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New Technologies to Combat Desertification

Proceedings of the
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held in Tehran, Iran
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The United Nations University

Environment and Sustainable Development
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The United Nations University (UNU) is an organ of the United Nations established by the General Assembly in 1972 to be an international community of scholars engaged in research, advanced training, and the dissemination of knowledge related to pressing global problems of human survival, development, and welfare. Its activities focus mainly on environment and sustainable development, and peace and governance. The University operates through a worldwide network of research and postgraduate training centres, with its planning and coordinating headquarters in Tokyo, Japan.

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The United Nations University and Its Role in Desertification Issues

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Introduction

The United Nations University (UNU), as an autonomous organization under the United Nations umbrella, contributes to the goals of sustainable development set by the UN through research, advanced training, and dissemination of knowledge. It provides and manages a framework for bringing together the world's leading scholars to tackle pressing global problems. In particular, it helps alleviate the isolation of researchers in developing countries. Additionally, the UNU works in collaboration with existing academic and research institutions in the various parts of the world. It also works closely with the UN Secretariat, UNESCO and other UN organizations, acting as a link to the academic community and serving as a think tank for the entire UN system.

On the whole, the UNU takes a multidisciplinary approach towards investigating pressing global issues, ensuring a broad range of viewpoints. Environment and sustainable development issues are an example of this approach, which have featured centrally in UNU's programme since its inception more than 20 years ago. In this context, issues related to desertification have also been an important element of the activities at the UNU.

This paper provides an overview of the activities directly linked to the issues pertaining to land degradation and desertification. Several symposia and conferences that have taken place under the UNU umbrella are highlighted. Some of these scientific meetings have led to publication of the findings and their dissemination. Based on this contextual involvement with these issues, UNU's role in desertification issues is identified in this paper. In this regard, some key activities are recognized that should be undertaken with UNU providing the leadership and resources.

Background

A major milestone in the context of desertification issues was the United Nations Conference on Environment and Development UNCED (1992), organized in Rio de Janeiro. A significant outcome of the conference, also known as the Earth Summit, was the development of Agenda 21. In Chapter 12 of Agenda 21, the desertification issues are clearly presented and their importance in achieving sustainable development is highlighted. This was also the first time that a formal definition of desertification was adopted: "Desertification is land degradation in arid, semi-arid and dry sub-humid areas resulting from various factors, including climatic variations and human activities."

In order to meet the challenges posed by desertification problems, the following programme areas were identified within the Chapter 12 of Agenda 21:

- Knowledge base, including information and monitoring systems,
- Intensified soil conservation, afforestation and reforestation,
- Eradication of poverty and promotion of alternative livelihood,

- Comprehensive national anti-desertification programmes,
- Comprehensive drought preparedness and drought-relief schemes, and
- Popular participation and environmental education.

These provisions in the Agenda 21 led to an in-depth discussion of various issues at an intergovernmental level, which was formally initiated in May 1993. The main purpose of these intergovernmental negotiations was to elaborate an international convention to combat desertification in those countries experiencing serious drought and/or desertification, particularly in Africa. The UN Convention to Combat Desertification (UNCCD) was formally adopted on 17 June, 1994 and opened for signature on 15 October, 1994. Its 50th ratification came on 26 September, 1996, leading to its entry into force by 26 December 1996. To date, 145 countries have signed and ratified the convention.

Within the UNCCD, the overall approach for combating desertification is identified. The key elements of this approach are:

1. **Innovation is the key:** New and innovative solutions to the problems posed by desertification have to be sought. This means that a bottom-up approach for development of technologies has to be adopted. Additionally, there has to be a significant transfer of technology from the developed countries to the developing countries.
2. **Emphasis on sustainability:** The various methods adopted for combating desertification should be truly sustainable as a long-term measure. Short-term and quick-fix solutions have to be avoided.
3. **National Action Programmes:** The member countries have to develop national action programmes to combat desertification. This should involve development of long-term strategies and policies, and integration with other national development plans. There should be an emphasis on involvement of local communities in developing and implementing specific measures to combat desertification. In general, the national governments have to provide conditions inducive for combating desertification, including allocation of financial resources.
4. **Partnership Agreements:** There have to be regional agreements to address issues related to transboundary problems.

