PREPRINT

RECOMMENDATIONS

TO THE

UNITED NATIONS ENVIRONMENT PROGRAMME

FOR THE UTILIZATION OF MICROBIOLOGICAL PROCESSES FOR CONTROLLING DESERTIFICATION AND IMPROVING THE PRODUCTIVITY OF ARID LAND

Workshop panel, UNEP-ISEB Workshop on Uses of Microbiological Processes in Arid Lands for Desertification Control and Increased Productivity

6 to 12 October 1983

Albuquerque and Santa Fe, New Mexico, USA

TO: United Nations Environmental Programme

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PREMISES AND SUMMARY

The soils of arid and semiarid lands generally are lower in organic matter, plant nutrients (especially nitrogen), and microbial biomass and activities than soils of more mesic environments. The workshop panel emphasized the importance of increasing the retention and effective management of natively available and added residues and organic wastes in these soils as a necessary first step toward controlling desertificaiton and improving their productivity. The panel proposed utilization of a number of microbiological processes which they felt could achieve these objectives. For the purposes of the addressed problems, the workshop panel has emphasized nonirrigated land management systems and avoided sociological and socio-political aspects.

The various strategies selected for controlling and/or reversing desertification of arid and semiarid lands will depend on the intended level of management, that is, whether the lands are used only for grazing or more intensely for diverse agricultural production. For example, in a low intensity management situation involving mainly grazing, any removal of organic residues for other purposes or elimination of plant biomass should be discouraged. These alternatives, however, may be permissible for high intensity management where yields of plant biomass would be substantially greater from the use of fertilizers and irrigation.

The principal factor limiting the production of plant biomass in arid and semiarid ecosystems is water. The presence and availability of nitrogen, however, plays an important role in regulating organic matter decomposition and retention in these systems. Nitrogen is also the primary soil nutrient required for plant growth. The comparatively small amount of plant available nitrogen in arid soils derived from perennial vegetation is concentrated mainly in the surface layers. The activity of plants and microorganisms in these soils increases rapidly during brief seasonal periods when water is available. Microbiological processes, such as dinitrogen fixation, organic matter decomposition, ammonification, nitrification and denitrification tend to ocur as intense pulses during this time. The considerable spatial and temporal variation in microbiological activities makes the collection of representative samples for evaluative analyses especially difficult.

There appear to be significant differences in the relative importance of certain biological processes in soils of different arid ecosystems, including dinitrogen fixation by cyanobacteria, nitrification and denitrification, and soil organic matter decomposition and retention. The exact reasons for these differences are not entirely clear. Information on nitrogen uptake and assimilation by plants, and on plant response to nitrogen fertilizers is generally lacking for nonirrigated arid systems. Information in this area is needed.

Promising approaches for rehabilitating degraded arid soils and increasing their productivity include utilization of certain photoautotrophic and dinitrogen fixing organisms, such as cyanobacteria and microbial-plant symbionts. As primary producers, cyanobacteria provide some organic matter to soil and enhance soil stabilization. Alone or coupled with bacteria and fungi, cyanobacteria may be used to initiate the stabilization of degraded arid soils and sand dunes. The role of cyanobacteria in fixing nitrogen and improving up soil structure, and in stabilized cryptogamic crust formation is well recognized. However, currently there appear to be no practical way of reducing losses of nitrogen which occur through the denitrification activities of other microorganisms and by ammonia volatilization.

The value of legumes as agents for supplying considerable amounts of protein-rich food and fodder has been long recognized. Studies are in progress to select legumes and rhizobia to suit the dry and often saline, alkaline soils of the arid lands. Selection of Rhizobium species with characteristics favorable to stressful environments should be pursued. In the selection of advantageous plant species, attention should be focused on legumes and nodulated non-leguminous species found to grow naturaly and reproduce in the most highly stressed arid environments. Revegetation programs should also include breeding and selection for increased lignin content of plant residues as well as dinitrogen fixation. Residues with higher lignin content will produce more humic matter and allow a more gradual release of nitrogen from the humus.

Vesicular-arbuscular mycorrhizal fungi have been shown to increase phosphorus uptake and may increase the water use efficiency of herbaceous plants. They increase the growth of xeric plants as compared with similar nonmycorrhizal plants. Establishment and maintenance of this plant-fungal symbiosis in undisturbed and in agricultural arid habitats should be an essential component of the desertification prevention program.

Where more intensively managed agricultural areas are located near population centers, various nutrient-rich residues such as pit latrine wastes and street refuse can be utilized as valuable organic amendments for soil stabilization and improvement of agricultural productivity. Some of these wastes can be made more acceptable through composting which destroys pathogenic organisms, reduces malodors and increases the availability of plant nutrients. There is a distinct shortage of good quality organic wastes and residues in many countries, particularly those which are located in arid and semiarid regions. Competitive uses of some materials have intensified this situation. For example, cereal straws often have multipurpose uses, including fuel, fodder and thatch, among others.

The workshop panel has concluded that properly treated domestic sewage can be effectively used in semiarid and arid regions to build up the soil organic matter content. Other kinds of organic residues, such as municipal solid wastes, could likewise be used. These could especially prove useful in areas where soil organic matter reserves have declined below the levels predicted by the known carbon-climate relations. Attempts to raise the levels above those predicted have been ineffective on a long-term basis. Increasing the organic matter content of degraded soils should involve appropriate and locally-available technologies, and a recognition that any improvement in organic matter retention (and reversal of desertification) will most likely require extended periods of time. The role which organic matter plays in plant growth and plant protection, maintenance of soil structure, and water retention represents a major focus on which to develop longer term ecologically and economically-effective strategies for desertification control. However, more work is needed to improve our knowledge on the stability of soil organic matter in desert environments. For example, we need to know how changes in the chemistry of organic matter (humus) relate to soil biological activity. This should provide a better understanding of how certain adverse ecological events can impact land and render soils vulnerable to desertification. This implies that microbiologists, ecologists, and land managers need to coordinate their efforts more closely with soil chemists and organic matter specialists than has been done in the past.

In the final analysis, economics will dictate the extent to which microbiological processes are utilized to resolve these problems. The application of sound ecological principles would seem to offer the best solution for controlling desertification and increasing soil productivity. However, appropriate and available local technology, and expertise in the application of these principles and best management practices for the protection and rehabilitation of arid and semiarid lands will be absolutely essential to ensure a successful effort.

The concensus of the workshop panel was that the primary attention should be focused on the following items:

1. Utilization and management of available organic matter sources
2. Application of conservation tillage practices
3. Utilization of new and improved legumes
4. Use of mycorrhizae for improved revegetation efforts
5. Use of cyanobacteria as primary producers and soil stabilizers

Some information on the utilization of these processes is already available from semiarid and irrigated arid areas. However, their utilization in arid nonirrigated soils will require a certain amount of development work for successful implementation.

