An example of American foreign aid in Niger. This soybean meal was for human consumption during the five year drought across the African Sahel.

result is water and wind erosion of the thin top soil, and ultimate loss of the irreplaceable soil resource. Instead of becoming soil moisture where it falls, rainwater moves across the land and accumulates into damaging floodwater at lower elevations. But there is one more final outcome of man's misuse of grassland: the destructive floodwater with its cargo of topsoil causes expensive man-made reservoirs to fill with sediment. The big dam that was to be the salvation of the region is destined for a short life.

Grassland is used for grazing because it offers little other economic utilization to man. On a small unit basis it does not offer great benefit to man. But there is also very little economic input, or none at all in many areas where grazing is practiced as an entirely "extractive" industry. However, the sheer vastness of the overall extent of grassland in the world makes the resource of great value to man in terms of meat, dairy products, leather and many other by-products, as well as the means of earning a living for many millions of people. Grassland is the only significant resource that many countries have, especially in Africa, and a primary resource in others that earn income from exporting meat. It is a neglected and forgotten resource in still others where the economy is currently based on oil or some other mineral export. It is important to note here that if properly managed, the grazing resource is self-renewing, while the minerals are not.

The result in human suffering is the loss of a way of life at best and hunger and starvation at worst. The surviving herdsmen migrate to population centers, where there is no employment for them even if they did have useful skills to offer. During periodic drought, which is a fixed characteristic of grassland climate, these proud and otherwise fiercely independent people must reduce themselves to the social mercy of domestic and foreign disaster assistance. The five-year drought across the African Sahel, which left human deaths in the thousands and livestock mortality in the hundreds of thousands, is well remembered by those of us who tried to cope with the problems.

What Can Be Done?

No one knows how many millions, or billions, of hectares of the earth's grasslands have been damaged or devastated. Climatic fluctuations complicate any attempt at evaluation. We do know that as a result of loss of the thin topsoil that much of this land is beyond reclaim—it can never be restored. We know that virtually all grasslands have been damaged to some extent. But, looking at the other side of the coin, we also know that the condition of most of this remaining land can be improved by changed management, and that much of it can be restored to original productivity by modern revegetation technology and equipment.

Aside from the management option, which involves too many social, cultural and political problems to discuss here, the revegetation option has become more of an economic than a technical question. In some cases the countries that need revegetation most can least afford it, or can't afford it despite an acceptable cost-benefit ratio. The Bureau of Land Management in Arizona states that a cost of $75 per hectare is too high. However, there are many private ranchers who can face the economics of revegetation, along with a number of countries that can now understake such programs on their public or communal lands. Examples of these statements are financially comfortable ranchers anywhere, and the oil exporting nations of North Africa and the Mid-East. (We come back to where desertification began). These latter peoples should be turning some of the incoming wealth to their soil and to self-renewing resources. Mexico, too, is now reaching a financial position where it can devote newfound income to improvement of depleted, yet basic, biological resources.

Because the deteriorated condition of grasslands is not well understood, and the existence of the knowledge and equipment to restore them is not widely known, little thought and planning have been devoted to the opportunities available.

Technology for Reversing Desertification

Grassland Resoration

Revegetation is more of an economic than a technical problem. For many years the knowledge, the domestic and exotic seed, and the machines to do the job have been available. Aerial and ground seeding have been tested with and without soil preparation, with and without brush removal, and with a wide variety of expensive machines. Twenty years ago grass and seed fertilizer were tried in pellet form. To destroy brush, heavy marine anchor chains were pulled between two large tractors. Chemical destruction of brush was also tried (now illegal in many countries).

We learned that several operations were necessary for successful revegetation, but also that the combined cost was too high. Where cost has not been a factor, and with the help of normal or higher rainfall, it has been possible to guarantee successful revegetation. However, the land administrator is forced to consider the cost-benefit ratio. The high imbalance of cost has tended to maintain revegetation efforts on more of an experimental than an operational basis, especially in the countries needing it most. High cost has been the economic roadblock and anything less than normal rainfall has meant a high risk of project failure.

Given the knowledge that, (1) brush removal, (2) some kind of soil preparation to conserve moisture and, (3) seeding, are all necessary operations—but separately too expensive—the problem evolves into one of how to do all of this in one simple operation.

Three in One—and More

Over the past several years a new machine has been developed by the U.S. Department of Agriculture.[1] The machine performs all of the necessary functions simultaneously and utilizes minimum rainfall to the maximum extent.

The new "land imprinter" is a simple cylinder 1 meter in diameter and 2 meters in length, and can be pulled by an ordinary farm tractor. The surface of the cylinder has V-shaped ridges and grooves that leave imprints 10 centimeters deep in the soil in a criss-cross pattern that keeps rainwater where it falls. These imprints are excellent seedbeds able to use sparse rainfall extremely efficiently, and this is the primary concept of the machine.

The basic imprinting pattern is one type of "runoff" groove which channels water to the "seedbed" groove, *where germination and plant growth can occur even under less than normal rainfall.* It is this characteristic of maximum rainfall retention and reduction of the risk of project failure due to drought which provides both the technical and economic answers to revegetation problems.

The interior of the imprinter is a hollow cylinder which can be filled with two tons of water, to increase the imprinting pressure when used on more resistant soils. However, a varieity of imprinting patterns are available, offering flexibility in working with different soils, terrain, and climatic conditions, or for different agricultural purposes.

Seeding is done by an inexpensive broadcast-type seeder mounted on the tractor or on the towing tongue of the imprinter, permitting the following machine to firmly press the seed into close contact with the soil. The soil imprinting assures that the seed is literally irrigated by rainwater.

