time of year when less desirable species are more palatable than preferred plants. In South Africa, it was found that the longer the period of grazing, the lower the carrying capacity and the more adverse the effect upon the associated rangelands.

Nutritional quality of forage is highest early in the growing season and declines as the plants mature. Grasses, forbs, and browse are similar in quality in the earliest growth stages. As plants mature, substantial structural changes occur that usually decrease palatability and always reduce nutritional quality. When the seasonal changes are complete, grasses remain good and are often adequate sources of energy for ruminants, whereas shrubs (or browse) are deficient in energy but usually adequate in protein and important vitamins and minerals (many are deep-rooted legumes). Forbs vary considerably but tend to be intermediate in nutritional quality, although they are often unavailable because of weathering and disintegration of leaf tissues. In the dormant season, a forage supply on the range that consists of mature grasses and shrubs will more closely meet livestock nutrient requirements than will a pure stand of either forage class.

The seasonal forage quality and palatability can be managed by grazing programs to some degree. Maturity results from the natural behavior of range plants with respect to the annual moisture and temperature cycle. When a plant is grazed in the growing season, the annual growth cycle will start over if there is sufficient soil moisture to permit regrowth. If enough of the annual evaporation, transpiration, and precipitation cycle has been completed, the regrowth will not mature and thus will cure before the quality has declined. The magnitude of this response will depend on the timing of grazing. On many range sites, it is possible to condition the forage by grazing in the growing season to yield a nutritionally adequate and palatable forage supply for the dormant season with respect to important macronutrients.

Controlling the time of grazing is as important as defining the proper stocking rate and, in

fact, may control the stocking rate. Grazing a perennial grass during the early stages of seed development will invariably stress the plant, and a period to grow without grazing will be required if the plant is to recover from that stress. Conversely, grazing a mature perennial grass offers little stress to the plant. A higher stocking rate can be supported on a perennial grass range grazed largely in the dormant season than if the same range were grazed largely in the nondormant season, though in the dormant season a variety of nutrients would need to be considered for supplementation.

As previously mentioned, grazing can be used to condition forages for use later in the year. In these situations, the effect of timing of grazing may reduce yield while improving quality. The stress on the vegetation caused by the timing of grazing can be acceptable when incorporated into future plans for utilization of the specific pasture. When plants or animals are stressed, their productivity will decline.

In most range ecosystems, the desirable ecologically stable climax species are long-lived perennial plants. Many of these plants are poor seed producers and do not reproduce readily from seed. If these desirable species are depleted by overgrazing or drought, it can be difficult or even impossible to encourage their recovery by manipulating grazing. In a dominantly perennial plant community, however, grazing use can be adjusted to encourage seed formation if seed production is important for reproduction. Similarly, vegetative reproduction of certain species can be encouraged by manipulating the time of grazing.

Desirable perennial plants produced on rangeland must be used moderately during the growing season; thus the old guideline: use half and leave half. Where additional soil protection is required, herbage utilization should not exceed 40 percent. Heavy use of perennial forage plants, followed by prolonged drought, can result in the death of many desirable plants. On the other hand, usage greater than 50 percent is beneficial under some conditions. Ephemerals, often annual plants, generally are grazed by animals

extensively when they are available. The forage crop may vary greatly from one time to another because of precipitation differences. It is not unusual for the annual forage crop on rangeland to vary between 50 and 150 percent of its average productivity.

Distribution of grazing

Proper grazing use of forage plants most often calls for an even distribution of livestock. In the large range units, prevalent in most arid and semiarid areas, it is possible to find serious overgrazing near watering points (figure 6-1) and no use of forage in other portions of the unit. Animal distribution can be improved by (1) increasing the number of watering points (though this must be done carefully, since increasing the number of waterpoints increases the number of cattle and can lead to overgrazing), (2) establishing salting and supplemental feeding areas 1-3 km from watering points, (3) using more fencing or herding, (4) building trails, (5) fertilizing selectively, and (6) using a different class of livestock. Any practice that improves animal distribution will increase range productivity.

Provided that water and protection are available throughout the grazing areas, traditional systems of herding found in many tropical and subtropical countries largely overcome the distribution problem and have usually evolved to use the area for optimum productivity.

Type of animal grazing

Another method of favoring the desirable forage species for one type of animal is to use different kinds of livestock or wildlife to reduce temporarily the less desirable plants.

Animal species use plants in significantly different ways. For example, camels can eat more woody shrubs (figure 6-2) than any other domestic species, roam farther from water to forage, and reach parts of trees that would not be accessible, even to goats. Goats also make effective use of shrubs and are especially adept at selecting leaves and other high-

quality parts of the plants (figure 6-3), but they cannot move nearly as far from water as can the camel. Cattle (figure 6-4) and sheep prefer grass. Sheep, however, will eat more tender shrubby materials and have a preference for forbs (figure 6-5). They prefer short to tall grass and can graze to the base of the plants at soil level. These many differences in eating habits require that projects deal with several types of vegetation rather than with a single species.

Because of their food preferences, animals may also be used to some extent to control the composition of the vegetation. For example, goats and water buffalo may help to control brush. Cattle may reduce the dominance of tall grasses, allowing a greater diversity in vegetation that may favor other animals such as sheep and wildebeest; cattle are grazed in southern Brazil, Uruguay, and adjacent parts of Argentina in order to prepare the rangeland for use by sheep.

Number of animals grazing

The concept of reducing the number of animals owned is very threatening where livelihood and proper herd management, as well as prestige, depend upon the size of one's herd. A more acceptable approach might be to regulate the intensity of grazing wherein time of grazing is more controlled than the number of animals.

Grazing intensity is measured in animal unit months (AUM), which is the livestock concentration per unit area (stocking rate) multiplied by the proportion of time that a unit or portion of a unit is grazed. The intensity of grazing on rangeland forages will always be a pivotal consideration in developing a grazing program. There is, of necessity, a limit to the number of animals that a given range will support. Management will have a major influence on stocking rates, which will be higher as management integrates the biological and economic considerations to provide the optimum plan for a specific range unit. Stocking rates that exceed the carrying capacity of the range may increase livestock

offtake in the short term but in a very few years will lead to declines in the land's productivity and, therefore, substantial decreases in livestock (figure 6-6).

To achieve maximum production per unit area, liveweight gain per animal is reduced. High production, both per animal and per unit area, can be achieved by varying the stocking rate during the grazing season. Relationships between intensity of grazing and livestock production are shown in figure 6-7. This relationship, described by Heady (1975) as he adapted it from Mott (1960) and Bement (1969), has been applied to the Somalia case (Bement, 1981). Stocking rate is related to product per animal and product per hectare.

Individual animal grazing and gain per hectare are shown with increasing amounts of ungrazed or available forage on a conceptual basis. The left side of the figure indicates insufficient feed for animal gains. With increasing feed, animals gain in weight, reaching to a maximum at points A and B. At point C, the animals are in balance with the forage and optimum production of both vegetation and animals is attained. Point C is the proper stocking rate. It can be approximated with relatively few data points on the two curves and continually adjusted as additional data become available. This procedure provides a flexible and practical procedure for determining stocking rates in response to changing forage supplies.

This relationship indicates that individual animal gains are maximized at the lowest stocking rates. As intensity of stocking increases, the gain of individuals declines while the yield per hectare increases. At the point of optimum productivity, the individual animal gains are still high and the yield per hectare is near, but not at, maximum. Further increases in stocking result in deterioration of the range, which eventually decreases the ability of the range to produce. As grazing continues in the overgrazed portion of the range, productivity declines per hectare. If this results in significant soil loss, the original productivity may never be regained.

Grazing management planning

Consideration of the overall management plan, including both range improvements and the grazing scheme, is critical. All practices that are beneficial and economical should be integrated into the management plan.

Range units feature varying characteristics and must be managed accordingly. They may differ in their improvements, such as fencing and water developments, the proportion of various soils and types of vegetation, the numbers and kinds of livestock and wildlife supported, and the recreational opportunities they provide. Cultural, economic, or political conditions may determine the degree of management applied. As conditions change or technology improves, the range manager may decide to modify management objectives.

Wide fluctuations in the forage crop, in both the amount present and the kind of plants that are prominent, are common. When range operators adopt a grazing scheme, they may allow for flexibility as to time of grazing and deferral from grazing as well as the number of livestock involved. This flexibility may be the difference between success and failure in the grazing scheme. Both plant and animal requirements must be considered. For example, some range units may be manipulated to furnish highly nutritious forage during a period when livestock need greater nutrition. The critical growth stage of plants also varies over time because of weather conditions. Because of grazing history and weather conditions, it may be more important to defer grazing in some periods than in others. Range units should be grazed when the key plants are damaged least by grazing and when the forage best meets the nutritional requirements of the animals. In many cases, this means grazing in no set or predetermined sequence.

Many indigenous pastoral systems in Africa and Asia provide excellent examples of flexible response to changing rangeland conditions. A description of the pre-Colonial management system centered in the Masina region of Mali, prepared by Malian range scientist M.-L. Ba,

follows this chapter.

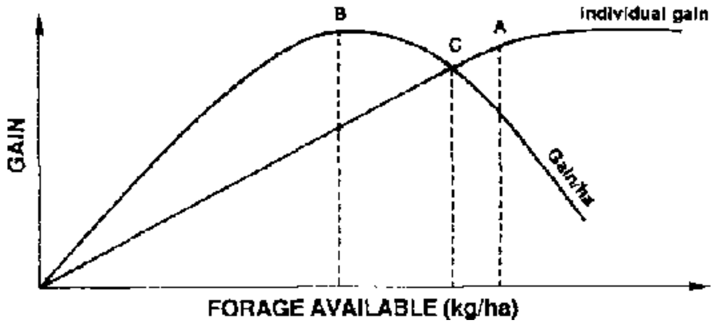

FIGURE 6-7 Relationships between intensity of grazing (forage available) and livestock production. (Source: Bement, 1981)

Grazing schemes should also be tailored to conform to a variety of vegetation types, soil types, physical facilities, and herd-management plans. There may be considerable variation among ranch operations in the specific details of operating a certain grazing scheme. In some instances, it may be desirable to use a particular grazing system to attain a certain measure of improvement and then change to a different system for maximum net returns while maintaining the resource. South African research suggests that the advantage of multiunit schemes is their greater flexibility in permitting the range manager to alter the grazing scheme as the precipitation varies and as the specific requirements of each unit dictate.

Livestock control is absolutely the most important factor in successfully managing grazing on rangelands. If grazing is not controlled to meet the objectives and requirements of the grazing plan, the plan will fail. Livestock control is usually carefully organized by farmers and herders in tropical and subtropical countries. In many areas, the extensive

overgrazing that dominates range use results from a decision to graze during a given time in a given place, not from a lack of livestock control. Consequently, grazing controls within planning specifications can only be accomplished through joint decisions of herders, livestock owners, range managers, and government officials. The key to livestock control is, of course, an understanding of costs and benefits of control.

Grazing management systems

Grazing systems or methods can help improve distribution irregularities for widely ranging livestock, can improve rangeland forage conditions by protecting plants during critical growth periods, and can improve livestock performance by ensuring that plants are utilized at the best times and sometimes even improving their quality for livestock late in the grazing season.

Managing the range forage resource becomes a science of balancing the plants, their requirements for growth, and the needs of animals for nutrients that are best supplied by immature plant tissues. Grazing programs that maximize animal benefits are most stressful to plants, and those that maximize plant growth are least beneficial to animals. Design of grazing management programs must consider the long-term maintenance requirements of the forage base and recognize that it may not be possible to meet all of the nutritional requirements of livestock from the range. A grazing program can, with necessary nutritional supplementation, be designed for any range to be productive of the right kind and number of livestock and at less cost than production systems based on other kinds of forages.

Most grazing programs will need to be supported by a variety of developments. Holding pens and corrals are necessary to confine livestock for animal husbandry programs (figure 6-8). These structures can be easily constructed of native brush or new materials such as nylon mesh fences that are easily portable. Dipping vats may be required to control

parasites (figure 6-9); portable vats are commonly used because they increase management flexibility. Water structures such as wells, catchments, or springs are necessary (figure 6-10), and these can be placed in each pasture or at a central facility if animals are close-herded. Fences are required to confine animals to specific pastures if herders are not used in a grazing system. If land control and management do not exist, however, fencing is a costly and futile exercise. Finally, access is needed for transportation of supplies and products.

Use of a grazing system may alter the species composition of a plant community. An increase in palatable plant species may permit increased use of the range resource. Nevertheless, the benefits obtained from improved grazing management practices are relatively few compared with those possible from manipulative range improvements.

Long-duration grazing refers to continuous grazing, where livestock are left in one pasture for the full grazing season or for periods of several months to more than a year. The periods of deferment from grazing may also extend from several months to more than a year. Single herds or several herds of animals may be involved. Conversely, short-duration grazing involves one or a few herds of animals that are moved to a new unit every 2 to 28 days. Deferment from grazing extends from 42 to 180 days. Both grazing and deferment periods are important.

Long-duration grazing often requires a minimum outlay of capital for fence and water developments. Management inputs are also relatively minor because decisions on livestock numbers and when to move the animals to another unit are not critical so long as the permanent range resources, both plants and soils, are not irreversibly damaged.

Short-duration grazing, on the other hand, may require a larger outlay of capital for fence and water developments. Decisions on movement of livestock are critical because young plants should only be grazed once before receiving some deferment from grazing.

Therefore, both the risk and management requirements are greater with the more intensive shortduration grazing. However, higher effort management inputs, whether they involve a grazing system or an improvement practice, do not guarantee higher returns to the operator.

Continuous, year-long grazing in perennial plant communities can be successful for a number of reasons:

· Herbage production depends primarily on summer rainfall, and monthly summer herbage production can vary tremendously.
· Most species are grazed by cattle at one time or another.
. Many "increaser" species, those that increase in number under grazing pressure because they are often less palatable and are not selected as frequently by the grazing animal even though they are excellent plants for grazing, may be productive under certain environmental conditions.
· Cattle compete with natural losses of forages, and with other forage consumers such as rabbits, rodents, and insects.
. Young forage and regrowth forage are more palatable and more nutritious than mature forage.
· Grazed plants save soil water for later green growth.
. Favorable growing seasons, combined with proper grazing management, allow ranges to recover a desirable species composition.

The success of year-long continuous grazing in perennial plant communities is further enhanced because grazing is light during the growing season, and lighter stocking per unit area means less soil compaction by livestock when the soil is wet.

Some of these same reasons could also be attributed to rotational schemes. Under rotation systems of grazing on perennial rangelands, units have sustained increased numbers of

livestock and have shown greater improvements in range condition than have units grazed continuously on a year-long basis at various stocking rates. An advantage of deferred rotation is the infrequency of livestock movement required. Under the system, livestock must adjust to the new forage of each grazing unit only once every grazing sesson.

A rotation system using as many as 16 units, each grazed 2 weeks or less by 1 or 2 herds, has been studied in South Africa and Zimbabwe. Livestock are not moved at any set time, nor are the units necessarily stocked in sequence. When plants are growing rapidly, the livestock are moved frequently, perhaps as often as every 5 days, to prevent injury to plants. When the plants are dormant, livestock movement is determined by the nutritional requirements of the animals.

An evaluation of grazing systems in southern Africa concluded that the following principles are important:

· Slow rotation systems do not eliminate selective grazing.
· In a 16-unit, high-intensity, low-frequency system, 12 units are grazed once for about a 2-week period every 6 months, and the 4 other units can be used as reserve grazing in dry years or given a full year's rest in years of average precipitation.
· High-intensity, low-frequency grazing is designed primarily to combine sufficient rest with efficient use to permit rapid restoration of denuded rangelands. There is less advantage to using this system on rangelands in good condition.
· Range restoration may be retarded and greater abuse may occur if stocking increases more rapidly than indicated by herbage production.
· With variable precipitation, no system can eliminate selective grazing if set grazing periods and stocking rates are maintained, but high-intensity, low-frequency grazing reduces selective grazing.
· High-intensity, low-frequency grazing, because it is an intensive system, may require more labor, fencing, and water development, but the relatively high capital investment

required to implement this grazing may be justified by the resulting increased carrying capacity.