This convention, thus provides a suitable framework for implementing specific measures to combat desertification. It is important to point out that the emphasis on the regional nature of desertification problems is present in the convention. Similarly, the involved parties are urged to seek innovative solutions to the problems faced. In this respect, it should be realized that there is also a close linkage between desertification and other existing regimes at the international and global scale. These include:

Biodiversity Issues: The efforts to combat desertification are closely linked to conservation of biodiversity, particularly in arid and hyper-arid lands.

Wildlife Protection: Also related to biodiversity conservation, the protection of wildlife in arid lands is an important issue when designing efforts to combat desertification.

Climate Change Impacts: The changes in climate can profoundly affect (positively or negatively) the extent and level of desertification, particularly when focusing on climate change as a result of anthropogenic activities.

Food Security (and land resources): Another key element of efforts to combat desertification is to preserve the land as a resource for food production and livelihood. Significant efforts are, thus, focused on ensuring food security in arid lands.

On the whole, the UNCCD has provided the backdrop for the activities related to desertification undertaken at the UNU. However, it is important to point out that the UNU was actively involved in these issues even prior to the existence of the convention. These activities can be classified into three broad categories: (a) international conferences, symposia and workshops; (b) papers written for and presented at UNU; and (c) books published by UNU. Although, the some of the publications are interlinked with the workshops and symposia, each one of these categories is discussed here individually.

Conferences, Symposia and Workshops:
UNU had organized a number of workshops during the late 1970s and during the 1980s to focus on issues related to desertification, land degradation and sustainable development in arid lands. These include: a workshop held in Chiang Mai, Thailand in 1978 (Ives et al., 1980); a workshop held in Hamburg, Germany in 1979 (Mabbutt, 1980); a workshop held in Tuscon, Arizona, USA in 1979 (Mabbutt et al., 1980a); a workshop held in Coahuila, Mexico in 1980 (Mabbutt et al., 1980b); a workshop held in Gaborone, Botsawana in 1982 (Arntzen et al., 1986); an international symposium held in Tokyo, Japan in 1992 (UNU, 1992); and a seminar on Aral Sea held in Tokyo, Japan in 1995 (UNU, 1995).

Additionally, a special meeting on desertification was organized as a part of the 20th International Geographical Congress held in Japan (1980). This meeting, supported by UNU and UNESCO, was held at the foot of Mount Fuji. It included a presentation by Dr. Chao Sung Chiao which provided a detailed description of Chinese deserts and related issues.

In 1995, UNU organized a symposium on the Central Asian water crisis, with a particular focus on three enclosed seas: Aral, Caspian and Dead Seas. Among other leading experts, two Iranian specialists gave presentations on the Caspian Sea issues. In 1996, UNU organized another workshop on arid lands: “Fresh Water in Arid Lands.” These meetings resulted in publication of books by UNU Press that provide an excellent overview of the problems related to these three seas.

In parallel to the activities described above, UNU has collaborated with international institutions such as the Chinese Academy of Sciences. As an example, this collaboration has provided opportunity for Chinese scholars to visit Japan. The so-called south-south programme has resulted in similar collaborations. UNU has supported researchers in developing countries to visit other developing countries with same environmental and scientific background. For example, in the case of using biomass in semi-arid regions, UNU sent Indian researchers to Africa to help assist the technology transfer.

More significantly, UNU co-sponsored the UNCCD meeting on Desertification and the Role of NGO's. This meeting was held at the UNU Headquarters in Tokyo in 1997. This meeting has indirectly provided an excellent linkage to the convention secretariat and may lead to close collaborations in the future.