The workshop panel also concluded that certain microbiological processes important for soil fertility and desert ecosystem stability have been poorly investigated for arid soils. Some of these that need significant further study and development work in arid areas before practical implementation is attempted include:

1. Nitrogen losses by denitrification
2. Use of associative (rhizosphere) nitrogen fixation
3. Controls and manipulative alternatives in natural succession, including inhibitory effects of plants on microorganisms

The workshop panel recognized all too clearly that most of the recommendations offered would be virtually of little value if local expertise is not available and committed for their implementation. Unfortunately, in many arid zone countries such expertise is, indeed, lacking. Consequently, training of technicians and management personnel is a critical requirement and a comprehensive program of education and training should be initiated in the impacted regions to ensure early adoption of the recommendations and procedures. Such training preferably should be based on intensive, short-term courses with considerable emphasis on pre-graduate technical training. Post-graduate type courses should be directed toward land and project management personnel. In additon, demonstration plots or farms should be developed in central locations of arid zone countries; these will act as catalysts for publicity and education. Visiting scientist exchange programs have been valuable in the past and should be expanded. It is recommended that international agencies, especially those of the United Nations take a lead role in planing and implementing such educational programs.

The purpose of the local educational and international exchange programs is to enhance the expertise of technical and managerial personnel and to ensure that recommended policies and technologies are implemented properly and with minimal on-site assistance.

In conclusion the workshop panel expresses its hopes that the political decision-makers and managers of arid lands recognize the importance of soil microbiological processes for the maintenance and improvement of desert soils. Without microorganisms there would be no renewed nutrient sources, especially nitrogen for plant growth, no soil stabilization, no improvments in the physical and chemical properties of soil. The panel hopes that the efforts for the rehabilitation of deserts and improvement of soil fertility for agricultural use are viewed and implemented in a context of the total interrelated biological system including soil biology, in other words, that the total systems approach is used. Only then the desired long-term goals can be achieved.

A. UTILIZATION AND MANAGEMENT OF ORGANIC MATTER RESOURCES

A 1. ORGANIC RESIDUES PRODUCED _IN SITU_

Microorganisms play an important role in soil humus formation and stability of soil organic matter in arid enviroments and their activities and contributions are important factors to be considered in arid ecosystem management. A variety of mechanisms control the processes of organic residue inputs, and the formation, accumulation, turnover rates and decomposition of soil organic matter, including soil humus. Soil organic matter should be viewed as a complex, responsive system, in terms of its prior history, present status and future transformations. The various processes (formation, accumulation, stabilization, degradation) should be considered on short- and long-term time scales. Short-term precipitation events (<12 mm) which may have minimal effects on plant growth in arid areas can have major effects on decomposition processes, organic matter dynamics and nitrogen mobilization. The presence or absence of cryptogamic crusts may markedly affect the direction and magnitude of these dynamic processes.

For most arid systems being subjected to desertification the plants which are present, or which can be successfuly established at a particular location are the best above- and belowground organic residue (litter) suppliers. Only in the case of areas adjacent to urban zones where intensive agriculture can be maintained will it be possible to consider the use of imported off-site organic residues for augmenting soil organic matter reserves.

In plant-soil systems where desertification processes are being reversed, soil processes of organic matter accumulation should be considered in terms of longer (25-30 year) time frames for the management of particular systems as the accumulation of soil humic matter is an inherently slow process. Where soil organic reserves have declined below natural equilibrium values according to carbon-climate relationships, it would be difficult to increase the organic carbon values above predicted levels.

Plant breeding and selection programs for desert rehabilitation should give consideration to the lignin as well as nitrogen content of the plant. Higher lignin residues produce more humus and may reduce nitrogen losses by incorporating more nitrogen into the humus, thereby providing a better slow release nitrogen fertilizer during subsequent humic matter turnover.

Previous experience in North Africa and elsewhere has demonstrated that by appropriate management practices, including controlled grazing, soil organic matter indeed increases, the soil surface becomes stabilized, and total plant productivity increases, permitting support of larger herds.

Recommendations:

1. The following management practices should be implemented immediately on all endangered arid land ecosystems:

   a) implementation of practices by which organic matter removal, other than by grazing, from particular sites can be diminished;

   b) implementation of practices which permit crop residues, such as straw or stubble, to remain *in situ*;

   c) implementation of appropriate controlled grazing and crop management practices.

   Implementation: This recommendation is deemed the most important by the Workshop panel for controlling desertification and further degradation of arid ecosystems. It is recognized, nevertheless, that considerable difficulties may be encountered in implementation of recommendations in certain geographic areas because of economic and social considerations.

2. To implement the above recommended management policies rationally, it is necessary to obtain information on soil and vegetation status for a proper evaluation of applied practices. The following actions should be initiated immediately in the affected areas:

   a) determination of organic matter content and accumulation rates and the state of plant community development, based on contemporary surveys, and wherever possible, on the historical status of affected areas;

b) development of an inventory of information concerning the response of the existing and potential plant communities to grazing.

Implementation: immediate; methodologies are available.

3. The following processes and methods should be avoided as undesirable for various reasons in areas of low population density and on grazing lands:

a) extensive irrigation;

b) importation of organic residues;

c) extensive plant community manipulation except for recovery of drastically denuded areas;

d) removal of plant residues other than by controlled grazing and crop harvest, where applicable (such as removal for fuel);

e) extensive fertilization.

4. On a longer-term basis, applied and basic studies of microbial relationships to soil organic matter dynamics in arid soils are needed:

a) to relate soil organic matter dynamics in arid ecosystems to N cycling information and to identify critical edaphic controls on microbiological transformation of soil organic matter;

b) to develop a better understanding of the release of organic residues by existing plant communities and those potentially able to function in particular locales in terms of timing and extent of herbage removal, and of the effects of other stresses, such as drought and temperature variation;

c) to develop a better understanding of the role of cryptogamic crust contribution to soil water dyanmics, soil organic matter input and soil surface stability;

d) to develop a better understanding of soil organic matter dynamics in alkaline and saline soils;

e) to continue and intensify studies on chemical characterization of fresh versus stabilized soil organic matter, including soil humic matter and to relate this information to other physical and chemical characteristics of soils, to soil nitrogen availability, and to climatic parameters;

f) to investigate the feasibility of selecting plant species and variants usable in desert rehabilitation programs for increased lignin as well as nitrogen content in residues.

Implementation: These recommendations for extended studies indicate the lack of useful information currently available on arid soil biology, which, however, is needed for successful desert rehabilitation programs and soil fertility improvement. Applicable methodologies are available from extensive related studies on mesic and humid soils.