Short-duration grazing or "cell" grazing uses some of these same principles. Cell grazing, however, requires even shorter periods of livestock grazing when range plants are actively growing. This is a one-herd system wherein the units can be (but need not be) laid out somewhat like a wagon wheel. In the center are pens and watering devices. Livestock are moved to the next unit to be grazed by opening the gate, which is located at the hub, and letting the livestock move themselves. Frequent movement among units prevents livestock from abusing individual plants.

All of these grazing systems and approaches have merit and all have been successful. On the other hand, all have failed when applied without concern for either plant or animal production requirements. In the final analysis, a specific range unit will produce most economically when all its unique characteristics are specifically considered. Prescription grazing to adapt grazing use to the site, to the needs of the people, to emergencies like drought, to market demands and all the other factors that affect the ecosystem and its use will result in protection and stability of the investment in the range and in the livestock. Only when grazing is managed by wellthought-out prescriptions for each grazing unit can the range manager be considered successful.

Livestock management

To achieve the livestock benefits from any grazing program, a workable program of animal husbandry must be in place. This includes animal health to prevent and cure disesses and parasite problems. Many tropical and subtropical countries have national campaigns to provide inoculations for endemic diseases and to provide advice on animal husbandry to the farmers and herders.

In planning the grazing use of the rangeland, one must consider the total annual

nutritional needs of the herds with respect to lambing or calving seasons if animal reproduction is attempted throughout the year. The availability of sufficient quality and quantity of feed will dictate the probable success in livestock production. In many countries, the structure of the herd includes lactating and dry females, young growing animals, and mature animals. This is a normal situation since the livestock may be the "bank," and the offtake is marketed throughout the year. A lactating animal requires

a more nutritious diet than does a dry animal. If the herd is largely in the lactation production phase or, conversely, in the maintenance phase of the animal production cycle, the needs for nutrients from rangeland can be reasonably estimated. Herds that consist of growing, dry, and lactating animals should be fed according to the needs of the growing animals, unless special supplementation can be provided to those with the greatest nutrient demand. It is generally agreed that the animals with highest nutrient demand set the base nutritional requirement of the herd. In tropical and subtropical countries, however, the demand for quantity of forage is so great that little attention is paid to quality. A range manager who can find a way to upgrade the diet quality in growing or lactating animals could greatly increase productivity.

The range probably cannot provide the quantity or balance of nutrients during the entire year. If animals are fed when rangeland forage is deficient, then a grazing program should be developed to complement the feeding period. It may be necessary to provide only a portion of the nutrients during part of the year, and feeding can be replaced with supplementation that can bring the animal's nutritional level up to minimum requirements. Supplementation will be less costly than feeding and, when correctly used, will provide for excellent livestock performance on ranges that without supplementation cannot meet the minimal needs of the livestock. Supplements can be worth many times their cost since they add what is needed to provide a correctly balanced diet, but supplementation is not a normal practice in most countries because of the comparatively high cost of desirable supplements. Furthermore, in remote areas, the cost of transportation of supplements to

the herds is often prohibitive.

Since rangelands by their nature exist in areas with variable and extreme climates, a grazing program must have some plans for the expected but unpredictable droughts or storms. Forage reserves can be of utmost importance over the long term. Excellent use of shrubs and cacti is being made in many countries where the grazing demands exceed supply in extreme years. Forage reserves can prevent catastrophic losses if they are predictably planned for and used (figure 6-11). Although some use of forage reserves during normal years may be appropriate, it is critical that they be sufficient to ameliorate the forage losses that are sure to come to the semiarid and arid rangelands during drought. Many forage reserves are considered a luxury, since in many countries demand exceeds supply of forage in normal years. The hema system of North Africa and the Middle East

is a management strategy from previous centuries that still has merit for maintaining forage reserves for the expected drought years.

The herima system in Mali

The herima system is a variant of the hema system. It was introduced into the Masina Region of Mali in the 1820s by the Pulo cleric, Shehu Hamadu. The system is belived to have been derived from management systems established earlier in the Sokoto Region of Nigeria. The herima system was installed to:

· Regulate the use of the upland rangelands;
· Reduce animal-disease hazards very common in the swampy lowland areas; and
· Reduce conflicts between farmers and pastoralists.

The problems of the Masina Region have not changed greatly since the last century. Every year, more than 20,000 km² of land associated with the Inland Delta of the Niger River are

temporarily

flooded and, as a result, the lowlands can support livestock only during periods when the swamps dry out. Infestation by various parasites and insects associated with the swampy conditions is a major cause of animal loss. The reduction of grazing areas during the period of inundation prompted overgrazing around villages. The insecurity of livestock herds outside the Inland Delta Region during the wet season, from July to November, had increased this deterioration of rangelands. Since the Inland Delta Region had great potential for rice cultivation, many conflicts occurred between farmers and pastoralists.

Shebu Hamadu developed the herima system as a strategy to solve a number of problems in his kingdom. There are several characteristics of the herima system. For example:

· Grazing zones were allocated for milch cows and were placed under the control of the community.
· Large grazing areas were allocated for use by dry herds, which come from everywhere.
· Transhumance was established to reduce disease hazards. This was possible only when Shehu Hamadu organized troops to protect pastoralists in regions not controlled by the kingdom of Masina.
· Rules were formulated to regulate the use of the rangelands and reduce conflicts.

The herima system was readily accepted because it was sanctioned by Islam, and Shehu Hamadu ruled his country according to the tenets of the Qur'an and the Hades. Some of the results of the herima system can be seen even today. Among them are:

· Respect for the organizational structures developed by Shebu Hamadu endures because these structures have religious support and the organization responds to the needs of the people in the area.
· A high-intensity land use pattern is in operation that includes the entire range of available resources.

· The calendar for the use of rangelands and the migratory routes established in the time of the Dina (herima) are still respected.
· A strong sense of ownership has developed among pastoralists who control the use of their communal herimas. Pastoralists also are in charge of improving these lands.
· Land is allocated for the production of rice, which is the major staple food in the Inland Delta Region.

Pastoralists living in the Inland Delta Region consider the herima system as essential for the use of the resources, and are strongly concerned with its gradual deterioration, which has resulted from several factors:

· Livestock build-up both within and outside of the Inland Delta Region as a result of the recent progress in disease control;
· The government policy of abolishing the right of ownership for the grazing lands, which allowed pastoralists who were strangers to the areas not to respect the system and even use areas reserved for milch cows;
· The development of nonintegrated projects that give higher priority to rice production and thus decrease the area designated for grazing and the migratory route (resulting in conflicts between pastoralists and peasants);
· The deterioration of unflooded rangelands surrounding the Inland Delta Region, which reduces the animal waiting period before entering the region upon returning from the Sahel; and
· The 1968 drought, which substantially reduced the forage potential of the flooded region. As a result, many pastoralists left their traditional grazing areas.

In summary, the herima system can be considered to be an effective system for the natural resources of this area. Its success can be explained by its relevance to the social, religious, and environmental systems of the area.

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Rehabilitation techniques

Establishing plants on the range

It may be useful to consider the practices used in range management in terms of the relationships shown in figure 7-1. By so doing, levels of range productivity can be seen as functions of environmental, cultural, social, and political factors, as well as the availability of technology. It is important to understand these factors when determining effective approaches to range rehabilitation.

Extensive Practices

Range rehabilitation techniques vary greatly. Examples of extensive practices for rangeland management are the manipulation of grazing and the use of fire. These practices may require fencing, water supply development, and/or fire lines, but they generally require little management and do not risk the loss of the existing vegetative

cover (as do some of the more intensive manipulative practices). Extensive practices are low cost, but opportunities to increase production are correspondingly limited. Other practices, such as water management, require a higher level of input than the manipulation of grazing or the use of fire, and are, therefore, intermediate between extensive and intensive practices.

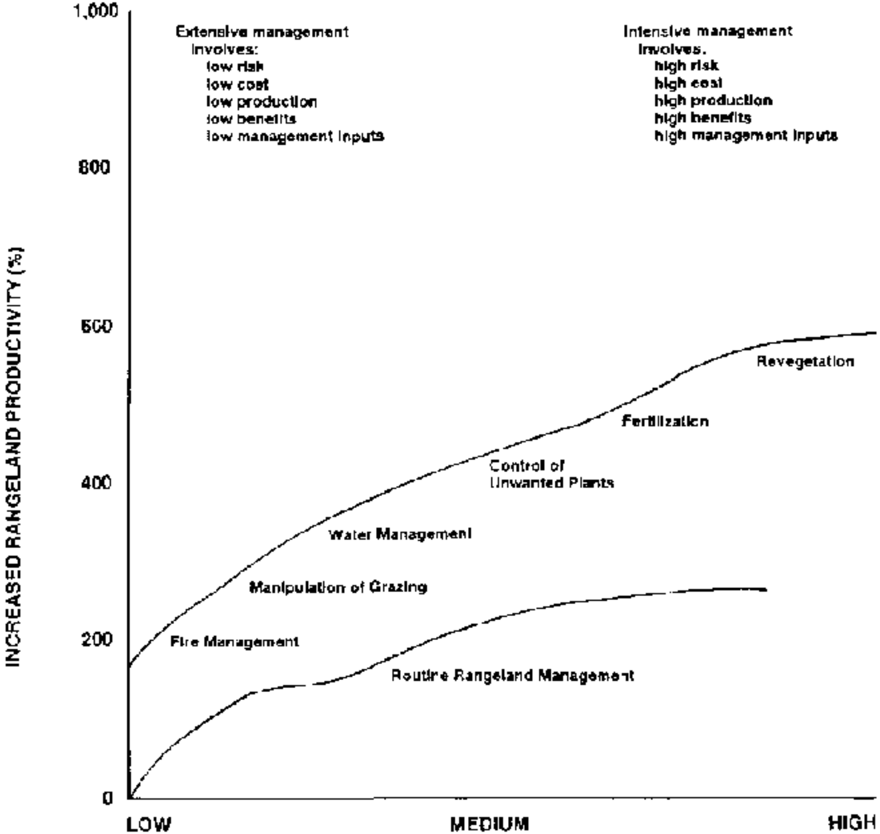

FIGURE 7-1 As site potential improves, the opportunities for increasing production are enhanced. By application of range improvement practices under intensive management, productivity can be significantly increased.

Intensive Practices

Drastic manipulations of range ecosystems are sometimes necessary. The use of intensive practices to control unwanted plants and to revegetate with desirable plants may be necessary because of the invasion of unwanted plants, the effects of severe droughts, past abuses by foraging livestock and humans seeking fuelwood, or the desire to change botanical composition to increase productivity on all or part of the range. The risks in using plant control or revegetation are high because even if attention is given to every detail, the practices may not have the desired effects. A thorough understanding of the range ecosystem and factors of production, as well as a commitment to high management inputs, is required if these risky, costly practices are employed. During the planning phase of intensive range rehabilitation programs, site potential must be carefully assessed.

Subsequent consideration might be given to the use of plant species from other locations in the world that may be more productive or better able to meet a particular requirement than the plants currently growing on the site. Generally, control of unwanted plants, revegetation, and fertilization are intensive practices for rangelands.

Combined Practices

Few, if any, land managers use intensive practices exclusively on a unit of rangeland. Rather, intensive and extensive practices are combined. To increase plant production and soil protection, each unit of rangeland must be managed to maximize economic, political, and social factors while maintaining or improving the basic resource. For example, in the Northern Great Plains of Canada and the United States, this may mean seeding part of the range unit with Russian wildrye Psathyrostachys juncea) and standard crested wheatgrass (Agropyron desertorum), and using nitrogen fertilizer on both native and introduced species. In portions of the Northern Plains, the best practices may include judicious burning of some native rangeland areas and plowing up the native sod on some of the

better sites and seeding wheat for forage, or for forage and grain.

On the semiarid southern Great Plains of the United States and the associated grasslands of Mexico, a useful strategy may include seeding weeping lovegrass (Eragrostis curvula), side-oats grama (Bouteloua curtipendula), common wheat (Triticum aestivum), and Sudan grass (Sorghum sudanense). In the arid portions of the southwestern United States and northern Mexico, efforts to increase range productivity sometimes include the control of mesquite (Prosopis spp.) and tarbush (Flourensia cernua), and seeding with Lehmann lovegrass (Eragrostis lehmanniana) and Boer lovegrass (E. chloromelas), and fourwing saltbush (Atriplex canescens). On some rangelands dominated by big sagebrush (Artemisia tridentata), control of the sagebrush and seeding with fairway crested wheatgrass (Agropyron cristatum) results in greater productivity and soil stability than would be obtained without sagebrush control and seeding. In some instances, composition of plant species may be manipulated to improve wildlife habitat, while at the same time maintaining or improving livestock production. Suitable proportions of trees, shrubs, and grasses in tropical and subtropical rangelands would, of course, be determined by the characteristics of the environmental system considered, as well as by the specific requirements of the forma of livestock being managed. For example, trees and shrubs increase in importance in low rainfall regions and in regions in which livestock inventories contain high proportions of browsers, such as goats and camels (Le Hou�rou, 1980).

The most economical method for improving deteriorated grazing lands is through natural means, that is, methods that do not require the planting of desirable species. This may be accomplished by control of unwanted plants, concentrating moisture or harvesting precipitation, or by grazing management. Grazing use of desirable plants is discussed in more detail in chapter 6. If natural revegetation is not feasible, the planting of desirable vegetation may be needed.

The machinery used as examples in this chapter can be expensive, difficult to obtain, and costly to operate and maintain. However, these examples may provide an opportunity to develop inexpensive and innovative techniques and simple equipment that employ the concepts upon which the more expensive equipment is based. Whether natural methods of revegetation or artificial planting are used depends upon the residual vegetation. In any case, the use of inexpensive and innovative techniques must be maximized.

Natural revegetation

For natural revegetation to be effective, there must be a residue of desirable plants to take over and occupy the site. More importantly, reduction of unwanted plants will not result in a stand of desirable plants if they do not already exist at the site. Undesirable vegetation that would severely compete with the establishment of desirable vegetation may have to be reduced or eliminated. Natural revegetation can occur quite rapidly following control of unwanted plants.

Plant control in range management involves reduction of unwanted or undesirable plants that have invaded or increased in a plant community. The migration of certain species out of their normal habitat is a major problem on rangelands in arid and semiarid regions. Each species or plant association has a habitat range to which it is naturally restricted. The environmental factors in a given habitat favor certain plant species and plant associations. This has the effect of confining the favored species and associations to the habitat type and rejecting others, but is true only in an undisturbed situation.

Plant species or plant associations are released from their habitat range restrictions by reducing the adjoining better adapted species or plant associations. This reduction or elimination of competition can be brought about by "continued disturbance." The more common types of disturbance are frequent burning, drought, and continual and excessive harvesting. The greatest and fastest change can be caused by two or more factors acting

in conjunction. Drought in conjunction with excessive harvesting, for example, has been a leading cause of disturbance in many areas of the world.

Control of unwanted plants will make more water available for the reproduction and production of desirable vegetation. This may be accomplished by chemical, biological, or mechanical means; by judicious use of fire; or by the use of certain animal species.