Paper Presentations and Related Publications:
Several lectures presented in the UNU Open Forum have focused on desertification issues. These lectures have also been published as stand-alone papers by the UNU Press. These include an overview paper on the myths and facts related to desertification by Prof. Monique Mainguet (Mainguet et al., 1996). Also related are the papers presented by Dr. François Doumenge (Doumenge, 1997) and Dr. Arie Issar (Issar, 1997). Dr. Doumenge discussed the problems faced in the Mediterranean Sea area, whereas Dr. Issar focused on the projected impacts of climate change.

Books Published:
Over the years, several books have been published by UNU on subjects directly related to desertification issues. The topics cover a wide range of subject areas, including: overview of desertification issues (Heathcote, 1980), water resource management (Murakami, 1995; Uitto and Schneider, 1997), land resource utilization (Ruddle and Chuanjun, 1983), ecosystems and technology development (Cordes and Scholz, 1980; Burley, 1982; Spooner, 1984; Davies 1985; Parkes et al., 1985), regions at risk from land degradation (Kasperson et al., 1995), and water management for enclosed seas (Kobori and Glantz, 1998). It is obvious that these publications do not cover all the aspects of desertification, yet they form a worthwhile collection of reference documents.

Network Development

We must recognize that UNU is quite different in its function and operation from other UN organizations. Particularly, it is important to understand the fact that developing networks among researchers and scholars is a key mode of operation for UNU. For developing countries, this also eventually leads to capacity building in terms of their human resources.

Organizing workshops and symposia on a regular basis is an effective means of establishing and maintaining these researcher networks. With this goal in view, the Environment and Sustainable Development programmes at UNU has organized several workshops in connection with desertification issues.

This Tehran symposium and workshop marks the development of a relatively new network within UNU to focus on desertification issues. It is important to point out that desertification issues impact several different fields of knowledge; which include technology development, social sciences, environmental sciences, and sustainable development. Therefore, the structure of this network has to be flexible and multidisciplinary in its approach. It is hoped that these UNU-sponsored workshops will help crystallize such a network of researchers and scholars.

Proposed Future Directions

Considering the importance of desertification issues, UNU is seeking a more active role in research and technology dissemination related to desertification. To achieve its goals, UNU proposes several mechanisms:

- **Development of a Network of Researchers** – The geographical area of focus includes Northern Africa, Middle East, Central Asia and China.
- **Capacity Building** – This can be achieved through the training workshops and information dissemination, particularly focussing on young professionals and decision-makers in developing countries.
- **Holding International Workshops and Symposia** – The focus of these issues will be on management of desertification problems within the network region with a particular emphasis on water management.
- **Publishing a Series of Proceedings** – The technical papers presented at the symposia and other highlights of the workshop will be combined into these proceedings for dissemination purposes.

It should be pointed out that several other UN organizations are already engaged in various aspects of desertification, either directly or indirectly. These include UNCCD, UNESCO, UNEP, WHO, WMO, FAO, UNSO, and CGIAR group. Global financial institutions, such as UNDP, World Bank, and IFAD are also involved. Furthermore, we should not forget the role of NGO's that have been working in this field. The role of UNU has to be viewed in this context.

The small organizational size of UNU means limited resources for activities. However, it is an institution that emphasizes academic excellence in the work done under its umbrella and is academically "neutral." Additionally, there are several Research and Training Centres and Programmes (RTC/Ps) working under the UNU Headquarters which may support research on desertification issues, these include: Institute of Advance Studies (UNU/IAS; Tokyo, Japan), Institute for Natural Resources in Africa (UNU/INRA; Accra, Ghana), International Leadership Academy (UNU/ILA; Amman, Jordan), International Network on Water, Environment and Health (UNU/INWEH; Ontario, Canada), and World Institute for Development Economics Research (UNU/WIDER; Helsinki, Finland).

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2

Iranian Agriculture and Salinity

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Introduction

Iranian agriculture is thousands of years old and this reflects the length of time during which soil and water resources of the country have been utilized for crop production.