The machine rolls over and crushes the brush, including individual plants with a basal diameter of up to 10 centimeters. Although the destruction of brush is not as effective as more specialized machines designed for total brush removal (only), some of the brush is effectively killed and the remainder is sufficiently damaged to delay recovery until after the critical period of successful establishment of the new grass seedlings. At that time the recuperating brush is encountering strong soil moisture and nutrient competition from the new grass. It is also now generally recognized that a mixture of grass and brush is superior to either grass or brush alone, for either domestic livestock or wild game or both together.

In situations where some grass is still present, the existing grass is damaged only slightly by the imprinting action and after the first rain is producing more forage than before because of improved soil moisture.

An additional benefit is mulching of any existing vegetation into the soil, to help retain moisture, provide soil aeration, and contribute to soil structure and nutrients. With all of these necessary functions provided by one machine and in one inexpensive operation, it is no surprise that the land imprinter is receiving wide use in the United States. It is also being tested in Israel, Argentina, Australia, and Mexico.

The imprinter also presents interesting potential for res-

[1]All inquiries should be sent to the author at P.O. Box 12594, Tucson, Arizona 85732, U.S.A.

The land imprinter forms two sets of interconnected furrows with the downslope furrows shedding rainwater into the cross slope furrows, where it infiltrates deeply to germinate seeds and establishes seedlings.

Two imprinters in tandem with broadcast seeders mounted. This operation is near Fort Huachuca in southern Arizona, where 500 acres of bull-dozer-cleared shrub-infested rangeland were seeded to weeping lovegrass in 1978.

Nine months after imprinter seeding shown in the second photo, weeping lovegrass becomes established in a criss-cross pattern of V-furrows designed to capture and infiltrate the limited rainwater.

Thirteen months after the imprinter seeding shown in previous photos a good stand of weeping lovegrass has become well established. Man in picture is Floyd D. Myers, Director of the Arizona-New Mexico Area of USDA's Agricultural Research.

toring overused and abandoned farmland. There is no lack of this kind of land in many countries. Due to a higher cost-benefit ratio on arable land, this type of application may become the most immediate use in some countries.

Purchase and Operating Costs

Current cost (1980) of the machine is $5,000 to $7,000, but this would be much less under volume manufacturing conditions. There are no breakdown problems or rapid wear; it is virtually indestructible. The only maintenance required is lubrication of the two axle bearings, the only moving parts. Fuel consumption of the towing unit is low. It can be easily pulled by a 30-horse power tractor and can be used on a wide variety of soils and terrain, including areas considered untillible by conventional equipment.

The cost of operating the imprinter in Arizona in 1980 is about $25/hectare. The seed cost is usually the same and doubles the overall cost to about $50/hectare. However, costs of grass seed varies greatly according to current demand and availability. Other procedures involving two or more operations can cost as much as $90 to $150/hectare.

Costs Are Immediate—Benefits Are Delayed

Revegetation projects are long-term in nature, and the required follow-up management is endless. It must be understood that a new and delicate stand of grass cannot be grazed for at least 2 years, until it has become firmly established and reseeding itself. Then rigid grazing controls must be continuously employed to prevent the previous misuse from happening again. With good grazing management the process is a one-time operation and does not need to be repeated.

While new grazing management techniques are admittedly difficult to impose and enforce in conventional situations, an entirely new stand of grass where little to no forage existed previously—and established by the land administration agency—does present an entirely new opportunity in firmly introducing rational grassland management. This in itself is an interesting challenge and is likely to result in self-regulated agreement to obey the rules if the life-giving grass is caused to reappear.

Expert advice and advance planning are necessary to determine if the ecological condition of the proposed project area will justify the expense, to determine soil hardness and terrain characteristics (which in turn determine the appropriate imprinting pattern), and to select the adapted grass species for the soil and climatic conditions. Large projects may be planned to extend over a 10- or 15-year period. Effective operational time is only 3 or 4 months each year, in advance of the annual moisture. (A $29,000,000 revegetation project is now being planned in Texas). The writer envisions several imprinters connected together and operating over a 10-meter width, pulled by a large crawler tractor.

In the case of a large project, advance planning would be necessary to arrange to have the imprinters manufactured and to acquire the seed. In the interest of price protection on the seed, it may be necessary to arrange for production contracts for the required volume over the life of the project.

The land imprinter has evolved from the experimental to the operational stage. Economic and technical problems have been solved. The research is finished and it is now possible for land administrators to plant a revegetation project at low cost and acceptable prospect for success. The simplicity of the machine and the procedure are ideally suited to remote areas of the world and uneducated people. Both domestic and foreign financial assistance are available, if actively pursued. The final outcome will be expanded economic activity in poor rural areas, more food exports or less food imports, and restoration of the original productivity of self-renewing biological resources.

Special note from the author dated September 11, 1980:

Advancing experience with projects undertaken during this current (1980) growing season has illustrated problems with the imprinter that could not have been anticipated. Here are a few of the problems.

Private fabrication and use of imprinters has unearthed some unexpected problems. There is a strong tendency for individuals to re-design the imprinting pattern, along with increasing the diameter and width of the cylinder (bigger must be better!). These things are done without realizing that all of these modifications have been tested and rejected. Furthermore, the wrong imprinting pattern could actually accelerate erosion on incline areas.

Other problems are of a more conventional nature, such as selecting the wrong grass species, seeding too early or too late, and seeding too heavy or too light. The seeding rate must be adjusted over both time and space. Serious project failure can result from either improper equipment or procedure.