Control by Planned Fire

The use of fire is best known in relation to "slash-and-burn" agriculture in many tropical countries. This approach, if misused, is generally not beneficial in terms of stabilizing the long-term nutrient base. However, for subsistence agriculturalists, it is the easiest and cheapest way to clear land of unwanted vegetation, drive out game or predators and snakes, and provide the first crop with a flush of nutrients from the ash.

Rangeland burning may be designed to fit one or more objectives:

· Increase or improve livestock for age by eliminating some competing plants.
· Reduce litter and stimulate growth of desirable forage plants.
· Improve wildlife habitat by opening up dense plant cover while retaining diversity and adequate escape cover or nesting sites.
· Reduce high volumes of fuel, which lowers the chance of catastrophic wildfire in forests and scrublands.
· Improve visibility of livestock and wildlife after planned burning of certain ranges, especially in dense tree and shrub areas.
· Reduce the labor costs of handling livestock.
· Reduce predation losses in general.

Follow-up management after a prescribed burn differs in several ways from an emergency treatment that is usually applied following wildfires. The frequency of repeated burning is

critical and, in general, frequent burning is undesirable as a management tool. Because prescribed fires are planned with specific goals under constraints that will assure minimum damage to plant cover and soils, much less injury to the site occurs. With proper planning for range improvements (including seeding where needed) and a grazing strategy to accommodate the prescribed burn, there should be little disruption of livestock operations. After wildfires, management objectives often are limited to minimizing expected damage from flooding and erosion, and the repair or replacement of range improvements (Jordan, 1981).

Management of burned areas can be directed to take advantage of the woody plant control caused by fire. Because wildfire is likely to cause greater damage to desirable plants and sites, such benefits are costly (Arizona Interagency Range Committee, 1977).

Effects on Soil

Depending on its intensity, fire may have far-reaching effects on soil characteristics, erosion, water yield, and plant succession. Removal of the litter cover, often exposing mineral soil, subjects the surface to the impact of rain; sealing the surface soil increases overland flow and attendant soil loss. In grassland or mixed grass-shrub areas, however, there is seldom enough litter to fuel catastrophic fires; light rapid burns, characteristic of grassland, seldom modify surface soil structure or seriously inhibit infiltration as do intense burns in forest, woodland, or chaparral. At the same time, fire seriously inhibits growth of woody plants.

Burning may significantly affect nutrients in range soils. Burning sometimes provides a temporary increase in the supply of nitrogen, phosphorus, and sulfur available for plant growth. Because nitrogen is frequently a limiting factor, especially on brush-supporting soils, the addition of even small amounts of available nitrogen may have a profound effect on revegetation.

Certain physical properties of soils may be adversely affected by burning. Particularly on forest ranges where slash and litter make heavier fuels, or in a thick scrub, intense fires may decrease soil aggregates and porosity and increase bulk density. These results usually reach a peak in the first or second postfire years, then disappear within about 4 years. A temporary increase in overland flow and erosion may be expected where the intensity of burn causes major changes in soil structure.

Some moderately permeable soils may develop resistance to wetting as a result of burning. This characteristic frequently has been observed as a result of fires in scrub, woodland, or forests where much fuel has accumulated. Apparently, a hydrophobic material moves downward in the soil and condenses on soil particles, greatly retarding percolation.

Infiltration also may be reduced if this water-resistant layer is at or near the soil surface. In any case, the "nonwettable" character may last a year or more, and may be a prime factor in the typically high runoff and erosion rates observed following fires on steep slopes.

Pattern in Vegetation

Most ranges subjected to random or intermittent burning are not uniform, and the vegetation comprises a variety of species, age, and density classes. Burn intensity varies greatly from spot to spot, and "skips" may occur where fuels were lighter, or where perverse winds altered the fire path. The resulting habitat diversity may be highly beneficial to wildlife, livestock, and landscape aesthetics. These benefits may be reduced or may be absent, however, following catastrophic wildfires.

Fire-Tolerant Species

Certain species are wholly dependent on fire, and tend to disappear from the plant

community in the absence of burning, because their seeds require heat scarification to germinate. Forbs, seldom found on unburned ranges, may become abundant for a few postfire years, then decline abruptly. Other species may adapt to occasional burning by vigorous production of crown or root sprouts. Some shrub species may regain dominance quickly after intensive fires. However, young seedlings or sprouts are more susceptible to burning damage, and frequent fires could keep them in check (figure 7-2) (Reynolds and Bohning, 1956; Humphrey, 1962; Goumandakoye, 1984).

Large bunchgrasses can be damaged more than smaller bunchgrasses because more fuel is present, the fire lasts longer, and heat penetrates deeper into plant tissue of the larger plants. The presence of soil moisture retards heat buildup in the base of grass plants. However, the most effective control of a shrub might not be attained unless the soil is dry. Grasses tend to be more fire resistant than shrubs because of protected growing buds near the surface, and dormant grasses are more resistant than those having active growth.

Fire can be very effective in controlling nonsprouting shrubs such as sagebrush, but is only partially effective in controlling sprouting species, such as creosote-bush (Larrea tridentata) (Jordan, 1981).

Burning may affect the palatability and availability of forage for both livestock and wildlife. Cattle tend to congregate on recent burns, largely because of the accessibility of the tender, succulent new growth and the temporary communities of forbs that commonly develop in the early postfire periods. The use of weeping lovegrass, for example, may increase more than 50 percent after a winter burn (Klett et al., 1971).

Fires in productive grasslands may occur rather frequently; in less productive areas, burning may be possible only under unusual circumstances. Because grass crowns regenerate quickly after burning, light fuels soon accumulate and many areas can be reburned in as little as 1-3 years. On shrub-dominated ranges, however, this is not so.

Usually, fuel accumulates more slowly, and, once burned, such areas may be relatively "fireproof" for 15-20 years. For example, ponderosa pine (Pinus ponderosa) ranges may be reburned on a 6- to l0year schedule.

Topography

As the steepness of the slopes increases, the rate of fire spread increases. The upslope rate is favored because of convection (the rising of hot air currents) and the more intense radiation that occurs on the upslope side of the fire. Winds tend to move upslope during the day and downslope during the night. Vegetation in depressions is more readily burned because the depressions are subject to wind tunnel effects.

Fuel

Sufficient fuel must be present to carry a ground fire, and under ideal conditions this should be at least 700 kg per ha. The surface-to-volume ratio affects the rate of combustion. A high surface area of small-sized fuel releases heat quickly; that is, the area has a high heat intensity. Larger fuels burn with less intensity but for a longer time. Intensity and duration are the controlling influences on plants and animals. Fire duration is related directly to total heat yield and fuel quantity, and indirectly to intensity. heat penetration into soil, bark, and other plant tissue increases as fire duration increases. Penetration is by conduction - the slowest rate of he at transfer. In addition to size and amount of fuel, environmental temperatures and moisture levels need to be prescribed within rather narrow limits (Jordan, 1981).

Weather

Weather patterns before, during, and after a burn must be considered in developing the prescribed control burn management plan. Of the three elements necessary for combustion - oxygen, fuel, and heat - fuel and heat can be manipulated by prescribing the

weather conditions to be met during the burn. Before combustion can occur, the fuel must be raised to the appropriate temperature. All moisture must be removed before this temperature is reached, or else temperatures remain near the boiling point of water. Thus, fuel moisture, relative humidity, and temperatures are critical elements of weather that must be within narrow limits preceding and during a prescribed burn. While the cooling effect of water or moisture on a fire is elementary knowledge, its overall effect on a large fire is much more difficult to predict.

Air Pollution

Air quality near large urban centers is apt to be marginal at best, and any land management activity that tends to add significantly to the pollution is undesirable. Prescribed burning of extensive areas can be planned when fire weather forecasters predict airflow away from urban centers to avoid stagnation and/or mixing with polluted air layers. Most range burning involves relatively light fuels, and unless areas are very large, the air pollution - mostly from particulates - tends to be rather transitory.

Particulate matter from man-made fires can be a principal source of condensation nuclei necessary for the production of clouds and precipitation. Forest and grassland fires also yield charcoal, ash, and other products having a great diversity in form, structure, porosity, and absorptive capacity. These products are very different from those produced by the internal-combustion engine and by burning oil, rubber, or plastics (Arizona Interagency Range Committee, 1977).

Water Quality

Rangeland burning has not seriously affected water quality. Water quality studies have shown that initial conversion of chaparral to a grass-shrub range, for example, may temporarily increase nitrates in runoff to high levels, but these peaks do not last long and apparently are confined to the first or second year. Nitrate concentration then drops to a

relatively low level (from 10 to 16 parts per million), and occasional reburning of the light fuels has little or no effect on nitrates. No significant increases have been noted in phosphorus, calcium, or total dissolved salts (Arizona Interagency Range Committee, 1977).

Erosion

Wildfires often result in massive sheet and gully erosion, but prescribed range burning is much less of a problem because it is planned in advance. For example, steep, heavily wooded slopes that produce heavy sediment loads when burned, usually are not included in range burning plans. On such slopes, wildfires tend to be more severe, and leave little residue to provide soil protection.

Even the most carefully planned and executed range burn may produce sediment. Sediment yield declines rapidly, however, and even after wildfires, yield drops to near pre-burn levels within 3-5 years (Pase and Lindenmuth, 1971). Establishing a good grass cover early and subsequent conservative management virtually assure soil stability and low sediment yields on moderate slopes.

Effects on Wildlife

Well-planned prescribed burns may benefit wildlife. By maintaining a variety of vegetation, including brush islands of various sizes and ages, a highly diverse habitat can be provided. Habitat diversity encourages species diversity. Leaving shrubby areas of adequate size as escape cover and providing a number of serial stages of post-burn vegetation generally benefit both game and nongame wildlife (Bock et al., 1976).

Aesthetics

People with a limited understanding of the role of fire in the development of natural

communities see a newly burned forest or range area as land management at its worst. They find the bare, blackened soil with occasional burned stubs of shrubs profoundly disturbing (figures 7-3a and 7-3b). However, like a plowed field or a homesite under construction, the disturbance does not last long. From a positive point of view, many serial plant communities, including some of the most colorful, exist only during the brief postfire recovery period; without fire, these communities would disappear forever (Arizona Interagency Range Committee, 1977).

Planning for Burning

The steps taken to develop a prescribed burn are planning, preparation, burning, and post-burn management. Technically qualified help must be available. Participation and cooperation of technical help with all interested persons adds to adequate planning. Planning provides for adequate preparation, which in turn promotes a successful burn. Burning should not be done unless planning indicates it is the most practical method in comparison with other management objectives or brush treatment methods. The area must have the potential to be improved. The costs of burning, such as labor, equipment use, supplies, and short-term loss of forage, should be considered. The size and shape of the area should be such that burning can be completed within the allotted time. In the United States, areas up to 400 hectares approach maximum cost effectiveness and manageability for daily burns.

Preparation includes the construction of firebreaks, fuel-break systems, and the placement of fire lines. For better control, fire lines are commonly started on ridgetops. Fires should not be started in valley bottoms but rather 10-100 m upslope. Various topographic features such as streams, roads, and old burns may be used as boundaries to control burns. Up-to-the minute spot weather forecasts are needed to determine wind velocity, relative humidity, and temperature. Wind speeds of 5-15 km per hour are desirable, but burning during higher velocity winds should be avoided. Finally, public information is

important. It is better to have an informed public than to try to justify the burn to a concerned public after the fact.

The actual burning can be conducted by several ignition designs. The general principle is to have cool fires on the perimeter and hot fires in the center. Most designs start the fire 15-30 m inside the fire line. The sequence of ignition varies according to fuel, topography, and weather conditions. It should be remembered, however, that one fire tends to draw another fire to it through convection and radiation processes. There is no substitute for experienced help in conducting a prescribed burn.

Post-burn management objectives must be part of the prescribed burn project. Fire alone seldom attains the management objective. Herbicide treatments might be necessary to control regrowth of undesirable species. Where feasible, selective grazing by deer or goats can suppress sprouting. Seeding may be necessary to obtain the desired cover and erosion control. Grazing control also will be necessary to obtain adequate protection of the range until stand establishment (Jordan, 1981).

Benefits

The benefits of a range- burning program remain for varying lengths of time. The following can be considered directly or indirectly beneficial.

Increased Forage Production Increase in forage production is probably the main reason for range burning, usually to suppress undesirable woody plants. Burning may be insurance against some future decrease in carrying capacity due to woody plant encroachment, or planned as conversion from a brush to a grass-shrub range for increased forage production. Benefits may last 5-10 years, seldom longer.

Improved Forage Quality Forage quality may be improved because of the higher nutrient content and digestibility of the regrowth, or because of improved species composition.

Better Utilization and Livestock Distribution Utilization and livestock distribution may be improved. Reduction or retardation of woody plant growth permits better distribution of stock and more uniform forage utilization. Another benefit is the reduced manpower needed to work livestock, especially in areas that were formerly dominated by a dense shrub cover.

Increased Water Yield Significant improvement in water yield has been reported from treatment of some chaparral ranges by reducing transpiration losses. Most range burning, however, improves on-site water (soil moisture) savings and use (McKell et al., 1969).

Improved Wildlife Habitat Wildlife can benefit from the increased diversity of habitats following well-planned range burns. Wildlife food may be increased. Non-game birds and mammals also may benefit from the increase in habitat diversity caused by careful range burning.

Harvesting Precipitation

Natural revegetation is improved when more water is made available to desired vegetation. Poor infiltration of water into the soil is a key physical process. Often the soil surface can be treated to improve infiltration and prevent erosion, while the desired vegetation is increased or maintained.

Practices that help concentrate moisture and increase percolation in the soil include pitting, ripping, and contour furrowing (table 7-1). These practices, as discussed here, are used on rangeland not in need of direct seeding. In fact, these operations should not be considered as a means of seedbed preparation. Basins or pits created through the use of cut-away pitters, road maintainers, or other equipment are used to concentrate moisture in a smaller area.

Ripping is used to break up impervious layers in the soil (figure 74). This usually increases

percolation of water into the soil and reduces surface runoff.

Contour furrowing has the same effect as pitting. It is generally a more drastic treatment in that it involves more soil disturbance. As the name implies, water retention furrows must be on the contour.

Water spreading is used to conserve water needed for restoring or increasing the production of a forage crop. In water spreading, excessive peak storm flows are channelled out of an intermittent stream bed and spread out on gentle sloping land with a soil (medium or heavy textured soils) capable of absorbing and making productive use of the extra water (figure 7-5). A National Academy of Sciences publication, More Water for Arid Lands (1974), describes techniques of precipitation harvesting in some detail .

Direct seeding

Direct planting can speed range rehabilitation, but it is not a cure for all range ills. It is expensive; it is not universally applicable; and there is a calculated risk as to whether success can be achieved. On the other hand, if the following general considerations are carefully observed, and the options realistically evaluated, then chances of success can be high.