Geographically speaking, Iran is located between 25-40° N latitude with total area of 165 Mha. Climatic conditions of Iran are mostly typical of arid and semi-arid regions. Nevertheless, the country has a wide spectrum of climatic, physiographic, edaphic, and hydrological conditions. As such, it is no surprise that both tropical and cool-season crops are grown and produced in Iran. Just to name a few, one could mention citrus dates, pistachio sugarcane, and rice, as well as apples, cherries , walnuts, and apricots. However, the most extensive cultivated area is devoted to wheat and barley, which are the main sources of staple food and protein for the average Iranian. Wheat alone covers about one third and fruits cover nearly one fifth of the total irrigated land of Iran.

Both systems of irrigated and rainfed farming (dry farming) are practiced in different parts of the country while the area devoted to each system varies considerably depending on agroclimatical conditions. Rainfed agriculture and dry farming are most successful in western and northwester of Iran, as well as the sloping lands in the Caspian coast. In other parts of the country, dry farming is also practiced in hilly areas, but the yields obtained are limited. In the central plateau, as well as the southern plains and the southern coastal areas of Iran, crop production is mostly possible only under irrigation. This is because of low rainfall and high evaporation rates. In some low lying plains of the central plateau, the annual rainfall is about 50 mm while the annual evaporation may exceed 4000 mm. The country-wide average precipitation is about 250 mm.

Soil, Water Resources & Salinity

The major types of land use in Iran are presented in table (1). As shown there, approximately 11% of the total land area of the country is used for crop production. Of this area, annually, about 12.7 Mha is cultivated (irrigated plus rainfed) and nearly 5.8 Mha is left as fallow. According to this table, an estimated area of 32 Mha of unused land of Iran is potentially suitable for crop production, but shortage of water resources on these lands limits their role in agriculture. It is noteworthy that more than half of the country is covered by rangeland (mostly of low to medium productivity), waste lands, and mountains. Sand dunes, salt flats, and other non-productive land, mostly in the central plateau and the southern coastal area, comprise 11.6 Mha. Major soil types of Iran are Xerosols, Arenosols, Regosols, Solonchalks, and Lithosols.

As to the water resources, by far the largest source is the annual precipitation. The latest estimate of the average annual precipitation is 416 Km^3. Out of this volume, nearly 300 Km^3 directly evaporates from soil surface or is evapotranspired from forest canopies, rainfed crops, etc. The annual surface streams with internal origin are about 105 Km^3, including 13 km^3 of surface water which enters the country from

Table 1. Agricultural and general land use in Iran

Land use			**Area/million**
1. Irrigated Land	annual crops		5.2
	orchards		1.1
	fallow		2.2
		subtotal	8.5
2. Rainfed	annual crops		6.4
	fallow		3.6
		subtotal	10.0
3. Unused but potentially productive land in arid environments			32.5
4. Forest and scatted woodland			12.4
5. Range, wateland and mountains			90
6. Sand dunes, salt flats, others			11.6
Total area			165

the neighboring states. Direct recharge of the alluvial aquifers amounts to 25 km^3/year. Also, 29 km^3 of utilized water returns to the surface streams and ground water each year. This means that the total potential volume of water for annual use is 159 Km^3. (130 Km^3 of renewable water resources and 29 km^3 of return flows). Presently, the annual volume of water used in different sectors is as follows: agricultural sector 81 km^3, urban and industrial sectors 6 km^3 (2).

Salinity of soil and water resources is a serious threat in many parts of the country. Estimated land area affected by salinity varies between 16 to 23 Mha (Kovda, 1970, Dewan, et al 1964, Roozitalab, 1987, Siadat et al 1997). These figures include both cultivated and barren lands. No exact data is available on the extent of this problem in the farmlands. The main difficulty in this regard is the temporal variations of salinity during the growing season, due to the effects of irrigation water which add or leach the salts.