A 2. NON-TOXIC MUNICIPAL AND INDUSTRIAL ORGANIC MATTER RESOURCES

Production of crops and reclamation of arid lands for agricultural use is often limited by water and nutrients, particularly N, P, and organic carbon in soil. On the other hand, municipal wastes and wastes from some industries are rich in organic matter and nutrients. These nutrient rich resources, unfortunately called "wastes" are often transported by water and discarded. In natural waterways, lakes and reservoirs, as well as in coastal marine environments, the wastes cause severe environmental problems by contributing to pollution and eutrophication. However, if adequate microbiological and sanitary controls are implemented, they can be converted into a valuable resource of organic matter and nutrients. Thus, utilization and recycling of organic rich wastes fulfills multifaceted benefits by (1) solving problems of waste disposal, (2) solving problems of public and environmental health, (3) enhancing the aesthetic and commercial value of property and sites, and, most importantly, (4) preserving valuable resources for improving the fertility and productivity of arid zone agricultural soils.

Implementation of recycling of organic waste products for different arid areas needs to be assessed separately according to the demographic patterns: (1) regions which are currently under grazing, (2) regions where cultivated crops are produced, and (3) urbanized regions.

Arid regions where nomadic or sedentary grazing is practiced usually support very low population densities of people and domestic animals. In these areas there is a general shortage of organic matter available for food, fodder, fertilizers and fuel, and it is unlikely that waste materials could be found and successfully used. In certain arid regions with moderate to low population densities where grain and other crops are cultivated, human waste together with animal manure has been traditionally used as fertilizers. This and related practices are desirable and should be encouraged as they are effective and do not require technological improvement. In addition, use of municipal and industrial wastes should be encouraged where it is economically feasible.

The utilization of off-farm organic wastes on agricultural lands for soil improvement and nutrient recycling is particularly feasible and practical when such lands are located in a close proximity to urbanized areas with high population densities. Urbanization results the consumption of organic produce and the concentration of organic wastes from an area of agricultural production much larger than the urbanized area. Although the transportation needed for collection and distribution of the food supply may be regularly provided, and the costs thereof included in the price of goods, the money available for the redistribution of the organic wastes often is inadequate. The costs of redistribution are considered to be external and are not accounted for in the price. Consequently, organic wastes that accumulate in urban centers are seldom returned to the land and, indeed, represent the loss of a valuable resource. This situation occurs in both developed and developing countries.

Sophisticated and often costly waste treatment technologies are often available in the municipalities of most developed countries, including primary, secondary, tertiary, and sometimes quarternary sewage treatment. Valuable resources (organic matter rich in nitrogen and phosphorus) are to be found in sludges produced in primary and secondary treatment. However, these resources are reclaimed only on a limited scale in the majority of industrialized and developed countries, usually because of economic considerations. Because of technological and financial constraints it is not likely that developing countries would significantly expand waste treatment technologies in the future. Consequently, there would be only a few opportunities to reclaim resources from sewage sludges. In the few cases in which it would be feasible to build and operate treatment plants, the safe utilization of the resulting sludges would necessitate the provision of separate treatment facilities for those industrial wastewaters that contain heavy metals and toxic organic compounds.

As developing countries in arid climatic regions become urbanized and industrialized, they will probably seek solutions for waste disposal and treatment, applying similar technologies, and facing the accompanying problems. These problems may be compounded by specific aggravating conditions such as (1) water shortage, (2) public health problems, (3) prohibitive costs, and (4) traditional and culture-dependent practices and attitudes which may be in conflict with some implementations.

The following practices may reduce implementation costs, as well as the risk of malfunctions during maintenance when applied in arid regions: (1) use of water for dilution, removal, and transportation of organic wastes should be reduced or avoided, and (2) abbreviated and combined organic waste solid treatments using uncomplicated, small-scale low level technologies and decentralization of treatment facilities are recommended.

Although the amounts of usable sewage sludges produced in arid zone countries may be relatively minor, those of urban organic solid wastes--the "street refuse" (garbage, refuse, market wastes) are significantly large when considered as a source of organic matter for agricultural lands surrounding the urbanized areas. Solid waste generation rates in urban centers in developing countries range from about 0.3 to 0.9 kg per person per day. The amount actually available is dependent upon the thoroughness and efficiency of the solid waste collection systems, which usually are far from satisfactory. Improvement of such services are highly recommended. To be useful in agriculture, the urban wastes must be processed (manually or mecahnically) to remove nonbiodegradable components. The segregated raw organic wastes may either be applied to the land without further processing, or they may be further processed, preferably composted.

Composting and co-composting of urban and other wastes are considered desirable for the following reasons: (a) the amount of water required is relatively small, (b) with respect to wastewater treatment, results and benefits from primary and secondary treatments are achieved in one step, (c) composting and co-composting urban with agricultural wastes can be carried out, but arrested at an earlier stage to assure a higher organic matter-to-inorganic nutrient ratio in the residue. Most of the food processing wastes (for example, olive residues following oil production) may be used directly for composting or co-composting purposes. Co-composting is especially recommended where low mineral nutrient wastes may be supplemented with high nutrient content organic wastes. The resulting materials are considered superior as fertilizers of arid agricultural land because their higher content of organic matter contributes to the improvement of soil structure, water retention, cation exchange capacity, and to a more gradual release of nutrients used by crops. Resulting increased crop growth from the use of organic composts will increase the amount of crop roots and residues returning to the soil and thereby increasing the soil humus content.

Use of waste materials for biogas production should be of low priority. Although in some countries, especially those located in more humid areas and with inherently higher soil fertility, biogas production has relieved some pressure from the use of valuable organic materials for fuel, in the arid areas it is preferable that organic wastes are used for soil improvement. Only in the situations where available wastes are not suitable for agricultural use because of contamination or other reasons, biogas production should be encouraged.

The evaluation fertilizers for arid soils should consider the content of organic carbon in addition to the customary N-P-K assessment. Generally, it is recommended that costly high technology solutions to agricultural fertilizer problems be avoided in favor of low-cost easy maintenance alternatives. All implementations must be planned and considered within the framework of the future use of the land.

Recommendations:

1. Utililization of locally produced human waste and animal manures should be encouraged and expanded for use in crop production in areas of low population density.

   Implementation: immediately, no technological improvements are required.

2. Development of municipal and suitable industrial waste collection systems in population centers with the following characteristics: (1) abbreviated and combined organic waste treatment processes, (2) a low-level technology, (3) decentralized, and (4) a minimal requirement of water usage.

   Implementation: development and construction of such collection and treatment facilities are considered imperative for the utilization of waste for the purposes recommended in (3) and (4):

3. Composting and co-composting of municipal, industrial, and agricultural wastes and their utilization for increasing soil fertility should be strongly encouraged.

   Implementation: practices for these purposes have been developed and may be used immediately.

4. Production of biogas from agriculturally nonsuitable, contaminated wastes should be encouraged.

Implementation: immediate, practical utilization methods are available from a number of countries.

In order to assure adequate and locally applicable strategies, more information and study is needed as defined in recommendations (5) through (11):

5. Surveys are needed country-by-country to assess the kinds, amounts and quality of organic wastes that are available. Such assessment should identify wastes that are potentially unacceptable due to heavy metal or other toxic constituents.