Method of Treatment	Type of Equipment	Swath Width	Working Weight	Kilowatt Requirements	Advantages	Limitations
Pitting	1. Rotary Pitter (Spike Tooth)	1.5 m per unit. Generally pulls two units	5,200 kg/unit when filled with water	2 units 30-34 kw	1. Relatively cheap to operate	1. Penetration is limited on dry, fine-textured soils
					2. Breakage free under normal operation	2. Not effective on rocky soils or areas with hard pan near surface

						3. Soil disturbance not sufficient for seeding in conjunction with pitting
	2. Scranton Cutaway Disk Pitter	6 m per unit	750 kg/unit	1 unit 22-30 kw	1. All parts are standard, can be purchased locally	1. Limited to slopes of less than 30 percent
					2. Seeding can be done in conjunction with pitting	2. Will not work in areas of brush infestations; brush balls up in the disk
					3 Hydraulic control enables uniform control of depth of pits	
					4. Opposite disc eliminates side draft	
Ripping	1. Self-Cleaning Ripper	3 m (2 units)	450 kg/unit	35-45 kw	1. Units can be moved in pickup	1. Self-penetrating tooth will not work in rocky or frozen soil
					2. Self-cleaning of limbs and trash	
	2. Road Ripper	N.A.	Pull type 2,700 kg; tool bar type 450 kg	90-110 kw	1. Will operate in rocky areas with very little maintenance	1. Pull type difficult to move from area to area
	3. Jay Hawker	2 m	4,500 kg +		1. Discernbile surface rip	1. Not suited to rocky areas
					2. 25 cm tube at 72 cm that fractures 1 m each way	

TABLE 7-1 Summary of Equipment Used for Soil Surface preparation, advantages, and limitations

Method of Treatment	Type of Equipment	Swath Width	Working Weight	Kilowatt Requirements	Advantages	Limitations
Furrowing	1. Model B Disc Type Contour Furrower Pull	2.4 m	2,700	35-45 kw	1. Seeding attachment allows furrowing and seeding in one operation	1. Limited to slopes of 30 percent or less 2. Will not work in extremely rocky soil
	2. Holt Furrower	N.A.	Double disc 635 kg Single disc 400 kg	25-36 kw 18-25 kw	1. Continuous trenches or scalping at 1 m intervals 2. Reversible disc always throws dirt downhill in trenching	1. Brush less than 50 percent density and less than 1 m tall 2. Will not work in extremely rocky soil
	3. Front End Mold-Board Plow	N.A.	90 kg per unit attached to dozer point	50-70	1. Trench is made in front of uphill track; helps level tractor on slopes 2. Low cost of mold-board equipment 3. Minimum time required to install trenching equipment	Will not work in heavy brush or rocky areas
	4. Mold-Board Plows	N.A.	Varies, about 225 kg per bottom	10-15 kw per bottom	1. Operating costs are low 2. Easily moved from area to area	1. Not adapted to rocky soil
	5. Road Maintainers	N.A.		Self-propelled		1. Very limited applications to level, rock-free, and brush-free area
	6. Hula Dozer	N.A.	N.A.	Fits any	1. Hydraulic control tilt dozer is an	

excellent tool for digging contour trenches, ditches for pipeline, etc.

SOURCE: New Mexico Inter-Agency Range Committee, 1971.

TABLE 7-1 Summary of Equipment Used for Soil Surface preparation, advantages, and limitations - continue

Choice of Areas

In deciding whether an area should be seeded, the range manager should ask the following questions:

1. Is seeding absolutely needed?
Ranges can be rehabilitated more positively and at lower cost by better livestock distribution, better systems of grazing, or reduced stocking. Only where the desirable native perennial forage plants are almost completely killed out is seeding essential. Such areas will have a forage condition rating of poor or very poor. Where the forage condition rating of a range is fair or better, and acceptable forage species are present, a range will generally improve under good grazing management.

2. Are proven methods available for the site?
If the answer is no, projects should not be undertaken until satisfactory procedures have been developed. Sites with the highest potential should be chosen; otherwise adverse site conditions may increase the risk of failure.

3. Can proven methods be used?
On many sites, the procedures are known for the general type of processes but cannot be followed because excessive rocks, steep slopes, or other factors prevent the use of

appropriate equipment or the application of established methods.

4. Can the area be given proper grazing management after seeding? Seeding should not be started until proper grazing management can be assured.

Preliminary Considerations

Plant Cover The usual goal of developing a useful stand of desirable plants may be achieved by selective plant control or a change in grazing management. Seeding is an expensive and risky undertaking, and should be avoided if possible. As a general rule, at least one shrub and 10 desirable herbaceous plants per 9 m² should be present following revegetation.

Terrain and Soil Deep, fertile soils on level to gently sloping land are preferred sites for seeding. Shallow or rocky soils seldom have the potential to justify expensive reclamation measures. In some areas, excessive amounts of soluble salts in the soil require additional attention to ensure adequate plant establishment.

Precipitation In addition to being appropriate for the terrain and soils of the area to be seeded, the species selected should be well adapted to the precipitation regime of the area. Existing vegetation is generally a good indicator of available moisture. In areas of unreliable precipitation, the germination, establishment, and survival of the seeded species is better assured if available precipitation is augmented by additional water made available through precipitation harvesting techniques.

Competition Most plants used for revegetation are perennials. Seedlings of these species are often slow-growing and compete poorly at the seedling stage with existing, unwanted plants. A good seedbed will provide the best possible moisture conditions for germination and plant growth (figure 7-6). This requires the control of most existing plants before seeding.

Improvement of tropical and subtropical rangelands

Plant Materials The plant species selected for seeding must be compatible with management objectives (for example, palatability and growth period). It is important to use only those species and varieties well adapted to the soil, climate, and topography of the specific site being revegetated. If native species are chosen, seed of local origin should be used. Improved ecotypes, varieties, and introduced species may be available for revegetation and should be used. Species chosen for seeding must not only be adapted to the site but also appropriate for the future use and management capabilities of the site. (See chapter 8 for more details on plant selection.)

Plant Diversity A diverse ground cover will generally result in reduced soil erosion, and mixtures of grasses, forbs, and shrubs will better meet the multiple needs of the land user. The danger in monocultural seeding is that disease or insect infestation can eliminate the one species planted, whereas in a mixture, the differing characteristics of the various species would better assure a higher percentage of survival. The numerous ecological niches of variable terrain generally support higher levels of species diversity.

Seed Treatment The dormancy of most seeds can be overcome through the use of pretreatments designed to soften, puncture, wear away, or split the seed coat in order to render it permeable without damaging the embryo and endosperm within. They include physical and biological methods, dry heating, and soaking in water or chemical solutions. For further information, see Willan (1985). Various microbial treatments, such as nitrogen-fixing bacteria or mycorrhizal fungi, may enhance seedling survival.

Seeding Rates It is important to use enough seed to establish adequate plant densities, but not more seed than necessary to accomplish this. Too much seed can produce a stand of seedlings so thick that individual plants compete with each other. Species of plants, the number of pure live seeds (PLS) per kilogram, and the potential productivity of the site are

major factors in determining the rate of seeding. PLS is determined by multiplying the germination of a lot of seed by its purity. Seeding rates providing 125-250 PLS per m² should be used when the seed is placed in the soil with a drill. Broadcast seeding is an inefficient method of revegetation, and should be used only where other methods cannot be used. Many broadcast seeds are left on the soil surface where germination and seedling establishment are tenuous. On steep slopes or sites inaccessible to drills or other equipment, broadcast seeding may be used. In this case, a doubled seed rate of 500 PLS per m² is recommended.

Planting Depth Proper depth of seeding naturally depends upon the species being planted. Optimal depth of seeding is roughly 4-7 times the diameter of the seed. Seeding equipment should be used that provides positive seed placement at the desired depth. More stands are lost because seeds are planted too deep rather than too shallow.

Timing The most desirable time to seed nonirrigated areas is immediately before the season of the most reliable rainfall, and when temperature is favorable for plant establishment.

Seed Distribution Uniform seed distribution is essential. Skips and missed strips should be avoided. Seeding equipment must be checked frequently to assure it is working properly and is not plugged.

Microenvironment In many areas, soil moisture is insufficient for germination and seedling establishment. Germination and establishment are also affected by high soil temperatures. Greater moisture availability and soil temperature regulation can generally be accomplished through practices such as mulching, summer fallow, and the use of various water-harvesting devices (Herbel, 1972a). In some instances, additional soil treatments might be necessary (Herbel, 1972b). For example, where heavy crusts have formed over medium- to heavy-textured soils in arid and semiarid areas the arid-land seeder (figure 7-

7), or similar implements, can be used to improve soilmoisture relationships (Abernathy and Herbel, 1973; McKenzie and Herbel, 1982).

Seedbed Preparation The major objectives for preparing seedbeds are: (1) to remove or substantially reduce competing vegetation, (2) to prepare a favorable microenvironment for seedling establishment, (3) to firm the soil below seed placement and cover the seed with loose soil, and if possible, (4) to leave mulch on the soil surface to reduce erosion and to improve the microenvironment.

Fertilization Where water is not a limiting factor, the addition of a nitrogen-phosphorus plant fertilizer in bands near the seed zone may be helpful in plant establishment. Broadcasting fertilizer is not advisable, because it will overstimulate competing plants.

Management All seedlings must be protected from grazing animals through the second growing season, or until the seeded species are well established. Under certain conditions, spraying to control weeds competing with the new seedlings can prevent the loss of a seedling. Rodents, rabbits, insects, and other pests should also be controlled where they pose a threat to new seedlings.

If not properly managed, seeded rangelands may soon be less productive than they were before removal of the original vegetation.

Animals can be herded by people on foot or on horseback to protect new seedlings from grazing damage, thereby avoiding the more expensive technique of fencing.

Direct Seeding Techniques

Direct planting may be accomplished by using a rangeland drill, press seeder, grain drill, range interseeder, browse seeder, or rotary spreader, as well as by aerial broadcasting, airstream, hand broadcasting, or other methods that take into consideration range seeding

principles (Valentine, 1971).

Drill Seeding

Drilling is by far the most effective method of planting seed where site conditions permit. The seed is covered to the proper depth by the drill control; distribution is uniform; the rate of seeding is positively controlled; and compaction can be applied if needed. Several types of drills are available (Larson, 1980).

Rangeland Drill This drill is a rugged seeder with high clearance designed to work on rough sites (see figure 7-7). It has performed well on rough seedbeds. It can be converted into a deep furrow implement by removing the depth bands. The depth of the furrow is controlled by adding or removing disk arm weights. Weights up to 30 kg can be used. The seed-metering device on this drill can be adapted to handle a variety of seeds at widely varying rates.

Press Drill The press drill is designed for seeding on light, loose soils. A heavy press-wheel packs the soil. The seed is placed in the packed furrow and an adjustable drag covers it (figure 7-8). This drill cannot be used on rocky or rough seedbeds. The feed on the drill will not accommodate trashy seed unless it is especially designed for this purpose.

Ordinary Grain Drills The drills in this group are designed and built for use on cultivated fields. They are too lightly constructed for rough rangeland seeding. Breakage is a problem, and often the seed is not placed properly in the ground. For these reasons, they have limited use for critical area seedings.

Trashy Seed Drill This drill is equipped with two types of seed boxes, one for planting trashy seed, such as buffelgrass (Cenchrus ciliaris), and another for planting fine seeds, such as lovegrass or teff (Eragrostis spp.). The boxes can be used together or separately.

The drill has a welded frame construction and uses rubber-tired wheels.

Broadcast Seeding

Broadcasting is any method that scatters the seed directly on the soil without soil coverage. However spread, the seed must be covered in some way if it is to germinate and become established. This can variously be done by dragging a chain or branches over the seeded area, raking with a hand implement, or driving a vehicle or livestock over the area after scattering seed. Seed size and the condition of the seedbed are important influences on the extent to which seed is covered with soil. A seedbed that is 5-8 cm of loose soil generally sloughs sufficiently to cover the seed. Covering the seed with a mulch is better than no coverage at all, but mulch coverage is inferior to soil coverage. If mulches are used in conjunction with seeding, best results are obtained by broadcasting the seed, covering it with soil, and then applying mulch.

Limitations to broadcast seeding are:

· Large quantities of seed are required (approximately double the amount used in drill seeding).
· Distribution of seed is often poor.
· Covering of seed is poor compared with drilling.
· Seed loss to birds and rodents can be great.
· Establishment is generally slower.

Aerial Applications Fixed-wing aircraft and helicopters are sometimes used where ground machines cannot operate efficiently. Aerial spreaders permit rapid treatment of large areas at relatively low cost.

Aerial spreaders are either rotary spreaders or venturi-type, ramair spreaders. The higher airspeeds of fixed-wing aircraft permit the use of venturi-type spreaders. Rotary

broadcasters are suited to slower airspeeds or lower application rates. In fixed-wing aircraft, the hopper is located inside the fuselage, with a sliding gate that is operated from the cockpit. The application rate is controlled by opening or closing the sliding gate. In helicopters, rotary spreaders are either attached to the sides of the aircraft, or are suspended beneath it. Agitators within the hoppers ensure a continuous flow of materials. The equipment is calibrated for the desired application rate. Overlapping swath patterns are flown over the treatment area to give fairly even coverage. Spotters or markers are deployed to mark previously treated areas and area boundaries. The pilot should fly as low as possible to minimize drift.

Although aircraft can rapidly seed extensive areas, and quickly and effectively treat areas with slopes, soil conditions, or terrain that limit ground equipment, they do have noteworthy limitations. Airplanes require airstrips for takeoff and landing. Aerial broadcasting at high speed does not allow precise placement of broadcast materials. The broadcast material may also be moved by wind or water after application. Seed may be damaged during the operation, or destroyed by animals afterward. Also, much of the seed may be wasted because it is not placed on a micro-site that allows germination. (Larson, 1980)

Ground Applications Ground broadcasters are primarily of three types, each of which is discussed below.

Rotary Spreaders In this type of broadcaster, the seed falls from a hopper into a ribbed spinner that distributes the seed by centrifugal force. The width of throw depends on the size and weight of the seed, the speed of spinner, and wind velocity. Rotary spreaders may be carried by hand, mounted on a tractor or seedbed preparation unit, or trailed behind. They are generally powered by hand, by gasoline or electrical motor, or by power-takeoff attachments. Limitations of this type of seeder are:

· Swath width and rate of seeding vary with speed of travel and the speed of the spinner. In most of these machines, there is no mechanism to control the speed of the drive motor.
· Seed is not spread as evenly as from a drill box. The amount of seed is greatest near the center of the swath.
· Where seed mixtures are used in spreaders without agitators, seed is segregated by weight and applications are uneven.

Seeder Boxes of the Drill-Like or Fertilizer - Spreader Type In these broadcasters, a fluted or force gear-feed mechanism lets seed fall out of the bottom of the box onto the ground. The seed box is mounted on equipment such as brushland plows or brush cutters. In general, the seeder-box type of broadcaster distributes seed more uniformly than does the rotary type.

Dribblers A recent adaptation of this type of broadcaster is the "seed dribbler." The dribbler was designed to be mounted on the right and left side of the deck of a crawler tractor. It has a direct drive from a rubber-tired wheel riding on the tracks of the tractor and utilizes either fluted-force-feed or spoke-and-thimble metering mechanisms. The seed is metered onto the track pad just as it breaks over the front idler. It drops off the pad in front of the track and is embedded in the soil as the tracks pass over. The seed box units of the browse seeder (figure 7-9) can be adapted for use as dribblers.

Units With Airstream Seed Dispersal The seed is metered from a hopper either by gravity or forced gear into an airstream. Blower spreaders are available that broadcast both fluffy and slick seed, or fluffy seed only. The airstream can be created either by exhaust from equipment motors or by a fan designed for this purpose. Seed distribution is poor when wind velocities are high, and uncovered broadcast seed is subject to movement by wind and water.

Manual Equipment This method is as old as civilization. Many small areas are still seeded

by a sower throwing seed from a sack suspended at a person's side with a shoulder strap. An experienced person can maintain a good distribution of seed by this method.

An adaptation of manual seeding is the Whirlwind seeder. This hand implement consists of a canvas seed container with a controlled feed that drops seed on a spinner. A crank is turned by the sower as he walks. The crank gear turns the spinner. The spinning action scatters the seed. Many hundreds of hectares are still seeded in this manner each year.

Land Imprinter

Rangeland revegetation often requires removing brush, preparing the soil, and sowing the seed in separate operations. If all three could be done in some simple mechanized operation, then large-scale rangeland renovation would be possible. The land imprinter is an innovative mechanism that attempts this.