As to the quality of the surface water resources, it is difficult to make general statements. However, it is probably fair to say that the major rivers of the country have a low salt load (an electrical conductivity of about 0.3-0.7 dS/m), Fig.(1). But, variations along the stream occur as these rivers receive drainage water of the neighboring farmlands. Besides, with the decrease in flow rate during the summer months, salts concentration may increase to limiting levels.

Salinity of the ground waters is more serious than the surface waters. This has been increasing in recent years due to the overdraft and intrusion of the surrounding saline bodies of water. Considering the fact that nearly half of the water used in Iran's agriculture comes from the ground water, the threat of salinity effects on the sustainability of crop production in the country becomes evident.

Causes of Agricultural Salinity in Iran

Considering the diversity of geological, climatic, and hydrological conditions of Iran, it is no surprise that many factors play a role in the development of salinity problems in Iranian agriculture. Siadat, et al, (1997) put these factors in two groups: Natural factors and human-induced factors. The natural causes of soil salinity in Iran are geological conditions, climatic factors (evaporation, rainfall, and wind), salt transport by water, and intrusion of saline bodies of water into the coastal aquifers. Nevertheless, what seems to be of greater concern and importance is the human-induced salinity. This type of salinity stems from poor water management, following, over grazing, and improper land leveling. Also, ground waters overdraft, which enhances saline water intrusion, is another human-induced salinity factor.

Agricultural Production and Salinity

During the last decade, agricultural sector has been one of the main priorities in the national, development plans. The most recent statistic on the annual cultivated area (Iranian. Ag. Statistic, 1996-97) reveals that this area is about 14 Mha. Annual crops occupy nearly 12 Mha of land and the other 2 Mha is under orchards. Cereal crops (i.e. wheat, barley, and rice) cover almost 70% of the cultivated land, while wheat alone covers nearly 52%. As to the permanent crops, the most important ones are, respectively, pistachio (354,000 ha), grapes (275,000 ha), dates (230,000 ha), citrus (230,000 ha) and apples (153,000 ha). The total production of annual crops is about 47.26 million tons (MT), and that of the orchards is 11.25 MT. All together, total annual production of agricultural crops amounts to 58.5 MT.

About 90% of this production comes from irrigated fields. This point is of prime importance because almost all of our agricultural salinity problems are confined to irrigated fields. In areas where we have our most serious salinity stress, we are most dependent on irrigation for crop production. Areas such as Sistan, Khuzistan, Yazed, Bushehr, Azarbijan Sharghi, and Ghom area some of the examples. Although in each of these areas non-saline soils are not uncommon, but development of salinity in soils (and sometimes in water) has been on the rise. It is unfortunate that there is no established observation network for monitoring the changes in soil salinity over years. Nevertheless, field observations of patchy crop stand, retarded growth, leaf burn (where sprinklers are used with poor water quality), as well as the increasing complaints by the farmers are evidence for the expansion of salinity problem. Another evidence in this regard is the salinity trend in waters, particularly the well waters (Siadat, 1997).

In Iran, it is a fact that the average yield of different crops is much higher under irrigated system than under dry farming. For example, the average yield of irrigated wheat is about 3200 kg/ha while under dry farming this figure is below 1000 kg/ha. This fact has led many policy makers and planners to emphasize the expansion of irrigated farming system. During the 1980's and early 1990's, irrigated area expanded at a rate of 3.8%. For the second national development plan (1993-98), an increase of 0.5 Mha in irrigated land, with emphasis on pressurized systems, has been set as an important target.

The policy of expanding irrigated agriculture may turn out to have grave consequences, especially in terms of salinization of our soil and water resources. The observation that salinization and water logging conditions have expanded in the old as well as the new irrigation projects should not be overlooked. Lack of proper water management, both on the farm and at the project scale, has resulted in low water use efficiency. A combination of 60% conveyance efficiency and 50% application efficiency, leading to an overall efficiency of 30%, is usually cited in official reports. Consequences of this low efficiency are obvious: the rise in water table, evaporation of water from the soil surface, and accumulation of salts in the top soil.