   Implementation: immediate, no sophisticated technology needed.

6. Assess chemical, physical and microbiological modifications that would enhance the value and quality of organic wastes in relation to properties of the recipient soils.

   Implementation: some developmental work is needed.

7. Determine organic matter stability, nutrient availablity and nutrient release rates of traditional farm wastes, municipal wastes and organic rich nontoxic industrial wastes.

   Implementation: some developmental work is needed.

8. Investigate the role of microflora to the decomposition process of wastes applied to soils. This should provide information on how the decomposition process in soil might be controlled to greater advantage.

   Implementation: extensive studies are required.

9. Develop methods and management practices for controlling the water regime in waste and residue treated soils. This would involve the placement or positioning of waste materials in soils and tillage practices to control their decomposition rate and to extend their residual effectiveness.

   Implementation: field demonstration tests should begin immediately; longer-term laboratory studies would be beneficial.

10. Determine the actual amounts of organic wastes and residues needed to (a) stabilize arid soils already impaired by desertification, (b) to protect unimpaired lands from future encroachment of desertification, and (c) to increase crop productivity.

    Implementation: field demonstration studies should begin immediately.

11. Determine the mode and methods of application, time of application, and rates and frequencies of application pertinent to recommendations

(7) to (10) for each respective region, and the effectiveness of the methods used on the basis of case-history type experiences.

Implementation: field studies should be initiated at demonstration farms in critically affected areas, and at locations not yet affected by severe desertification.

A 3. HYDROCARBONS

Arid lands may be exposed to hydrocarbons accidentally (e.g., by pipeline breaks) or intentionally as in the "landfarming" disposal of oily wastes. Low levels of hydrocarbons in asphalt-straw mixtures are applied to denuded land or shifting dunes with the objectives of physical stabilization of soil, and dust or erosion control.

The rapid biodegradation rates of organic matter in semiarid and arid lands in the presence of seasonally available moisture may make some of these areas suitable for land farming disposal of hazardous wastes, including oily sludges and other hydrocarbon wastes. However, specific information on biodegration rates and the overall role of biodegradation in hydrocarbon disappearance in arid soils is limited, and additional studies are needed prior to any large scale disposal operations.

Because of the need to augment soil organic matter and soil nitrogen during rehabilitation of degraded arid soils, the possibility of using waste oil disposal with land rehabilitation should be considered. It is documented that the disposal of high levels (in the range 500 m^3 ha^{-1}) of oily sludges increases soil organic matter content and stimulates atmospheric nitrogen fixation. However, the detrimental effects of the treatment such as initial kill of the existing plant cover, disruption of mycorrhizal associations, presence of phytotoxic hydrocarbon residues and increased content of heavy metals in the treated soil appear to outweigh the stated advantages. Low-level treatments apparently do not significantly alter the organic matter or nitrogen content of the soils.

Recommendations:

1. Hydrocarbon disposal with the primary purpose of land improvement cannot be recommended at this time.

2. The use of asphalt-straw mixtures and hydrocarbons at relatively low application rates for temporary physical stabilization of land devoid of plant cover has a definite positive role in arid land rehabilitation. Such physical stabilization, when combined with seeding, fertilization and temporary irrigation is helpful in establishing a self-sustaining plant cover.

   Implementation: this method could be used for the rehabilitation of drastically degraded soils when such hydrocarbon sources are economically available.

B. APPLICATION OF CONSERVATION TILLAGE

The organic matter content of arid soils is low, and can decrease even further with soil disturbance designed to enhance decomposition of recalcitrant organic matter or to permit cultivation for the introduction of crop plants. Soil disturbance by plowing or tilling also affects cyanobacterial and mycorrhizal fungal populations. More importantly, traditional farming methods subject arid soils to wind erosion. For the planting of crops by seeding in arid soils, the use of minimum or no-till techniques should be considered. Seeds and fertilizers may be introduced into narrow slots in the soil while leaving the bulk of the soil surface undisturbed. In temperate climates, application of these methods results in an increase in earthworm activity and some reduction in the activity of nitrifying organisms. However, it is often found that 40 to 50 kg N ha^{-1} fertilizer has to be added to achieve the same yields as in the traditionally cultivated plots. In arid areas care must be taken not to disturb below ground termite and other invertebrate colonies since their burrows aid water infiltration. Less fossil fuel energy is needed for the minimum or no-till process but specially designed disc drills are needed.

Since water is the primary limiting factor for all biological activities in arid systems, it must be conserved at all costs, and the use of contouring and "water farming" techniques are important. This includes the construction of dams and soakways and the strategic planting of crops in successional sequence to best benefit from available water. On a broader scale, water and organic matter enhancement may be achieved by modification of whole watersheds. This has been documented and implemented in Israel where water harvested from hill slopes by removal of stones is focused on a series of terraced fields where tree crops are grown. The runoff velocity is reduced and water is given a chance to spread uniformly over the terraced fields. Organic and inorganic sediments are added to orchard fields in addition to water that is stored in the soil. This technology is applicable to the lower slopes of watersheds with sandy or sandy loam soils but may not work effectively where soils have high clay and silt contents that could retard water infiltration. Problems remaining to be addressed in such agricultural systems include maintenance of soil fertility and efficacy of nutrient and water use by plants. In this context, understanding the roles of mycorrhizae, cyanobacteria, and rhizosphere communities will contribute greatly to a resolution of these problems.

A further technique successfuly used in Arizona is to drive a gouger (roller with irregularly spaced, raised portions) over the desert surface forming micro-concave depressions which reduces the surface flow of water and traps water in depressions. This water encourages the growth of cyanobacteria, and hastens the germination and growth of some plant seeds. The depression also may serve to collect plant litter and seeds being blown across the soil surface. The placement of water collecting systems of corrugated metal or plastic as used, for example, in Gibraltar also might have value in some situations and do not require an input of high technology.

Many of the general principles of conservation tillage and some of the less expensive procedures are ready for immediate application on arid lands but will require marked changes in traditional practices. The value of conservation tillage versus controlled grazing for the rehabilitation of affected grazing areas, however, should be evaluated on an individual case basis, considering socio-economic, environmental and soil factors.

Recommendations:

1. Considering that water is of primary importance for plant growth and soil biological activities, it is strongly recommended that the following methods be encouraged, promoted and implemented for retention of seasonably available water:

   (a) appropriate successional planting and interplanting of crops as already practiced traditionally in arid areas in a number of countries;

   (b) extended contouring and terracing of fields, where topography and soil texture is conducive to such practices;

   (c) use of depression-forming rollers on land used for controlled grazing to promote retention of surface water and hasten reestablishment of vegetation on deteriorated sites.

   Implementation: methodologies are curently available.