The land imprinter is a simple cylinder 1 m in diameter and 2 m in length, and is pulled by an ordinary farm tractor (figure 7-10). The surface of the cylinder has V-shaped ridges that, under appropriate soil conditions, leave imprints of up to 10 cm deep in a furrow providing an indentation pattern that retains rainwater where it falls. These imprints provide a small water and litter catchment capable of storing sparse rainfall.

The imprinter is a hollow metal cylinder that can be filled with up to 2 tons of water to increase the imprinting pressure when used on more resistant soils. A variety of imprinting patterns are available offering flexibility for working with different soils, terrains, and climatic conditions. Seeding is done by an inexpensive broadcast type seeder mounted on the tractor or on the towing tongue of the imprinter, which allows the imprinter being towed to press the seed into close contact with the soil. The basic imprinting pattern creates a "runoff" groove that channels water to the seedbed groove where germination and plant growth can occur even under less-than-normal rainfall.

The machine rolls over and crushes the brush including individual plants with a basal diameter of up to 10 cm, although it is most effective on stems of less than 5 cm. The destruction of dense old brush is not as effective as with more specialized machines designed specifically for total brush removal; however, some brush is effectively killed, and the remainder is sufficiently damaged to delay regrowth until after the critical period of successful establishment of the new grass seedlings. At that time, the recuperating brush encounters strong soil moisture and nutrient competition from the new grass.

The land imprinter creates an additional benefit of mulching the existing vegetation into the soil to help retain moisture, provide soil aeration, and contribute to soil structures and nutrients. When the land imprinter is operated on very dry soil, crushing stems into the soil is less effective than on moist soil.

Transplanting

Plants grown in containers or nursery beds can be transplanted to the field. Planting material includes plants propagated from seed, stem layerings, root suckers, root cuttings, and shoot cuttings. The young plants should be about 75-100 days old when they are transplanted: they should not exceed 20-25 cm in height nor have a diameter of over 5 mm at the neck. In arid zones, the resistance of nursery plants should be conditioned by low and infrequent irrigation at least a month before they are planted out. The above-ground part of the plant should be cut back to 20 cm (hardwoods and grasses, but not conifers) and, where appropriate, roots should also be trimmed.

Planting Container-Grown Plants

The use of transplants, with roots growing into the planting medium, ensures the greatest degree of success and the least interruption of growth after planting. It is especially suitable for planting very young and tender plants. The techniques employed involve plastic bags, tubes, plastic container halves, and cartons. When the work is properly done,

few plants fail to grow. It is a labor-intensive approach that is useful where it can be justified. Producing plants in containers is a logical operation because some species have proven difficult to grow as bareroot seedlings. For example, some species have brittle stems and fragile root systems that are sensitive to breakage during bareroot lifting operations, and the extensive root system of others makes it difficult to culture them in seedbeds. Some plants just seem to grow better in containers (Landis and Simonich, 1984).

Production Facilities

Whereas many ornamental crops can be produced in a single greenhouse or screened structure, some plants may require as many as four separate facilities. An ideal container nursery consists of (1) a production greenhouse in which to grow the seedlings, (2) a cold frame or shadehouse in which to harden the plants, (3) a shadehouse in which to store the seedlings until they are distributed, and, where feasible, (4) refrigerated storage to maintain dormant stock for late-season planting. The advantages and disadvantages of different facilities are discussed in detail in Tinus and McDonald (1979).

Propagation Methods

The choice of propagation method is probably one of the most critical phases in plant production. The majority of seedlings in forest nurseries are produced by direct seeding, but the stringent stratification requirements and limited availability of many plant seeds may require other approaches.

Direct Sowing Direct sowing of seeds into the growth container is the standard technique for most conifer species and wildflowers. This propagation method is limited to those species with little or no dormancy requirement. If a stratification period or other pretreatment is required, the seed should be treated prior to the planned sowing date. Otherwise, the seed is soaked in water at room temperature for 24-48 hours and surface-

dried before sowing.

The seeding procedure begins with the calculation of the proper sowing density based upon germination tests and past experience. Generally, several seeds are sown per container and are later thinned to one seedling per cell. The success of the direct seeding method depends upon the accuracy of the seed information. Germination tests vary from laboratory to laboratory, and no standardized tests are available for many shrubs and fortes. Since laboratory germination tests are run under controlled conditions, test results may differ from greenhouse germination. Sometimes the seed is obtained just before the sowing date and so there is not enough time for seed testing.

Germinant Technique The "germinant technique" is the sowing of pregerminated seed into the growth container. This propagation method is best for plants with simple dormancy requirements and species with seeds too large to handle mechanically. It is particularly suitable for seed lots of variable or unknown quality, because only good seed is sown in the growth container. Cell occupancy is maximized with this method as there are few blank cells and no subsequent thinning is needed.

The germinant procedure requires clean seed, so seed lots should be sterilized with chlorine bleach to reduce molding during stratification. The seeds are usually hydrated with a 24- to 48-hour soak and then prepared for the stratification chamber.

Seed can be germinated in "naked" stratification, where bare seeds are kept in a plastic bag or mixed with a moisture-holding material such as peat moss. The acidity of the peat moss helps retard seed molds during the lengthy stratification period, which can last up to eight months. Seeds are ready to transfer to the growth container when a white radicle becomes visible, but before the radicle becomes so long that it is easily damaged.

The planting operations consist of pouring the stratified seed out in a tray and picking out the germinants by hand or with tweezers. The germinants are placed in a depression or

small hole in the potting soil in the growth container and covered with grit or perlite. Seeds should be placed with the radicle oriented downward; if the radicle is pointed upward it will reverse itself in response to gravity, which may result in a stem crook in the young seedling.

Transplants Transplants are a third propagation method. Transplants are seedlings grown to the cotyledon state in trays and then transplanted into growth containers. This propagation method is best for woody plants with complex dormancy requirements, or for species whose small seeds would be almost impossible to plant by hand. This technique is ideal for seed lots of variable or unknown quality.

The transplant trays are filled to a depth of about 5 cm with standard potting mix and broadcastseeded by hand. The seed should be covered with a light application of a fine-textured material, such as sand-blasting grit.

When all the seedlings have been removed from the transplant trays, the soil is mixed, the trays irrigated, and the plants allowed to sprout again. Depending on the germination rate, the trays may produce up to three successive crops of transplant material.

Cuttings Rooted vegetative cuttings are started in trays and transplanted to growth containers. This is the best method for plants that are difficult to grow from seed or for which seed is difficult to obtain.

Cuttings are normally collected from plants in the field. The best season for collection depends on the species. Cuttings of two species of saltbush (Atriplex cuneata and A. confertifolia) rooted best when collected in spring or summer, but the rooting percentage dropped markedly when cuttings were taken in the fall (Richardson et al., 1979). Cuttings of some species, such as big sagebrush, root better when collected during winter dormancy (Alvarez-Cordero and McKell, 1979). A good step-by-step procedure for collecting cuttings is described by Norris (1983).

Before the cuttings are planted, they are often treated with a special hormone to stimulate production of root primordia. These "rooting" chemicals can be made from scratch by mixing indolebutyric acid (IBA) with common talc, or commercial products promoting root growth can be used. The best concentration of rooting hormone depends on many variables but, in general, the more difficult the plant is to root, the higher the concentration of rooting chemical that should be used (Norris, 1983). The rooting success of big sagebrush cuttings increased with increases in IBA concentration from 0.0 to 1.0 percent (Alvarez-Cordero and McKell, 1979). Treated cuttings should be inserted to a depth from 2.5 to 5 cm into a well-drained medium in a shallow rooting tray. Generally, the rooting medium does not contain any type of fertilizer, because of a possible stimulating effect on disease organisms.

Typically, the cuttings "callus over" first, and then produce adventitious roots from the callus tissue. Cutting success can exceed 95 percent with some species. The rooted cuttings should be transplanted immediately into a hole in the growth container; new roots should be protected from injury.

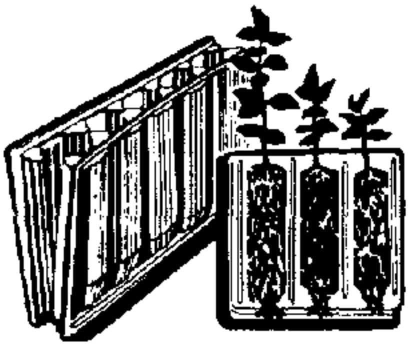

FIGURE 7-11 Tubepak container for mass propagation of plants for transplanting in harsh sites. Ribbed wall. of container direct the growth of roots downward and produce a root

plug 0.2 m long (McKell, 1986).

Growth Container and Potting Media

Barker and McKell (1979) grew fourwing saltbush and grease-wood (Sarcobatus vermiculatus) in four sizes and types of containers ranging from 98 to 1,147 cm³ and found that shoot length, shoot biomass, and root biomass all increased with size of container. A large variety of containers is available ranging from small unite in plastic or styrofoam trays to nursery pots: an ideal container is Tubepak (figure 711).

The best container size for good field performance is not necessarily the best container for seedling growth in the greenhouse. Plants grown in large containers generally perform beat in the field but require too much greenhouse apace and are costly to handle and ship. The best container also varies with plant species and environmental and soil conditions on the outplanting site.

The potting mix should be near pH 5.5 and have an electrical conductivity reading of less than 2.0 millimhos. Although there is much variation in potting mixes, mixtures of plain sand with sieved cow manure at a ratio of 1:1 are generally satisfactory (Weber, 1986). However, in some instances, special mixes may be desirable. For example, Ferguson and Monsen (1974) found that mixes containing peat moss and vermiculite produced better mountain-mahogany (Cercocarpus ledifolius) seedlings than did those containing sand. Ferguson (1980) studied 39 different potting media and found that no one mix was consistently superior. He did report that a potting mix of 50 percent peat moss, 30 percent arcillite aggregate, and 20 percent vermiculite is recommended for Bonneville saltbush (Atriplex bonnevillensis) and might be appropriate for other plant species native to alkaline soils. Mixing native soil into standard potting mixes can increase growth of some chenopod species. A survey of nurseries growing desert shrubs reported a wide variety of potting mixes that contained such diverse components as sand, cinder, peat moss,

composted bark, charcoal, sawdust, vermiculite, perlite, and native soil. In lighter mixtures, it might be desirable to include some clay in the mixture, so that the root ball holds together during transplanting (Weber, 1986). Old termite mounds are often good sources of clay.

The Hardening Phase

The hardening phase is one of the most overlooked, yet most critical, periods in the growing cycle. It is relatively easy to produce an acceptable plant in the greenhouse, but these plants have a low rate of establishment unless they are properly conditioned so that they can survive and grow on the planting site. The two most important factors to consider in designing a hardening program are the planting date and the climate of the outplanting site. Many plant species grow very rapidly under the optimal conditions in the greenhouse, but this rapid growth consists of relatively large cells with thin cell walls and little tolerance to cold temperatures or moisture stress. Hardening is the process in which growth is reduced, stored carbohydrates accumulate, and the plant becomes better able to withstand adverse conditions (Penrose and Hansen, 1981).

The hardening phase has three major objectives:

1. To minimize physical damage during handling, shipping, and planting;
2. To condition the plant to tolerate cold temperatures during refrigerated storage or after outplanting; and
3. To acclimatize plants to the outside environment and satisfy internal dormancy requirements of some species.

Dormancy is another term that is often used in conjunction with hardiness. Dormant seedlings have been shown to have the ability to produce abundant new roots when planted in a favorable environment. This high root growth capacity should increase the ability of seedlings to survive and grow on harsh sites. Both dormancy and cold hardiness

can be induced by proper scheduling of the hardening regime.

Hardiness should be induced in stages, and the process usually takes at least 6-8 weeks. The hardening begins in the greenhouse by shutting off the supplemental lights and by leaching excess nutrients out of the potting media. Night temperatures are lowered, and the seedlings are fertilized with a low nitrogen, high phosphorus and potassium fertilizer. Drought stressing should be carefully monitored because overly dry potting soil may be difficult to rewet, and stressed plants may not cold-harden normally. In the final hardening stages, temperatures are gradually lowered to the ambient level; tolerant plant species may even be taken slightly below 0°C.

Hardening can be achieved in either a cold frame or a shadehouse. Shadehouses are generally used to harden crops that are taken out of the greenhouse in summer or early fall when freezing temperatures are not expected.

Planting Bare-Rooted Plants

Under ordinary circumstances, bare-rooted plants are used in transplanting. Although such plants suffer greater loss and experience a greater interruption in growth than do plants grown in containers, the lower cost resulting from easier handling and transportation may compensate for losses and interruption of growth under most site and species conditions.

When planting stock has been properly wrapped, packed, and stored at the nursery, some plant death may still be caused by operational and natural hazards. Operational hazards include hauling plants from the nursery to the field, storage at the planting project area, and handling and planting practices in the field. Natural hazards that must be considered are weather, animal damage, vegetative competition, and insects and disease. Although natural hazards are often beyond control, the operational hazards can be largely minimized by careful planning, organization, training, and supervision. Each of these

hazards may be crucial in determining whether the planting is a success; each must be carefully considered (Levin et al., 1953).

Hauling plants from the nursery to the field would seem of little danger; yet speed in getting them to the planting site is essential to achieving a high rate of survival. Wherever possible, stock should be picked up at the nursery at frequent intervals to eliminate storing plants for long periods in heeling-in beds in the field (Levin et al., 1953). When packaged stock is hauled in an open truck, the shipment should be covered with a canvas to protect against sun and wind.

Desiccation by the wind stream can easily ruin the exposed plants for planting purposes.

Storage of plants at the project planting area need not be a problem. Ordinarily, baled plants may be stored a week or 10 days in the original package if placed in a cool, moist, sheltered spot away from the sun or wind. Sheds or root cellars allowing more control of temperature and ventilation will make possible the extension of the holding period by two or three weeks if periodic inspections are provided to ensure that the packing material (moss or shingle tow) is moistened when needed.

If seedlings must be held at the planting site longer than a few days, they should ordinarily be "heeled in." This process should be attended to with the utmost care. The best heeling-in ground is moist (but well drained), easily worked soil exposed to neither direct sunlight nor excessive cold. If natural shelter is lacking, brush, burlap, or canvas shelter should be provided, but care must be exercised to keep this covering off the plants to permit adequate air circulation.

The seedlings are placed against the side of a shallow trench, their tops projecting above the ground slightly less than in the seed bed. They should be in a layer not more than 8-10 cm thick, and the side of the trench may be nearly vertical or slope as much as 45° (a slope simplifies the packing of a 10-15 cm layer of moist soil against the roots). A thicker

layer of earth should be used if only one layer of seedlings is to be heeled in. The beds should be kept moderately moist. Good drainage is mandatory, however, because extremely wet seedlings will be hard to take out of the trench and standing water will kill the plants. Over-winter or dry-season heeling-in should always be avoided because of the damage to stock and resulting poor survival.

Poor handling of plants in the field is probably the greatest source of losses. A good rule is to do everything feasible to reduce the evaporation and transpiration of moisture from the plants. Care must also be taken to avoid smothering or drowning seedlings. Wherever possible, the stock should be left in the original bale for transporting to the planting area by truck or packboard.

The packing material in each package should be used by the planter to cover the roots of plants in his planting bag or tray to keep them moist. Each plant should be kept in this container at all times, not carried in the hand. The best container is a bag made of waterproof canvas or other stout waterproof cloth, with two loop handles. The bag should be divided into two compartments. A small bunch of plants from which the planter draws a plant for each setting is in one compartment, while in the other is the reserve supply. Each compartment should have enough wet moss or shingle tow to cover all roots.