Another problem associated with the expansion of irrigated farming is the overdraft of ground water. Presently, the total ground water recharge of Iran is estimated to be 46 km^3 while the annual abstraction amounts to 55 km^3. A negative balance of 9 km^3/year is alarming. This situation has resulted in both the lowering of ground water tables and higher salinity of water (Siadat, 1994). With the increase in salinity of irrigation water, soil salinity will certainly intensify.

Clearly, this suggests that expansion of irrigated farming without due considerations, particularly for training on water management, is very risky. The sustainability of our agricultural production is highly dependent on the "health" of our soil and water resources. But, the future of these resources is highly threatened by salinization and eventual decertification. The time has come that we take lessons from our previous experiences and provide a balance between the hardware and the software of irrigated agriculture.

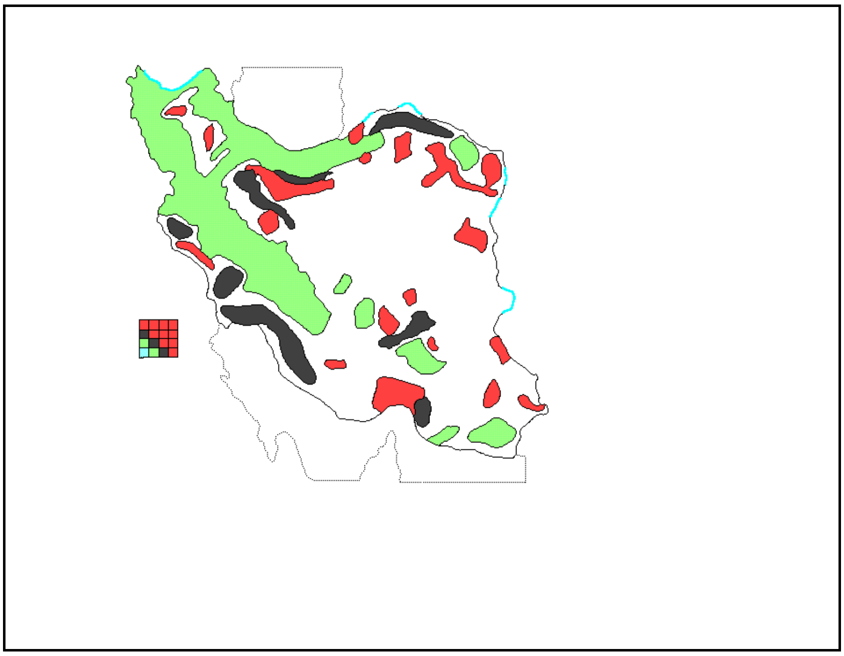

Figure 1: Intensity of Salt Load

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3

On Public Participation in Combating Desertification

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The Global Environmental Change

Currently, the world is in the state of change. The main factor of the global change is the excessive, and yet, increasing load that the human activities exert on the sphere where the humans live (the ecosphere). The global change has put on the world's agenda a number of major problems threatening the stability of the ecosphere, and, hence, the survival of mankind. Among these major problems are the ones associated with the deterioration of the biosphere as the area where the living organisms exist.

Human activities have deeply changed the Earth's face. Large pieces of virgin lands have been ploughed. A good portion of the primary forests was changed for arable land or secondary forests. Irrigation and drainage transformed dry or, correspondingly, wet lands. The mankind has transformed about 20-30 % of the ice-free lands to such an extent, that the present landscapes cannot any longer indicate what were there the primary landscapes. Initially untouched territories were converted into agricultural fields, orchards, pastures, human settlements, industrial and transportation infrastructures, etc. In total, about 60% of the world's ice-free territory have been antropogenically transformed. Out of 96 zonal types of landscapes that existed on the plain territories in the world, about 40 types have disappeared or are deeply transformed.