2. To avoid wind erosion, minimum-tillage practices should be encouraged where cultivated agriculture is practiced, especially for grain crops.

   Implementation: methods are currently available for more mesic agricultural systems; adaptation for specific soil textures, crops and water regimes in arid soils should be tested.

C. IMPROVED UTILIZATION OF LEGUMES

Legumes play several roles in arid environments: (a) they are a valuable protein source for food, (b) they provide grazing for livestock, (c) they provide firewood, charcoal and other components useful as energy sources, (d) they maintain soil fertility by increasing the soil nitrogen content, and (e) they can be used as primary agents for desertification control, reforestation, and reclamation of degraded soils. These roles are augmented by the activity of rhizobial (Rhizobium spp.) symbionts which can fix considerable amounts of atmospheric dinitrogen in the root systems of legume hosts.

There are, however, a number of factors which may limit the increased use of legumes in arid areas, including (1) sociological aspects, (2) marketing problems, (3) environmental barriers, (4) the selection of legume species adapted to arid conditions, (5) selection of Rhizobium strains best adapted for specific legume species and cultivars, and (6) supply of appropriate inoculants. Only the problems related to the microbiological aspects are considered here. In arid environments there are poorly known or underexploited legumes with great potential as a source of food or fodder. For example, Cordeauxia edulis, a leguminous bush of desert savannah in East Africa, is gradually disappearing due to overgrazing and deterioration of the vegetative cover. Immediate action is needed by international and national agencies involved in desertification control to save and to increase the use of this important food source. Research also is needed on other underexploited or unknown legume-rhizobia systems that are potentially useful as food and fodder sources. We note that only about 10% of the 16,000 existing legumes have been subjected to intensive study to date.

A better use of existing Rhizobium species and strains is desirable and a thorough assessment of inoculation benefits pertinent to different ecosystems, soil types and legume species is needed, especially for those forage and grain legumes which are known to have specific Rhizobium requirements. The use of legume shrubs and trees, particularly for use in intercropping, should be strongly encouraged for desertification control and rangeland management. Species of Acacia, Prosopis, and Clitoria have been used with considerable success for these purposes. If new and improved legume species are to be used successfuly, the utilization of specific Rhizobium inocula will be necessary. Consequently, the location of Rhizobium culture collections, like MIRCEN's in Nairobi, in Porto Alegre, or CIAT in Columbia, should be more widely publicized and new accessions made available, particularly for plant species in arid ecosystems. Increased grain and biomass yields can be achieved by the development of improved inoculation methods adapted to these environments. Examples are the use of granular inocula, immobilized cells, or pelleted seeds.

Improved methods are required for maximum protein recovery and for production of materials useful as energy sources, particularly in those areas which are afflicted by both food and energy shortages. As an example, the wet fractionation of green biomass is a technology which can be further developed to maximize the recycling of products derived from microbiological processes.

Recombinant DNA technology offers a powerful tool to improve the quality of rhizobia. Basic studies should be stimulated for the development of a) salt-resistant or pesticide-resistant strains, b) strains which are more efficient in energy recycling, and c) strains which exhibit reduced dissimilatory respiration capacity of combined nitrogen.

Recommendations:

1. Preservation, use, and recovery of existing native legume communities for grazing (such as Cordeauxia) should be of primary concern in rehabilitation efforts of desertified regions.

   Implementation: immediate, made in conjunction with programs for improved management of grazing land and soil rehabilitation.

2. Introduced legume species should be used for (a) forage, (b) food, (c) fuel production, and (d) soil stabilization wherever appropriate. This effort should include:

(a) selection of appropriate legume species,

(b) inoculation of seeds with appropriate rhizobia.

Implementation: some developmental work is needed for the selection of plant species; methods for inocula preparation are generally known and available, but will require some technological development on a local level.

3. International and national centers for collection of Rhizobium cultures should be made aware of the immediate need for rhizobial cultures for arid zone legumes.

   Implementation: immediate.

4. Use of leguminous trees and shrubs for desertification control and range management should be strongly encouraged where environmental conditions permit.

   Implementation: methods and techniques are immediately available.

5. Similarly, leguminous trees and shrubs should be extensively used for intercropping, where water availability is sufficient for combined crop and shrub or tree growth.

   Implementation: water and nutrient availability should be evaluated with respect to crop yields before implementation of intercropping.

6. Recombinant genetic technologies should be used to improve rhizobial strains adapted to xeric plants and arid environments.

   Implementation: long term studies required.

D. USE OF NODULATED NON-LEGUMES AND RHIZOPHERE NITROGEN FIXATION

The importance of dinitrogen fixation by microorganisms associated with the root surface and rhizosphere (associative symbiotic dinitrogen fixation) for certain mesic and humid ecosystems and agricultural crops is widely recognized. It is also known that numerous xeric plants exhibit these microbial associations. In the organic carbon-poor arid soils, plant roots are the primary sources of carbon availability and thus become the principal zone of microbial activities, including dinitrogen fixation. However, dinitrogen fixation is usually limited to short seasonal periods when temperature and moisture conditions are favorable. These favorable environmental conditions may be enhanced by soil particle agglomerations around the roots (rhizosheaths), especially those of perennial grasses (Poaceae). Reports on the importance of associative dinitrogen fixation which are based solely on the acetylene reduction assays are difficult to assess because of certain serious limitations associated with the tests. Much additional information is needed, based on isotopic nitrogen assays in order to properly evaluate associative dinitrogen fixation in arid plants.

Shrub communities of semiarid Mediterranean-type habitats are often inhabited by non-leguminous, but nodulated perennials, which at times exhibit significant dinitrogen fixation (Frankia-type nodulations). Although the significance of dinitrogen fixation by Frankia (an actinomycete) and by rhizosphere-associated bacteria in semiarid and arid soils is not yet well understood, some of the Frankia-nodulated trees, such as Casuarina are extensively planted for fuel production and as windreaks in arid soils. These plant species are nitrogen self-sufficient but require supplemental moisture for best performance.

Recommendations:

1. Frankia-nodulated tree and shrub species should be used for fuel production in areas wherever sufficient natural moisture is available for successful cultivation.

   Implementation: immediate.

2. Aggressively search for Frankia-nodulated plant species with potential in arid areas.

   Implementation: development required.

3. Expand studies to define environmental parameters and species specificities of Frankia-nodulated species to increase the productivity and dinitrogen-fixing potential of these plant species in arid ecosystems.

   Implementation: development needed.

4. Expand studies to identify plant species adapted to arid and semiarid environments which exhibit associative symbiotic dinitrogen fixation. Investigate the environmental parameters and microbe-plant species specificities with the specific objective of enhancing dinitrogen fixation in arid soils.

   Implementation: development needed.

E. USE OF MYCORRHIZAE FOR IMPROVED LAND REHABILITATION

Mutualistic associations between plants and fungi, known as mycorrhizae, are known for almost all desirable annual and perennial semiarid and arid zone endemic and cultivated plants. In xeric plants these mycorrhizal associations are predominateely of vesicular-arbuscular (VA) type.