Improper planting practices are the greatest hazard to planting survival. Some critical items are noted below (Levin et al., 1953, Penrose and Hansen, 1981):

· Do not plant in ground that has been "burned red" by a hot fire.
· Do not plant in bark or rotten wood, unless it has decomposed and is mixed with dirt.
· Place the plant at the correct depth (about 6 mm deeper - never higher - than in the nursery); it is easy to see the old ground line on the plant.
· Spread the main roots to a near natural pattern, not doubled or sharply bent.
· Tamp the soil firmly around the roots at the bottom of the hole, as well as at the top, to

eliminate air pockets, and anchor the plants so that they cannot be easily pulled up.
. Leave the plant in an upright position with the root collar even with the general ground level, not sunk in a hole or raised on a mound.

Weather is a major factor in seedling survival. The season of planting should, of course, be appropriate to the area to be planted. Ideal planting weather is warm enough so the planters are comfortable without heavy clothing and humidity is high, due to mist, fog, or rain, so that the roots will not dry out under ordinary care. During severe seasons, many plants may succumb to heat and drought. Careful planning, however, can cut losses even during the worst years.

Where local climate will allow it, planting should be done so that at least two months of moist soil conditions remain before the dry season. The choice of the planting season is naturally during the period when the stock is dormant. In temperate zones, most planting is usually done in the autumn or spring; in the tropics and subtropics it is usually done early in the rainy season. The usual practice is to initiate planting after a certain quantity of rain has fallen, or when the soil is wet to a certain depth. In Zambia, for example, planting is undertaken when the soil is moist to a depth of about 30 cm (Laurie, 1974).

Damage to plantations by mammals and birds may usually be traceable to a particular genus (Levin et al., 1953). Three main groups of animals are of concern: the rodents (including the true rodents and the lagomorphs, or rabbits and hares), the ruminants (or cudchewing animals), and birds.

Competing vegetation is harmful except where needed to prevent severe erosion, and plantings should be made before a competitive sod forms or the sod should be scalped where the plant is inserted. Scalping or removal of sod, brush, or other competing vegetation is necessary on some sites to prevent stunting or killing of plants. This occurs principally in three ways:

1. Root competition. This is most serious on dry sites, but it may also be a factor on the wetter highquality sites in dense vegetation. Greatest damage occurs during the critical first year or two when sod and brush roots are feeding in the same root zone as the transplant.
2. Competition for light. This is most serious on the better sites, where the surrounding vegetation and brush shades or suppresses the plant.
3. Smothering. This is most serious on sites that produce tall grasses and weeds that die in the fall and mat down over the plants.

Scalping of the area around the spot to receive a transplant is done by the planters at the time of planting, using a planting mattock or grub hoe. The depth and diameter of the scalped area will vary according to the density of the vegetative root systems and foliage.

Selected practices

Throughout the rangelands of the world, there are large areas where desirable forage plants have been reduced in vigor or eliminated by past abuse. Such lands produce few benefits and are a detriment to adjacent lands. Even with controlled grazing by livestock and, in some cases, complete protection, depleted areas might require 20 or more years to develop desirable plants. Secondary succession is very slow, or nonexistent in arid and semiarid rangelands where the vegetation has been depleted. Revegetation is the only means by which to establish desirable plants for protection and production in a relatively short period of time. Some examples follow.

Syria Transplanted container-grown seedlings of old man saltbush survived very well in western Syria (Csa) when placed in furrows dug 3 m apart. (For explanation of climatic classifications, see figure 1-1.) Plantings were made in moist soil at the beginning of the rainy season. Subsequent protection of planted areas resulted in the appearance of rangeland species such as bulbous barley (Hordeum bulbosum) and Artemisia herba-alba.

Israel Seeding trials in Israel (Csa) indicated that Mediterranean saltbush (Atriplex halimus) could not emerge from a compacted surface (Koller et al., 1958). Seeds were sown in moist, shallow furrows at a depth of 2-5 cm. The covering soil was firmly packed in part of the furrows while it was left loose in others. Upon drying, the packed soil formed a hard crust that most of the germinating seedlings could not penetrate. Full rows of seedlings appeared within 3-4 weeks after sowing in the furrows covered with loose soil.

Iran Seeding of many shrubs was generally unsuccessful in the dry steppes (BSh) and desert (BWh) of Iran because of unreliable germination (Nemati, 1978). However, transplants of fourwing saltbush, quailbush (Atriplex lentiformis), and Mediterranean saltbush had good establishment on arid to semiarid rangeland.

India Post-sowing compaction with iron packer wheels (20 cm x 5 cm, size; 9.2 kg, weight) reduced the soil water required for the germination and emergence of annual fortes in a loamy-sand soil (Yadav and Gupta, 1977). In order to obtain 75 percent ultimate emergence without compaction, a soil moisture level of 9 percent was required in the seedbed, whereas the use of the packer wheel resulted in the same emergence with 6-7 percent soil water.

Paroda and Mann (1979) studied the effects of seeding on a number of dryland sites in western Rajasthan, India (BWh). They reported that planting the seed 1 cm deep on the ridge of furrows 75 cm apart was the most advantageous. They used Lasiurus sindicus, buffelgrass, birdwoodgrass (C. setigerus), diaz bluestem (Dichanthium annulatum), and blue panicgrass (Panicum antidotale). Some of these species have yielded in excess of 3,000 kg per ha. Seedings of the local climax species indicate that average production can be increased to about 2,000 kg per ha. However, seed production and the availability of desirable species have been a problem.

Australia Successful regeneration of rangelands in the northeast pastoral zone of South

Australia (BWh) depends on: (1) trapping windborne seed, (2) concentrating moisture from light rains, and (3) protecting young seedlings from the blast effect of windborne sand (Young, 1969). A tyned pitter was developed for use in this area and has resulted in natural revegetation of desirable plants such as bluebushes (Kochia spp.) and saltbushes (Atriplex spp.).

Shrubs were successfully established by tyne pitting and broadcast seeding on hardpan sites in New South Wales (BWh, BShw) (Stanley, 1978). A mixture of old man saltbush (A. nummularia), bladder saltbush (A. vesicaria), bluebush (K brevifolia), and black bluebush (K pyramidata) were used. Initial establishment was favored by above-average rainfall, but growth of old man saltbush was more tolerant of prolonged flooding than either bladder saltbush or black bluebush. However, growth of the latter two species was greater during a subsequent hot, dry period during which old man saltbush and black bluebush began to die. Bluebush responded to subsequent rainfall, but old man saltbush did not recover.

Water ponding assisted in reclaiming bare scalds in arid (less than 25 mm annual precipitation) portions of New South Wales in Australia (Newman, 1966). The treated areas were relatively flat and the soils were deep clays to clay loam. Banks were constructed to collect water in a pond to depths of 15-25 cm. Good stands of several saltbush species were obtained.

A plow with opposed disk blades and a centrally mounted ripper point was developed for furrow-seeding in northwestern Australia (BShw) (Fitzgerald, 1968; 1982). Early experience indicated that a bank, formed when loose soil was heaped onto compacted ground, collapsed when wetted. The bank of loose soil proved more stable when a ripper point was placed between the disks. Buflfelgrass, birdwoodgrass, and kapokbush (Aerva tomentosa) have been successfully seeded with this technique.

A contour seeder was designed and developed in western Australia for a variety of conditions. The basic machine consists of two opposed disks to till soil into furrows and mounds, and one central ripper to create a broken seedbed for plant rooting. Discontinuous cultivation is activated by a short lift on the linkage every 10-40 m depending upon slope. In salty soils, the two opposed disks are placed so that a mound with a niche in the center is created. The niche is about 50 mm above the salt pan. Salts leach to the high ridges on the mound leaving the niche relatively free of salts. A seed and vermiculite mix is dropped every 2 m in the niche.

Australia is also a leading country in the application of aerial seeding to pasture improvement. For example, in the dry savannahs of Queensland, native pastures have been oversown with Stylosanthes spp. through aerial seeding. Initially, S. humilis and superphosphates were distributed shortly before the rainy season over roughly plowed seed beds, from which all timber had been mechanically cleared, windrowed, and burned. In 1974, S. humilis was superseded by S. hamata (Verano), as the latter was resistant to anthracnose (Colletotrichum gloeosporioides), as well as being more productive and competitive. S. scabra (Seca) was mixed with the Verano seed at a ratio of 1 kg to 3.5 kg, as Seca is better adapted to areas of the pasture with heavier soils. The stylo seed was not treated, and hard seeds were broken down through natural weathering.

From 1973 onwards, efforts were made to reduce costs of establishment by eliminating capitalintensive clearing operations, and aerially sowing into open savannah with no prior treatment other than burning or heavy grazing just before sowing. Plowing was eliminated after clearing the savannahs in 19751976, and the stylo seed and superphosphate rates were reduced from 1977 onwards. All of the methods have resulted in stylo-dominant pastures, but the times required to reach dominance have varied: 1 year on cleared and cultivated areas; 2 years on uncleared areas at high rates of seed and superphosphate; and 3 years when only 1 kg per hectare of seed and 60 kg per hectare of superphosphate were spread.

Heavy grazing (more than one animal unit per 2 hectare) immediately after sowing is essential for obtaining good establishment of stylo. Cattle selectively graze native grasses in preference to stylo during the first 2-3 months of the growing season, and this greatly increases the competitive ability of the stylo seedlings when compared with lightly grazed or ungrazed situations. Stylo dominance in the pasture increases with increased stocking rates. In Australia, improved pastures carry about 10 times more cattle than native pastures. (Edye and Gillard, 1984)

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Criteria for plant selection

Project planning

When planning any revegetation project or program, the first two questions that should come to mind are: what is the purpose of the project or program, and what are the management tools to be applied? Clear answers to these two questions would eliminate many problems and would restrict plant selection to a relatively limited number of possibilities. In the past, a number of philosophical views have been argued endlessly: for example, the selection of native species versus exotics; herbaceous species versus woody species; the planting of nursery-grown seedlings versus direct sowing; and single species versus mixed plantations (Le Hou�rou, 1984). Many personal biases would be avoided by first answering the two questions posed above.

Once the scope and objectives of the project or program are clearly defined, many controversial issues would solve themselves if a number of other questions were asked:

- **What is needed?**
- **What is available?**
- **What technologies have proven successful under similar circumstances, if any?**

· What are the principal constraints in establishment and in management?
· Is the project or program technically and economically feasible, and is it socially acceptable?

The purpose of a revegetation project may be single or multiple, simple or complex. Some examples are given below:

· To rehabilitate depleted rangelands and pastures;
· To establish multiple species for both agroforestry and sylvopastoral uses;
· To establish fodder-shrub plantations as drought buffer reserves;
· To stabilize watersheds, which will achieve a combination of goals;
· To develop a program for the reclamation of salt- or alkaline affected land (in either rainfed or irrigated conditions to produce fodder, fuel, amenities, etc.);
· To provide windbreaks and shelterbelts for the protection of agricultural lands;
· To stabilize sand dunes, preventing encroachment upon productive lands;
· To establish fuelwood plantations;
· To increase the potential for timber production by planting highly productive species and ecotypes;
· To reclaim mined land, quarries, and mine-waste dumps;
· To establish protective plantations that will arrest erosion or sedimentation in order to reduce the maintenance costs of highways, bridges, airports, reservoirs, and settlements, without other envisaged direct benefits; and
· To establish amenity plantings - for example, in association with settlements or highways.

Socioeconomic and management considerations in feasibility studies

Large-scale projects should be the subject of feasibility studies clarifying the cost-benefit ratios of the proposed undertaking. Such studies, however, should depart from

conventional economic analysis to the extent that social values, informal-sector economics, "the cost of doing nothing," and other factors that might affect project relevance and success are taken into consideration. Unfortunately, this broader approach to project definition is seldom employed in part because some benefits are not easy to quantify - particularly in amenity projects, in watershedmanagement projects, or in erosion control and anti-desertification projects. Social returns (such as reduced air or water pollution, recreation, and improved quality of life), although real and significant, are similarly difficult to quantify in monetary terms, but should nevertheless be factored into the planning equation.

Feasibility studies should also include management assessments. In fact, a general and mandatory rule should apply to all proposed revegetation projects: no project should be undertaken unless provision has been made for subsequent long-term management, with appropriate legal sanction and financial requirements that are acceptable to the land users. The infringement of this rule has resulted in general failures in the past - yet it continues to be ignored, despite the common sense of properly managing rangelands after expensive revegetation. Particular attention should be paid to the cost of protection and maintenance of revegetated areas. Studies have shown, for examples, that the cost of fencing and guarding is an overriding factor in cost-benefit analysis (de Montgolfier-Kouevi and Le Hou�rou, 1980). Another major constraint to successful revegetation is the difficulty of finding an alternative source of income for the populations concerned from the time that the projects are initiated until the time that they are fully productive.

Adaptation to ecoclimatic conditions

In all cases, the planner must match site characteristics with plant ecological requirements. In many cases, the selection of revegetation sites is imposed by local conditions in response to a pressing need for protection. The only possibility then left to the project planner is to select plants that are able to meet the ecological requirements of

the site while having a growth rate rapid enough to enable the project to fulfill its role in a reasonable period of time. Some ecologically well-adapted plant materials may have an intrinsic growth or expansion rate that is too slow to achieve any practical result in a reasonable period of time; the reproductive rate may be insufficient or unknown, or in many cases, seeds may not be available in sufficient quantity. Hence, the introduction of a faster growing species may be preferred. In the Mediterranean Basin and in Africa, Australian or American shrubs and trees are commonly used instead of native species.

Latitude, Day Length, Photoperiodism

Some species may have a wide area of distribution, such as:

Atriplex	20° Lat. N. to 45° Lat. N.
Atriplex halimus	25° Lat. N. to 55° Lat. N.
Eucalyptus camaldulensis	15° Lat. S. to 45° Lat. S.
Cenchrus ciliaris	35° Lat. N. to 35° Lat. S.
Cynodon dactylon	50° Lat. N. to 40° Lat. S.

Each degree in latitude results in a difference in day length of 12 minutes at the time of the solstice. Thus, the day-length requirements between the extreme northerly and southerly populations of Atriplex canescens or A. halimus may differ by as much as five hours, making southerly populations unfit for the northern part of the geographic area of distribution and vice versa. For this reason, most species of Atriplex do not produce flowers under intertropical latitudes, even though they can still thrive vegetatively under these conditions. Therefore, in photoperiodically sensitive species, care must be taken to address latitudinal compatibility between the zone or origin of the plant material and the site to be revegetated.

Rainfall and Rain-Use Efficiency

The amount, distribution, and variability of precipitation must be as similar as possible from the sites of origin to the revegetation site. For example, plant material from areas with a predominantly summer rainfall regime should not be expected to perform well in sites with a winter rainfall regime. Within a given rainfall regime, it is usually safer to take plants from dry areas to more humid sites, rather than from humid to dry sites. There are some exceptions, however: Acacia saligna, for example, thrives on sand dunes in southwestern Australia under a Mediterranean climatic regime with rainfall ranging from 700 to 1,200 mm per annum; yet, in the Mediterranean Basin, it grows successfully when annual rainfall is as low as 200-300 mm. Similar cases are known with some Eucalyptus species. Such situations, however, are the exception rather than the rule. Rain-use efficiency (kg of dry matter per ha per year per mm) may be a good general indicator for evaluating environmental suitability (Le Hou�rou, 1984).

Temperature

Tolerance of low or high temperature is usually a limiting factor to plant growth. The easiest criterion to use for assessing tolerance of temperature conditions in a first approximation of potential adaptability to a site is to compare mean minimum and absolute temperatures of the coldest month on the one hand and the mean maximum and absolute maximum temperature of the hottest month on the other. The monthly number of freezing days or the number of hours or days below or above given thresholds may be useful comparisons for some tangential or marginal cases. A certain margin of security must be included, particularly in cases of rough topography, since there may be rather large differences in temperatures over short distances. Temperature inversions may occur in any given elevation according to local topographical conditions; for example, valleys may be colder in winter and hotter in summer than the surrounding slopes above them.