Mycorrhizal dependency has been shown to range from minimal positive response in some C3 type grasses to nearly obligate dependence in shrubs and trees. Establishment of mycorrhizal associations increases uptake of water and nutrients, promotes tolerance to drought, salinity, and heavy metals, and ultimately increases plant production and survival. Mycorrhizal and rhizosphere microorganisms also bind soil particles forming soil aggregates. Thus, they are of primary importance in forming and maintaining soil structure in arid soils.

Use of high levels of phosphate and nitrate fertilizers, pesticides and elimination of plant cover will reduce or eliminate the populations of mycorrhizal fungi from soil. Techniques and methods are currently being developed in a number of countries for obtaining mycorrhizal inocula usable for large scale inoculations. Pilot-size demonstration plots in arid areas have shown that introduction of mycorrhizal fungi during revegetation may increase the length of growing season where it is restricted by drought and enhance the rate of growth equal to or better than artificial fertilization. Certain introduced crops have responded positively to mycorrhizal inoculations. Thus, in many arid areas inoculation might increase crop productivity and reduce the risk of crop failure.

Recommendations:

1. Encourage and expand inoculation of degraded soils during revegetation with soil pellets containing spores and hyphae of appropriate mycorrhizal fungi.

   Implementation: technological development needed locally for the production of inocula.

2. Plant or seed disturbed lands with plant species having low mycorrhizal dependencies followed by seasonally dependent planting of species with high dependencies in discrete patches. Select plant species with low water-use requirements and controle grazing for maintenance of stands.

   Implementation: adapt and use methods which have been found successful for reclaming areas; floristic and fungal characteristics of soils should be evaluated first.

3. In view of the increasingly high cost of fertilizers, studies should be conducted to increase yields of arid area crops by utilizing mycorrhizal fungi. Studies should seek to improve inoculation techniques and to address factors leading to improved mutual plant-fungi physiological responses.

   Implementation: Further development and testing required.

4. Use successional introduction of plant species to prime early establishment events during rehabilitation of severely degraded lands. Specifically, there is need to develop optimal planting patterns and densities for natural increase of mycorrhizal fungi, organic matter and cycling of nutrients (refer to Section H of Recommendations).

   Implementation: development needed.

5. Creation of a mycorrhizal fungal species bank for arid zones should be expedited.

Implementation: such mycorrhizal species collection would be most appropriately located and associated with existing international culture collections, such as listed by MIRCEN.

6. Identify the dependency of plant species on mycorrhizae for each area and ecosystem to achieve the goals noted in Recommendations above.

Implementation: extensive studies are required.

7. Studies of mycorrhizal effects on plant nutrition have been in evidence only for the last decade. Consequently, a basic understanding of plant-mycorrhizal interactions are still unknown. Knowledge in the following study areas is needed for improved utilization of mycorrhizae in arid zones:

   a) genetic potential of the various fungal species; this includes knowledge on the potential for genetic manipulation of fungal gene pools for use of known genetic characters for specific habitats;

   b) ecological interactions in the mycorrhizosphere;

   c) physiological and biochemical mechanisms of mycorrhizal effects;

   d) basic ecology of mycorrhizae to better formulate uses of mycorrhizae for specific, localized applications;

   e) utilization of the systems approach to link mycorrhizal processes with other microbial and plant-regulated processes, especially in legumes.

   Implementation: extended basic studies required.

F. USE OF CYANOBACTERIA AS PRIMARY PRODUCERS, NITROGEN FIXERS AND SOIL STABILIZERS

Cyanobacteria (Cyanophyta) can play three major roles in the reclamation and rehabilitation of land areas affected by desertification: (1) physical improvement (stabilization) of the soil, (2) contribution of organic carbon and nitrogen to the soil, and (3) production of biomass for use as animal fodder or human food, fertilizers and for methane generation. The increasing difficulty of implementation and increasing costs of development are projected to follow the same (1) to (3) sequence.

Cyanobacterial soil crusts result from the growth and migration of the organism, combined with production of a sheath, comprised mainly of a hydrated mucopolysaccharide polymer. Whereas the primary colonizers of soil (the non-heterocystous, filamentous species, e.g., Microcoleus) are motile throughout their life cycle, the dinitrogen fixing heterocystous species (e.g., Nostoc, Calothrix, and Scytonema) are sessile. This gliding motility, or lack of it, has important implications for the formation of soil structure; namely, the colonizing species migrate over a distance at least two orders of magnitude greater than that attained through organismal increase in length by growth per unit time. As a consequence, the organic carbon content of a newly colonized soil increases quickly and the cyanobacterial dinitrogen fixation commences in quantity when the soil is sufficiently stabilized to allow the sessile species to colonize and compete.

The hygroscopic nature of the cyanobacterial sheath is one of the most important properties of the community mediating further development of the soil crust itself, as well as in modifying the soil water balance available to higher plants and soil fauna. Water is imbibed almost instantaneously by dehydrated sheaths and they are very resistant to desiccation. Thus, in soils which have a significant fraction of cyanobacterial sheath the infiltration of water is accelerated during rain, and they constitute an effective conservation of water availability for the soil biota and plants.

Intact cyanobacterial soil crusts are highly resistant to erosive forces of wind and water. Once wetted, the crust becomes relatively elastic. As a result, the soil structure is most susceptible to mechanical disruption by trampling when it is dry, and relatively resistant to disruption and dispersal when moist. Grazing by livestock in arid regions is very destructive to this soil cover. Once grazing is completely excluded, 8 to 10 years may be required to double the area covered by a fully developed desert crust (mature cryptogamic crust is characterized by the appearance of soil lichens and mosses). The actual rate of recovery may be strongly correlated with the initial degree of grazing damage. More than 20 years may be required to reestablish a fully developed community on completely denuded soil. Reestablishment of a stable community may occur within 5 years on soil with only a moderate degree of randomly distributed disruption. Complete cessation of grazing, or restriction of grazing to short periods of light intensity following rains is the best way to halt this process and ensure the most rapid development of increased soil cover with this aridity-adapted microbial community. However, the degree of grazing control required will vary depending on the plant cover and moisture availability. Management for maintenance and recovery of desert crust communities requires highly regulated land use. It is recognized that such policies may be difficult to implement and enforce in some regions as they are most disruptive to local agriculture and traditional practices. However, this approach is the most inexpensive use of microbial processes for soil stabilization and can be initiated immediately. It is important to determine for specific ecosystems of the arid region of the earth the extent of soil coverage with cryptogamic crusts and whether these areas are spreading or declining. The trend in coverage of these communities could be the first indication of advancing or retreating desertification through overuse.

The use of cyanobacteria to enhance the quality of agricultural soils would involve growing large batch cultures of selected species for inoculating fields. The dinitrogen fixing species should be are the primary targets for such a program. Selective isolation of those species already adapted to the region in question is the most reasonable approach at this time, although genetic engineering techniques may provide improved strains for such purposes in the coming decades.

In some Asian and African countries as well as in Mexico species of the genera Nostoc and Spirulina have been traditional food supplements. The amino acid complement of certain of the species in these genera is remarkably suited to human needs. Yet, the present high cost of production and current marketing demand preclude this use as a basic source of protein for malnourished peoples, although some programs having this objective are under development. Whereas the use of cyanobacteria as a human food source on a large scale is still several years away from attainment, some progress has been made in harvesting natural cyanobacterial blooms as adjuncts to animal feeds. It is difficult to manage open air cultures because contaminants often become opportunists and outgrow the desired species. Also, large amounts of water and nutrients may be required as well as power for the aeration of cultures. Since cyanobacterial cells themselves are largely proteinaceous, it is possible that the harvestable biomass of any species, including that grown in saline or hypersaline ponds could be treated for use as a fertilizer or to provide additional organic matter for methane generation.

In summary, there are two possible approaches to land improvement involving cyanobacteria. The passive approach requires only new land management policies, and the active approach requires some further studies and development. However, this is certainly a promising opportunity not only for microbiological control of desertification, but also for providing supplemental food and fodder sources.

Recommendations:

1. Plans for recovery of degraded soils and for continuous future use of arid ecosystems should include consideration of the role and utilization of cyanobacterial soil crusts.

   Implementation: immediate.

2. Successful utilization of cryptogamic crusts to increase soil stability and fertility requires a better understanding of the characteristics of cryptogamic crusts, their mode of establishment and behavior. Studies should be directed to the following objectives:

   a. determination of crust establishment and recovery times in various ecosystems;

   b. determination of environmental and organismal parameters controlling dinitrogen fixation by cyanobacterial crusts;

   c. determination of soil factors required for successful crust establishment;

   d. determination of permissible crust disturbance rates under various intensities of grazing pressure and in pertinent ecosystems;

   e. determination of areas where crusts have been historically present, but are now destroyed due to various degradative processes; documentation of the specific conditions leading to degradation.

Implementation: further studies are required.

3. Cyanobacterial batch cultures, preferably locally produced, should be used as fertilizers for crops where soil and climatic conditions are suitable.

   Implementation: methodologies for this application are currently being developed in numberous countries; testing is necessary for determination of compatability of these cultures with and enhancement of yields of specific crops under local environmental conditions.

4. Methodologies for large scale cyanobacterial biomass production should be developed for its use as human food or animal fodder.

   Implementation: methodologies for these applications are currently being developed in numerous countries; further development and adaptation for arid countries are highly desirable.

G. LIMITATION OF GASEOUS NITROGEN LOSSES

The potential for heterotrophic denitrification losses from arid and semiarid soils is great. The organisms capable of performing this function are usually present and their activity rapidly begins and increases once conditions become favorable. The development of anoxic microsites in soil is possible even with a rather limited rainfall event. Thus, lack of water usually limits losses by denitrification in the arid environment. Of course, nitrate must be present or rapidly formed and organic carbon in a usable form must be present. Other factors that limit denitrification are not usually of concern in arid region soils except for seasonally low temperatures in cold deserts. Consequently, in most arid ecosystems both nitrate supply and soluble organic carbon will restrict denitrification losses. Soluble or active organic carbon becomes the primary controlling factor when nitrate is present in anoxic microsites which may be formed following rainfall. After each rainfall event, the level of soil moisture and temperature, as well as other soil properties will influence the duration of anoxic conditions. Over time the sum of the anoxic time intervals will probably be sufficient for large losses of nitrogen even in rather low rainfall regions. However, with soils inherently low in soluble organic carbon, little, if any, denitrification loss will occur. If carbon sources are added or are increased naturally by management practices, then and only then will denitrification become an important concern. Nitrogen-poor organic materials, however, may reduce the loss of nitrogen by denitrification, presumably by increasing immobilization. The loss of fixed nitrogen from cryptogamic crust (cyanobacteria), however, may be almost complete during seasons of favorable weather. Nitrification of ammonia released from decomposing cryptogams and denitrification of nitrite and nitrate apparently takes place in close proximity in the soil microsites. The conditions most likely favorable for denitrification in desert ecosystems will occur in the rhizosphere.

Under conditions of irrigated agriculture control measures have been discussed for various management systems. In natural desert ecosystems it does not currently appear that the denitrification process can easily be controlled or modified other than to avoid such soil management practices that would lead to the accumulation of higher nitrogen enriched organic matter. This, unfortunately, is counter-productive to overall soil productivity and the practices recommended herein.

Volatilization loss of ammonia by gaseous exchange to the atmosphere has not been thoroughly evaluated under the natural conditions of arid ecosystems as denitrification. Many studies have centered on the loss of NH_3 from NH_4^+ forming fertilizers applied to the surface of the soil. The formation of NH_4^+ at or near the soil surface results in NH_3 loss under natural conditions. This might apply to nitrogen fixed by cryptogamic crusts, particularly if nitrification is limited. For natural ecosystems it does not appear practical to impose practices that would limit ammonium volatilization losses.

Recommendations:

1. High C:N ratio organic matter additions to soil are more conducive to nitrogen retention. It has been recommended elsewhere herein, however, that addition of low C:N ratio organic materials to arid soils is a valuable practice. During such applications concurrent studies should be performed to establish the nitrogen loss parameters.

   Implementation: concurrent studies required during organic matter addition to soils; methodologies are available.

2. Further studies are needed on inhibition of denitrification. Such information may be drawn from studies in general agriculture, and would include inhibition of nitrification.

   Implementation: long term basic studies required.

3. Losses of nitrogen by ammonia volatilization require quantification and study in arid areas, particularly where dinitrogen-fixing cryptogamic crusts are present.

   Implementation: long term studies required.

H. MANIPULATION OF MICROBIAL SUCCESSION DURING INTENSIVE REVEGETATION EFFORTS

Use of natural successional processes for rehabilitation of disturbed lands has been recognized as a rational approach for several reasons. Application of agronomic techniques, such as seeding, mulching, fertilizing, and irrigating are often too costly and may not result in a stable system. The presence of appropriate microbial populations and processes in rehabilitated soils significantly improves the stability and yield of stable (climax) plant cover. The development of the necessary belowground microbial processes and populations will depend on the addition and maintenance of organic matter in soil. While plant propagules and techniques for reestablishing a climax vegetation are often available, microbial inoculum to reestablish the belowground ecosystem is currently not available, although the techniques are reasonably well understood. The establishment and proliferation of appropriate microbial populations in arid and semiarid soils need to be promoted by proper management for successional processes.