Evaporation, Evapotranspiration, and Water Budget

The site water budget is perhaps the most important single ecoclimatic parameter to be considered in any revegetation project. Water budget must be considered in a space and time perspective with due consideration for topographic, hydrological, and edaphic (soil) factors.

The regional water budget can be schematically shown comparing mean monthly rainfall and mean monthly potential evapotranspiration. When potential evapotranspiration is not known and cannot be easily calculated, a good substitute is the ombrothermic diagram (Bagnouls and Gaussen, 1953), which shows mean monthly rainfall expressed in millimeters on a scale double that of mean monthly temperatures expressed in degrees Celsius (see figure 8-1). The dry season is defined by P<2t, where "P" is mean monthly rainfall in mm and "t" is mean monthly temperature in °C. It has been shown that the rainy/dry season threshold P< 2t is very close to P < 0.35 PET, where PET is mean monthly evapotranspiration using Penman's or Turc's method of calculation (Le Hou�rou, and Popov, 1981).

The distribution of the P/PET ratio over the year shows the average length of dry and rainy seasons. In combination with mean monthly minimum temperature distribution, this allows for the evaluation of the length of growing season, the latter being defined by (1) a positive water balance (including water reserves in the soil), and (2) a mean monthly temperature above 10°C (50°F) or a mean monthly minimum temperature above 5°C (42°F).

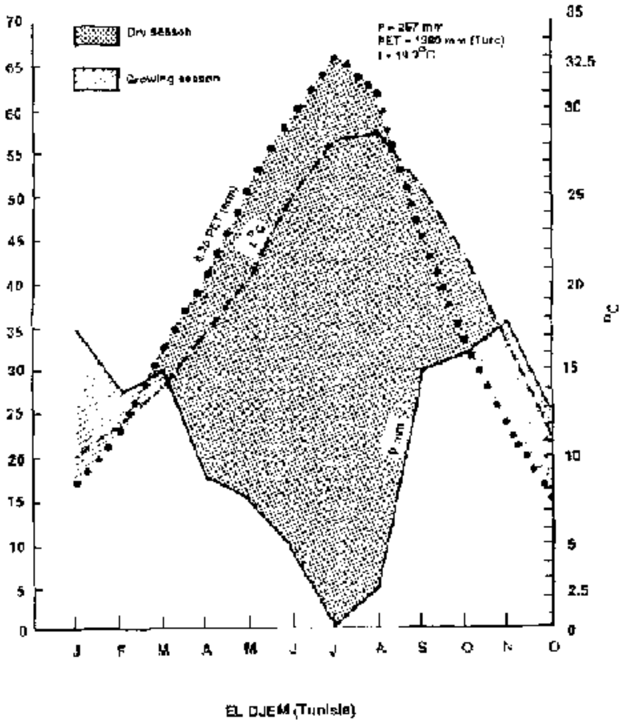

FIGURE 8-1 Typical ombrothermic diagram.

It may be useful or necessary at times to assess the probability of drought. In a first approximation, this may be evaluated from the coefficient of variation of monthly and annual rainfall. A good indicator of drought probability is the coefficient of variation (c.v.) of annual rainfall (standard deviation over mean). In the Mediterranean Basin, for instance, a c.v. of annual rainfall equal to 25-30 percent would indicate semiarid

conditions with a drought probability of 20-25 percent; a c.v. of 50 percent, arid conditions with a drought probability of 40-60 percent; and a c.v. of 100 percent or above, desert conditions with drought probability of 80 percent or above (table 8-1, and Le Hou�rou, and Popov, 1981).

P (mm)	Africa North of the Sahara	West African Sahel	South Texas USA	Northeastern Brazil
	Coefficient of Variation of P (percentage)			
10-100	80-200+	50-90+		
100-200	60-100	40-60		
200-300	40-70	30-45		
300-400	35-55	25-35		
400-600	30-50	20-30	30-40	30-50
600-800	20-35	15-25	25-35	25-55
800-1000	20-25	15-20	20-30	30-50
1,000-1,500	15-20	12-20		

Mean annual precipitation = P
CVP = Standard deviation x 100/P

SOURCE: Le Houérou and Norwine, 1985

TABLE 8-1 Relationship Between Mean Annual Precipitation and Variability/Probability of Annual Rains in Arid Zones

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P (mm)	Africa North of the	West African	South Texas	Northeastern

P (mm)	Africa North of the Sahara	West African Sahel	South Texas USA	Northeastern Brazil
	Coefficient of Variation of P (percentage)			
10-100	80-200+	50-00+		
100-200	60-100	40-60		
200-300	40-70	30-46		
300-400	56-55	26-36		
400-600	30-50	20-30	30-40	30-50
600-800	20-35	16-25	26-36	26-66
800-1000	20-26	16-20	20-30	30-60
1,000-1,500	16-20	12-20		

Mean annual precipitation = P
CVP = Standard deviation x 100/P
SOURCE: Le Hou�rou and Norwine, 1985

However, the local water budget at the site level may be different from the regional bioclimatic water budget because of physiographic and soil factors variously inducing infiltration or runoff. Runoff zones are obviously drier than the regional average and therefore more drought-prone, whereas zones with satisfactory infiltration may exhibit only temporary water deficits, or no deficit at all, because of the presence of a temporary or permanent groundwater table within reach of the surface vegetation.

The water budget at a site may also be assessed in a nonquantitative manner using the natural vegetation: for example, the presence of xerophytes, mesophytes, hygrophytes, phreatophytes, and other vegetation indicators.

Adaptation to soils

Soil suitability for plant production may be based upon a combination of water budget and nutrient status (including oxygen). These, in turn, depend upon physical and chemical characteristics. The main physical characteristics to consider are discussed below.

Texture

Texture, particularly of the topsoil, largely controls permeability and water intake, and therefore water budget. Texture also controls, to some degree, nutrient status. Some species are adapted to coarse textured soils (psammophytes), others are suited to fine-textured soils (pelophytes), and still others may be little affected by the texture factor. Textural differences play a large part in the ability of seeds to emerge or roots to penetrate dense soils composed of a majority of clay-sized particles that tend to form dense surface crusts when dry.

Structure

Structure affects soil permeability and drainage, redox potential (and therefore waterlogging), and temporary or permanent aerobic or anaerobic conditions (root asphyxia, H2S toxicity, etc.). Some species can tolerate anaerobic conditions, while others are very sensitive and fail to grow or survive.

Depth

Soil depth, in conjunction with permeability, controls water storage capacity, which is a key characteristic in arid and semiarid lands. Deep soils may store large amounts of water during short rainy periods where it is subsequently available to deep-rooted plants, thus buffering the effect of climatic aridity. In the arid zone, high productivity is achieved on deep sandy soils because virtually all rain is stored and then released to plants. Under higher and more regular rainfall, however, deep sandy soils tend to be relatively less

productive because of lower nutrient status. Nutrients, as well as water, can be a limiting factor to plant growth.

Shallow, stony, impervious soils, on the other hand, hold little water and can cause water stress in plants. Shallowness and imperviousness may, however, be corrected with adequate treatment, such as ripping, in order to break an impervious caliche (indurated calcium or magnesium carbonate) hardpan. Pitting, chiseling, and sweeping may considerably increase water intake by breaking a superficial thin-clay-sealed or loam-sealed pan that may have rendered the soil almost impervious.

The sealing of an arid-zone soil surface is a very potent factor in desertification and is sometimes reinforced by lichens or by microscopic blue-green algal encrustations. This sealing can be overcome by breaking the soil surface and roughening it with mechanical tools or by the hoof action of grazing animals, a technique that may greatly increase productivity. Conversely, if heavy traffic by hooves or equipment occurs when the soil is wet, compaction may occur to exacerbate the existing low permeability.

Water Storage Capacity

The role of water storage capacity obviously increases with aridity and rainfall variability. All the ancient techniques of "runoff farming" over 3,000 years old in the Near East, are based on water storage capacity - collecting surface runoff and storing it in the soil profile of run-in areas (Evenari et al., 1971).

Storage capacity may be increased by using well-known techniques tending either to reduce runoff (pitting, contour furrowing, or contour benching) or to collect runoff water and use it on another nearby site employing water harvesting and spreading techniques.

These techniques, which may be 2,000-3,000 years old, make it possible to grow crops on arid-zone soils. Under the meskat or jessour system techniques in the arid zone of Tunisia

and Libya, for example, over 10 million productive olive trees have been grown for centuries in areas receiving from 80 to 300 mm of precipitation (Le Hou�rou, 1959).

Chemical Characteristics

Among soil chemical properties, pH is one of the most important. Some plant species require acidic soil (acidophilic), others require alkaline conditions (basophilic), and a few are relatively indifferent to this factor. Nutrient status may also be a serious limiting factor. In many instances, however, nitrogen, phosphorus, or sulfur deficiencies can be overcome either by using fertilizers, ashes, or manure, or by using plant species that have low nutrient demands. The presence of toxic elements should also be taken into consideration. The most common toxic elements in soils are sodium, boron, and various chloride or sulfite and copper salts. The presence of toxicity calls for the use of specialized tolerant species, and often has important implications with regard to how the land and vegetation are utilized. Salt-tolerant species may be further differentiated as xerohalophytes, mesohalophytes, hygrohalophytes, and tropohalophytes (plants adapted to dry, mesic, wet, and alternately wet and dry soil conditions, respectively).

Revegetation projects are often concerned with the reclamation of soils that have been drastically disturbed or are inherently poor in their ability to support a vegetative cover. These soils call for specialized plant species adapted to particular habitats and able to grow well under various climatic conditions. Examples of these special areas, and the genera adapted to them are presented below:

Sand dunes: Calligonum, Haloxylon, Acacia, Phyllodineae, Hedysarum, Caragana, Tamarix, Eucalyptus, Cassia, Casuarina, Panicum, Pennisetum

Badlands (shales and marls eroded in gullies): Pinus, Cupressus, Ailanthus, Opuntia, Festuca, Agropyron, Hedysarum, Atriplex

Shallow soils: Pinus, Eucalyptus, Opuntia, Prosopis, Agropyron, Oryzopsis, Medicago, Bromus

Flooded/waterlogged soils: Taxodium, Pinus, Salix, Populus, Saccharum, Arundo, Phragmites

Mine waste: Eucalyptus, Tamarix, Atriplex, Maireana, Elymus, Agropyron

Saline/alkaline soils: Atriplex, Maireana, Tamarix, Lagunaria, Phoenix, Elaeagnus, Sporobolus, Puccinellia, Spartina, Distichlis.

Adaptation to physiography, geomorphology, topography, slope, and aspect

Physiographic characteristics of a site may play a very important role in positively or negatively modifying regional climatic data in terms of energy flow, temperature, evaporation, rainfall, and soil water budget (through runoff/infiltration and erosion/sedimentation, drainage, the presence or absence of waterlogging, or a satisfactory water table, and so forth). A simple calculation would show, for example, that a northern slope with a 30° dip under 40° latitude N. would have a potential evapotranspiration equal to only one-third of a similar southern slope, and therefore, if rainfall remains similar in both cases, the water budget would be three times greater in the former than in the latter (Le Hou�rou, 1972). The selection of species to be planted is therefore likely to be different in the two cases, if optimum use of the sites is sought.

Physiography may also strongly affect local precipitation if the site is exposed to rain-bearing winds; is in a rain shadow; or is subject to descending, warm, dry winds, similar to the F�hn of the southern Alps, the samun winds of Iran, the Santa Anas of California, the chinooks of the eastern Rockies, the berg winds of South Africa, the nor'westers of New Zealand, or the zonda of Argentina. Geomorphology and slope may also play an important role in determining rates of erosion or sedimentation and soil depth, thus

greatly affecting soil fertility and water budget. Hence, species selection and plant productivity calculations must be modified accordingly (see table 8-1 and figure 8-1).

Ability of introduced species to compete with native vegetation

Plant competition should be considered from the viewpoint of short-term establishment, long-term survival, and perpetuation of stands. Competition during the establishment stage may be reduced by the application of herbicides or mechanical treatments (mowing, plowing) to the native vegetation until the desired species become established. When high yields are desired, competition from weeds may be eliminated on a continuous basis by regular or periodic treatments.

Long-term perpetuation of stands of introduced species will depend on their ability to reproduce either vegetatively (for example, by suckers, runners, stolons, or rhizomes) or by seed. Some fast growing exotic species are not able to perpetuate themselves on the site and may need to be replanted after a number of years. However, some exotics have become invading pests (Opuntia spp., Prosopis spp., Nicotiana glauca, Parkinsonia spp., Euphorbia spp., Jatropha spp.).

Competition within mixtures, when mixtures are desired, can be reduced by using species with different root systems (for example, shallow-rooted species mixed with deep-rooted ones) as well as including species that have different seasonal patterns of growth.

Competition may also be reduced by selecting species according to their adaptability to microhabitats such as mounds, depressions, flat areas, or sloping areas. Diverse topography will create diversity in the resulting vegetation composition. Doing this, however, requires skill and experience and is not always practical for large-scale programs.

Use regimes

Forage Production

Revegetation for forage production is quite common either by range seeding (with or without water conservation techniques) or planting fodder shrubs and trees for fodder reserves. Sown pastures, also called "tame pastures," may be included in rangeland systems either for continuous grazing, for seasonal grazing, or for deferred standing hay to be used in periods of shortage. Range seedings are commonplace, and suitable species are well documented for use in a number of countries.

The use of rhizobial inoculants with annual or perennial legumes for agricultural areas is well known. The use of well-adapted trees that can serve both as forage and to enhance nitrogen in the soil is an obvious need. Various shrubs and trees are not only excellent sources of nitrogen but also serve larger roles in integrated land-use systems (National Research Council, 1979).

Fodder Trees and Shrubs

Fodder tree and shrub plantations probably occupy over one million hectares in the arid and semiarid zones. Some particularly useful trees and shrubs include acacias (such as Acacia saligna, A. Senegal, A. tortilis, A. albida, cacti (Opuntia ficus-indica), salt bushes (Atriplex nummularia, A. canescens, A. halimus), saksauls (Haloxylon persicum, H. aphyllum), and mesquites (such as Prosopis juliflora, P. glandulosa, P. chilensis, P. alba, P. cineraria). Some are managed as wooded grazing lands with evergreen oaks, such as Quercus rotundifolia, Q. ilex, Q. suber, and Q. lusitanica (for example, the circum-Mediterranean region and parts of California), with mesquites (India, Chile, Mexico), with olive trees (the Mediterranean Basin), and with acacias (East and West Africa).

Plantations of fodder shrubs or fodder trees may be integrated either into pastoral systems or into farming systems. They may be used as browse either for seasonal, deferred grazing or as buffer fodder reserves for periods of drought (Le Hou�rou, 1980).

They may be directly browsed, or cut and carried to livestock. Fruits, such as the pods of Acacia or Prosopis, may be collected, stored and fed, or sold as concentrated feed. Some of these plantations may be intensively managed and fertilized for high productivity, such as Leucaena leucocephala, which can produce as much as 5,000-10,000 kg of dry matter per ha per year of high-protein feed. Opuntia ficusindica plantations in Mexico, Brazil, South Africa, and North Africa may produce 5,000 15,000 kg of dry matter per ha per year under arid and semiarid conditions. Atriplex nummularia plantations may produce 2,000 5,000 kg of protein-rich dry fodder per ha per year in the arid zones of North Africa, the Near East, and South Africa with or without complementary irrigation, while 10,000 kg of dry matter per ha per year under brackish water irrigation have been obtained in Israel (Pasternak et al., 1979; Le Hou�rou, 1986). Two-year-old Atriplex canescens plantations in southern California produced 9,189 kg per ha (Goodin and McKell, 1971). Plantations of tree lucerne (Cytisus proliferus) and tree medic (Medicago arborea) are also capable of high production of quality browse under relatively intense management systems.