A large number of xeric plant species produce allelochemics which exhibit inhibitory effects not only on floral species but also on soil microorganisms. Inhibitory allelopathic effects in arid ecosystems have been especially noted on nitrogen cycle processes, such as nitrification and dinitrogen fixation by cyanobacteria as well as heterotrophic organisms. It would be advisable, for example, to control allelochemic producing plant species when cyanobacteria would be used in remedical practices or are otherwise important as primary producers and dinitrogen fixers for eventual carbon and nitrogen increase in soils. The effects of allelochemics on soil microbial processes, however, are poorly understood and information is scarce. Such effects should be examined as there are obvious implications for utilization of allelopathic effects to retain organic matter and nitrogen in soil as well as to reduce loss of nutrients, thus affecting overall soil fertility.

The following recommendations are directed to situations where intensive revegetation methods and practices are used to rehabilitate severely degraded arid soils.

Recommendations:

1. Green mulch should be used more extensively as it more nearly simulates organic matter input in soils where the early stages of natural succession are dominated by annuals. Multiple mulchings over the first few years may be necessary to produce reasonably stable organic matter.

   Implementation: immediate.

2. Amendments of inorganic fertilizers should be adjusted to the needs of xeric plants, considering that these have lower nutrient requirements compared to crop plants. Fertilization for the first few years may be necessary to couple decomposition, nutrient cycling and primary production.

   Implementation: immediate; application rates should be monitored for minimum needs.

3. Endemic or introduced plant species used to stabilize soil initially should be planted sparsely enough to allow colonization and succession by desired native species. This will increase diversity of plant species and associated microorganisms.

   Implementation: immediate

4. Seeds, seedlings and plants for transplanting should be inoculated whenever applicable. For legumes, use current technology as adapted

for arid areas (see Recommendations Section C) to inoculate seedling transplants or seeds. Plant species requiring mycorrhizal or actinorhizal associations should be inoculated with the respective organisms. Nursery inoculation of transplants is currently being tested for these purposes and should be expanded. For a number of xeric plants, however, the specific microbial symbionts still need to be determined.

Implementation: studies on plant-microbe specificities, culture conditions, and technological development at a local level are necessary for immediate implementation.

5. Qualitative and quantitative changes in fungi and microarthropods through time should be monitored to determine the success of rehabilitation. These will be the most important decomposers because of their ability to be active at low soil water potentials. Their activity will indicate the degree of success in reaching a stable system.

   Implementation: monitoring should be performed during intensive revegetation to determine success at reaching a stablized system.

6. We need to know the rate of change during succession for the following characteristics of the decomposer subsystem:

   a) baseline information on seasonal dynamics of microbial biomass associated with dominant plant species. This information is important for calculating carbon budgets;

   b) information of spatial heterogeneity of microbial biomass, rates of decomposition, and succession; these parameters will vary spatially and need to be quantified;

   c) rates of decomposition of different types of key plant species by associated fungi and arthropods;

   d) input on fungal-faunal interactions and effects on litter decomposition;

   e) climatic and edaphic parameters affecting the above factors.

   Implementation: Further studies are needed to ensure a high level of success in revegetation efforts of drastically degraded arid lands.

7. As the influence of allelochemics on soil microflora is a recognized but poorly understood controlling factor of nutrient turnover in arid soils, studies on the effects of xeric plant-produced inhibitory substances on soil microflora should be expanded.

   Implementation: long term studies required.

I. ACTIONS FOR TRAINING AND INTERNATIONAL COOPERATION

This workshop panel recognizes that there is a lack of expertise in developing countries having arid and semiarid zones who can implement policies and technologies pertinent to soil biology, and who can independently provide innovative and creative solutions to problems associated with control of desertification and rehabilitation of degraded soils. The international agencies should ensure that our recommendations listed in Sections A to H herein are seriously considered and, hopefully, adopted, utilized and implemented at national and local levels by assuring that appropriate scientific and technological expertise becomes available.

Recommendations for training and international cooperation:

1. Support for development and demonstration areas, and land mangement schemes in all countries with problems of aridity control must be expanded and made available at the level of implementation.

2. Training programs should be developed and used to ensure (a) that local scientists are familiar with the role of microbiological processes in arids lands, and (b) that local technicians are given "hands on" experience in the necessary techniques.

3. Programs to support visiting scientists in arid regions are of considerable value, but careful selection is necessary to ensure that they are also willing learners rather than dogmatic teachers or missionaries. Exchange visits both to and from affected countries are encouraged.

4. General education of national and local leaders in the seriousness of the problems of desertification, and of how microbiological processes as described here can provide strategies for stabilizating or rehabilitating the affected areas, and for increasing their agricultural productivity.

5. The following areas require special attention for training, education and cooperation:

   a) Establishment of demonstration plots, nursery installations, and desertification control stations appropriate to different ecosystems should be strongly encouraged.

   b) Because the effective and practical use of organic matter is considered the most important aspect of a rehabilitation program by this panel, proper training of technicians in the management of on-farm and off-farm sources of organic matter is critical. A basic understanding of microbial contribution to production, accumulation, and decomposition of soil organic matter in terms of the arid plant-soil systems should be emphasized. Information should be available to these personnel which will allow them to integrate responses of plant communities to grazing, and to soil organic matter and added industrial and municipal waste organic matter accumulation, degradation, and microbiological processes. This information should be used to formulate strategies for managing these systems. The strategies should lead to improved soil organic matter retention and to maximize contributions of biota for improved agricultural yields and land rehabilitation. Scientists in arid areas will need to acquire post-graduate knowledge and training in aspects of soil science, microbiology, and primary production to ensure that projects are successfully conducted.

c) Similarly, appropriate training should be provided for the technical and management personnel working in other areas, such as:

(i) nitrogen fixing systems involving Rhizobium and Frankia,

(ii) utilization of cyanobacteria (i.e., blue-green algae),

(iii) utilization of mycorrhizal-plant symbiosis, etc.

d) In addition to supporting selected local personnel for pre- and post-graduate training in developed countries, it is strongly recommended that intensive short-term courses for technical personnel involved in desertification control and land management, arranged locally, should be provided as important educational efforts.

6. Agencies and organizations that must provide support in the planning, implementation and conduct of these programs include the United Nations (UNDP, UNEP, UNESCO, UNU, IAEA, FAO), ICRISAT, ICARDA, DESCOM, and other similar governmental agencies or NGO's. Countries which have provided aid or contributed to bilateral programs with developing countries should be informed of these recommendations, including Canada, Denmark, Federal Republic of Germany, France (ORSTOM), Holland, Sweden (SIDA), and the United States (USAID). Some countries such as the USA and Germany arrange bilateral agreements only with qualified experts in affected countries. Unfortunately, some countries do not have such expertise and, thus, agreements cannot be promulgated.

Finally, funding agencies and donor countries should recognize that training programs need to be established on a long-term and continuing basis if efforts to control desertification, rehabilitate degraded lands, and increase agricultural productivity are to be effective.

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