Fuelwood Production

Fuelwood is in short supply in many countries, particularly around towns and cities. One solution to the fuelwood problem is to plant woodlots of fast-growing species of genera such as Eucalyptis, Pinus, Populus, Casuarina, Azadirachta, Cassia, Albizia, and Gmelina. Such woodlots may prove to be excellent investments when the site and species are appropriately chosen (National Research Council, 1980).

However, particular care should be taken in establishing woodlots of fast-growing trees, as such species are frequently heavy consumers of soil nutrients, and the soils of woodlots can become seriously depleted with the loss of the nutrients contained in the exported fuelwood. Further, in many species of fast-growing trees, the greater exposed juvenile growth increases their susceptiblity to predators, disease, and desiccation. Hence, solutions to fuelwood scarcity are increasingly being sought in diversified strategies,

possibly including the establishment of woodlots, fuelwood production in agroforestry systems, improved natural forest management, and more efficient fuel utilization.

Windbreaks, Shelterbelts, and Living Hedges

Although windbreaks and shelterbelts cannot alter regional climatic conditions, they do change microclimatic conditions at the ground surface by reducing wind speed and advective energy inputs (the oasis effect). Shelter plants are thus able to reduce temperature and potential evapotranspiration, which in turn reduces the water demand of crops, natural vegetation, and animals. An added benefit is the production of fuelwood and timber.

Traditionally, cut branches from thorn trees and shrubs are used for fencing and corrals. In the tropics, these structures need to be renewed frequently because of the destruction of the cut wood by termites, thus resulting in substantial losses of native trees and shrubs. The establishment of permanent live hedges composed of local thorn shrubs could help solve this problem.

Maintenance and improvement of Soil Fertility

The role of trees and shrubs, particularly legumes (such as Acacia, Prosopis, Albizia, Gliricidia, and Leucaena), in maintaining or restoring soil fertility has been documented for a number of agroforestry systems: for example, with Acacia albida in the semiarid tropics of Africa, with Prosopis cineraria in the Rajasthan Desert of India, with Leucaena leucocephala in various countries of the humid tropics, and with desert shrubs throughout the drylands of the tropics and the subtropics.

Leaf litter, combined with the shading effect of the canopy, produces a recycling of nutrients (N. P. Ca, K, Mg) brought from deep, subsurface layers to the topsoil. As a result, yields of millet under Acacia albida, Prosopis cineraria, or other legumes are up to two-

and-one-half times greater than in open fields in otherwise similar conditions (Charreau and Vidal, 1965; Garcia-Moya and McKell, 1970; Mann and Sazena, 1980).

Conservation and Rehabilitation

Anti-erosion revegetation projects have been successfully carried out in various countries under extremely arid conditions. For instance, saksauls (Haloxylon persicum, N. ammodendron, and Calligonum spp.) have been used in the Near East.

Sand dunes can be stabilized by planting short shrubs, such as Buphorbia spp., perpendicular to the direction of the wind. Commonly called palisades, this method requires a great deal of labor since the plants must be closely spaced - from 10 cm intervals at the base of the dunes to as close as 2 cm intervals near the tops of dunes. Lateral rows also need to be created so that the effects of lateral sand transport will be diminished. This may result in a grid or checkerboard pattern. However, there must be enough space between shrubs so that small quantities of sand can pass through. Otherwise, the formation of dunes superimposed over the old dunes could result. Local demonstration areas might be required to determine palisade orientation, spacing, and height.

Whatever the species chosen, a program of protection and managed use must be established and maintained to ensure the longevity of the effort. Regardless of the method used, the major obstacle is always the provision of appropriate management strategies and an alternative livelihood for the populations concerned until the revegetation projects become self-supporting. Ways and means to accomplish this should be spelled out in the feasibility studies.

Other Uses

Revegetation projects may consider adjacent plantations that can sustain multiple uses for

one or more of the reasons previously mentioned, such as using cacti (Opuntia spp.) for its fruits, fleshy pads, and joints in northern Africa; mulberry (Mows alba) for fruits and wine making, feed for livestock and wildlife, and silkworm forage; cashews (Anacardium occidentale, European filberts (Corylus avellana) and pistachio-nuts (Pistacia vera) for fruits; Eucalyptus spp. and Prosopis spp. for honey. Other uses include chemicals, gums, and tannins from species such as carob (Ceratonia siliqua) and Acacia spp., and fibers from Agave spp.

Availability of seeds and plant materials

After considering the environmental conditions of the site(s) to be revegetated and the purpose(s) for which the revegetation program was designed, the choice of species is the next task. A range management specialist will wish to examine lists of grass, forte, tree, and shrub species in the local flora and become familiar with the field characteristics of the most desirable species. From such information sources, comparisons can be made with well-known species used in other parts of the world that have been successfully used in revegetation projects.

It may be difficult to obtain the desired and best-adapted species. If many of the species tentatively chosen for revegetation are native or "wild" species in the local flora, an established commercial source of seeds may not exist. Two options are available to those planning the project. The first is to compare the ecological similarity of the project site with other areas of the world where adequate seed sources do exist and obtain a mixture of high-performance seeds that meet project objectives. The species must have a broad genetic base and meet standards for purity and germination. The rangeland seed industry generally follows a practice of requiring seeds on a pure live seed (PLS) basis, which assures that seeds will be free of trash and weed seeds and have a live embryo capable of germinating according to specified percentages (Valentine, 1979).

The second alternative is to develop or assist in developing local sources of seeds ecologically adapted to site conditions and capable of productivity and stability under expected project conditions. The development of such sources may have long-term beneficial consequences for future projects. With appropriate incentives, local individuals or small companies may be trained to collect and process clean seeds from local fields and uncultivated areas. Some grass species may be grown under field conditions for increased volume production. Obviously, considerable advance planning is required to supply the volume of seeds needed for large projects. The assistance of specialists in native seed production may be needed. Depending upon seed availability, seed mixtures developed for a revegetation project may include native species of the project site as well as seeds obtained from analogous locations elsewhere.

In the western United States, several seed companies have developed considerable expertise in collecting seeds from native stands or producing them under field conditions (Crofts and McKell, 1977).

Practical procedures for cleaning and handling assure high seed quality. Further information regarding the availability of germ plasm appropriate for range improvement projects in the tropics and subtropics could be obtained from the following sources:

Division of Tropical Crops and Pastures
Commonwealth Scientific and Industrial Research Organization
Private Mail Bag, MSO
Townsville, Queensland 4810
Australia

Forest Resources Development Branch
Forestry Department
Food and Agriculture Organization of the United Nations

Via delle Terme di Caracalla
00100 Rome
Italy

International Council for Research in Agroforestry
P.O. Box 30677
Nairobi
Kenya

Maintenance of biological diversity

Questions of reduced biological diversity have been raised in relation to range improvement projects carried out in the western United States during the 1940s and 1950s. Many of the early projects were designed for sites where the perennial bunch grasses were severely reduced by overgrazing, and where other shrubs of low palatability to livestock had come to dominate the sites. Remedial measures to remove or reduce the dominant shrubs, such as the application of broad-spectrum chemical herbicides or mechanical removal, also had an adverse impact on other species susceptible to the drastic control methods. The result was a severe reduction in the species diversity of the range vegetation.

In addition to the loss of diversity caused by the control measures, the number of species included in the seeding mix were very limited, sometimes consisting only of wheatgrasses. Experience in securing a satisfactory degree of establishment and in managing grazing on stands of varying species composition demonstrated that monospecific stands were easier to manage than stands with greater diversity (Valentine, 1979). Other factors, however, such as the susceptibility of a monoculture to insect infestations (Haws, 1978) and the need for species diversity to provide forage over various seasons or year-round, suggested that several species with diverse characteristics should be included in the seed

mix. Plummer and colleagues (1968) recommend that the seeding mix consist of several plant types for restoring big-game range and areas of multiple use because of four advantages that can accrue to the project:

· A mixture is better suited to the varied terrain and climatic conditions of mountain rangelands.
· A variety provides several nutritional sources for game animals and livestock.
· Including several species with different seasons of maturity prolongs the period during which green feed is available to animals.
· Mixtures provide a better overall degree of ground cover than does a single species.

Since the late 1970s, state and federal government regulations in the United States have required that a diverse and effective mixture of species be used for the reclamation of lands drastically disturbed by surface mining for coal. If seed supplies are available, species native to the area are to be given priority over non-natives. There is ample reason to argue that the emphasis should be placed on a high degree of adaptability and productive capacity in choosing species rather than their merely being native. Nevertheless, the critical factor is to provide the site to be revegetated with a sufficiently diverse spectrum of species that ecological stability will be assured during periods of environmental stress. Equally important is that various ecosystem functions that depend on a diverse vegetation will be supported.

An important issue is how range improvement operations that are planned in an often limited perspective can deal with the fundamental problem of maintaining biological diversity in rangeland ecosystems. Concern has been expressed in numerous conferences and symposia that the continued intensive development of agricultural and natural resource areas is seriously depleting the world of many valuable species upon which future genetic development and even the survival of mankind may depend (U.S. Department of State, 1982). Range improvement practices that require some degree of

control over various competing species, so that they will not prevent the establishment of the seeded species, should be planned with a sensitivity for ways to maintain the overall diversity of the plant community. Further, range technicians who select species for seeding should include those that will have a high degree of adaptability and longevity on the site to be revegetated. Where possible, seeds of desirable species from the local area should be included in the seed mixture. Subsequent management practices should seek to avoid highly selective grazing that damages only certain species that are needed to maintain the diversity and the stability of the range ecosystem.

Plant improvement

Plant improvement consists for the most part of developing genotypes that are superior when compared with the average of the species or genetic entity. Although the selection of superior types is the most expeditious way to obtain improved plants, by crossing genotypes that have particularly valuable features, a new entity is created that combines the desired features of the original parents into one. Thus, the plant breeder is able to produce plants that are more specialized than those that previously existed. However, this degree of specialization can limit the range of adaptation of the improved genotype, unless its selection and performance testing are done in an environment similar to that of the sites where the improved plant is to be established.

Ideally, a species to be used in range seedings needs to possess vigor, as well as considerable variation, in order to fit into the diverse niches and environments of rangeland sites. Although it is desirable to have uniform and highly productive species, it is also important to have sufficient genetic diversity within a population that some individuals survive and prosper in various rangeland situations. In range plant improvement, it is possible to make selections from the diverse gene pool of existing grasses, fortes, trees, and shrubs in order to identify the superior types available. As newer techniques in biotechnology become available, they can also be applied to the

challenge of unlocking the great reservoir of variability and useful features in arid and semiarid plant populations. The breeding of more specialized varieties, as has been done for pasture grasses and legumes, serves as an example of what can be done for tropical and subtropical rangelands.

An example of a successful plant improvement program is the extensive study, selection, and breeding of plants in the genus Agropyron by the U.S. Department of Agriculture's Agricultural Research Service group at Logan, Utah. Considerable progress has been achieved in the development of new varieties of wheatgrasses and crosses with closely related species (Dewey, 1983). Asay and Knowles (1985) documented the release of seven improved cultivars of Agropyron and Elymus for rangeland improvement. Because of their importance for forage and conservation use, many other taxonomic groups of grasses are the subject of efforts in genetic improvement. They would include Bouteloua (Heizer and Hassell, 1985), Panicum, Sorghastrum, and Tripsacum (Vogel et al., 1985), as well as Cenchrus, Eragrostis, Digitaria, Leptochloa, Muhlenbergia, Setaria, and Sporobolus (Voigt and Oake, 1985).

The improved palatability of range plants is often mentioned as a desirable plant improvement goal, but according to a review by Voigt (1975), the factors that influence palatability must first be understood. Plant chemical composition is a major palatability factor, but morphology, succulence, disease resistance, and stage of growth are also involved. The selection of superior plants with these characteristics is necessary to produce plants with improved palatability, and to relate palatability to management strategies.

One of the most critical needs is for grasses with a superior ability to germinate and establish themselves in stressful environments. Wright (1975) has reviewed the work of plant breeders in developing species with special traits useful in rangeland situations. He cited results in the improvement of Panicum antidotale for increased drought tolerance,

Bouteloua eriopoda for improved seed set, B. curtipendula for greater seed dormancy to avoid excessively early germination, and P. obtusum for improved seed viability.

Heinrichs (1975) pointed out that in many rangeland areas, the scarcity of adapted legumes appears to be a problem for maintaining the nitrogen level in the soil adequate to support good plant growth. Most of the research work in the United States has been done on legume fortes such as Trifolium, Medicago, and Vicia. According to Rumbaugh and Townsend (1985), more than 25 improved cultivars of legume species adapted to humid and semiarid rangelands are now available, but the greatest challenge is for an improved legume cultivar adapted to range sites receiving less than 250 mm of precipitation annually. There is also a need to develop improved varieties of leguminous shrubs. The International Livestock Centre for Africa,

The International Center for Agricultural Research in the Dry Areas, the Central Arid Zone Research Institute (India), and the Commonwealth Scientific and Industrial Research Organization (Australia) are among the growing number of organizations engaged in research into fodder legumes in the tropics and substropics.

McKell (1975) emphasized that inclusion of adapted fortes and shrubs in range improvement projects was a means of increasing the productivity of harsh sites. By including selected ecotypes of droughtand salinity-tolerant shrub species, such as Atriplex, Ceratonia, Acacia, and Purshia, the stress-tolerant biotypes within the populations would be the ones to establish themselves and survive. Release of "Rincon," a new variety of Atriplex canescens, exemplifies the opportunity to improve range plants by making selections from a breeding population of superior individuals. However, to be successful, such improved varieties must be genetically flexible for long-term survival (Stutz and Carlson, 1985). Interest in improving shrubs for range revegetation was stimulated by an international shrub symposium (McKell et al., 1972) and by the Shrub Research Consortium, a group of universities and natural-resource agencies in the western

United States. A symposium at the 1985 meeting of the Society for Range Management featured reports of some of the research groups. Monson and Davis (1985) pointed out that the family Rosaceae has a high potential for superior selections from species favored for their value as browse in range improvement programs and with certain genera, for symbiotic fixation of nitrogen. Other families of shrubs favored in improvement programs are the Compositae (McArthur et al., 1985), for their aggressive habit, persistence, and potential for industrial chemicals, and the Chenopodiaceae, for their protein content and tolerance to salinity (Stutz and Carlson, 1985).

Many leguminous trees and shrubs are important sources of feed for animals and for range improvement in East Africa (Pratt and Gwynne, 1977). Based upon nutritional and ecological observations, Bogdan and Pratt (1967) recommended species for reseeding in Kenya. During the 1940s and 1950s, Bogdan assembled a collection of tree and shrub legumes at the National Grassland Research Station in Kitale, Kenya, for the purpose of selecting those with superior growth, adaptation, and productivity, but much remains to be done with this valuable genetic resource. Further information regarding the role of trees and shrubs in African livestock production systems is contained in the proceedings of the International Symposium on Browse in Africa (le Hou�rou, 1980).

In summary, there is serious need for the development of improved plant materials for rangeland revegetation use. Within the diversity of plant species native to arid and semiarid rangelands, there is ample variability from which to select in developing varieties suitable for the stressful conditions characteristic of rangeland environments. Traditional methods, in concert with newer techniques in biotechnology, hold promise for developing improved plant materials needed to meet the challenges of renewing degraded rangelands.

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