The main features of the man-made transformation of landscapes and ecosystems are as follows:

- The fluxes of matters within a primary natural system are almost balanced, so that a system is almost closed. A system becomes ever more open due to the human activities such as the removal of harvest from a field. The same is correct for the energy fluxes in a natural system. One can say that the degree of the system's openness serves as an indicator of its man-made transformation.
- The homogeneity of the landscapes increases. It can also be an indicator of the antropogenic transformation of the territory.
- The ecosystem's productivity decreases in proportion to the value of the man-made load integrated over certain time.
- More is the integrated man-made load, more are the disturbances in the evolution of landscapes and ecosystems.
- Chemical equilibrium in landscapes and ecosystems have been formed as a result of their evolution. Currently, it is disturbed. The man-made fluxes of chemicals often are of one or two orders of magnitude larger than the natural ones.
- The fluxes of nutrients (nitrogen, phosphorus, etc.) are particularly on the increase due to man's activities.
- The man-made transformation of lands keeps going on.

Desertification as the Process of Land Degradation.

The man-made degradation of the world's ecosystems can be seen as a loss of ecosystems' biological productivity, as well as of their biomass. In relatively wet systems, the degradation of the landscapes is manifested, first of all, as deforestation and in relatively arid systems, as desertification. Natural conditions favorable for the development of these two degradation processes exist potentially in the world on over 90% of the ice-free land. The human actions convert this possibility into the reality.

The indicators of the desertification include the following: reduction of areas covered with vegetation; increase of the land surface's albedo; considerable loss of the perennial plants, in particular trees and bushes; degradation and erosion of soils; advancement of sand masses; salinisation and water logging of soils; etc. These processes are natural and they are typical of the arid systems. They are naturally controlled. But if the changes are triggered by man's actions, the consequences might increase above the usual ones and become irreversible.

According to the climatic conditions, the deserts in the world should occupy about 48 million sq. km (including the ice deserts). In fact, in accordance with the present distribution of the soils and vegetation, the area of deserts reaches 57 million sq. km. The difference of 9 million sq. km represents the man-made deserts. In addition, about 25 million sq. km more is the area of less severe desertification.

About 3/4 of the arid territories in Africa and North America are subject to degradation, that is to desertification. One sixth part of the world population lives in the zone of the desertification threat. The world economic losses due to the desertification are estimated at US$ 42 billion a year (1990).

Both the deforestation and the desertification are very complex processes, of a multidisciplinary nature, with the strong interaction of many natural and social actors. The principal subjects selected as the main topics for this Conference should not be considered as purely of the technical, or, on the contrary, for the one addressed in this paper, of the social nature, but rather as the systems combining the both.

The International Convention to Combat Desertification (1994) gives the following definition: "Desertification means land degradation in arid … regions, which occurs due to different factors, including oscillations of climate and man's activity." And further: "…Degradation of land means reduction or complete loss of…the biological or economic productivity of non-irrigated and irrigated lands, or else, of pastures and forests, due to the use of lands, or other actions leading to such processes as wind and water erosion of soils, deterioration of physical, chemical and biological properties of soils, and to the long-term loss of natural vegetation."

The Systems Aspects of the Desertification Process

The subject of the Public Participation in Combating Desertification is predominantly of the social nature and it is based on the principal features of the nation, such as its history, economic development, natural conditions, culture, traditions, legislation and other factors. The objective of this paper is to look at the expertise recently accumulated in the public participation in environmental management in other than Iran parts of the world, particularly in Central and Eastern Europe (CEE), where very important reforms took place over the last 10 years or so. Out of the relevant available literature, the following is referred to extensively in this paper: *Manual on Public Participation in Environmental Decision Making. Current Practice and Future Possibilities in Central and Eastern Europe* (edited by M. Toth Nagy et al. Regional Environmental Centre for Central and Eastern Europe. Budapest, 1994, 365 p.).

My colleagues members of the UNU team might wish to bring to the attention of the Conference participants the experience from the other parts of the world. It would be particularly relevant since the desertification in Europe due to the favourable natural conditions is not wide spread. It is confined mainly to the areas of Russia adjoining the Caspian Sea and, to some extent, to the Mediterranean region as well as to some pockets elsewhere, particularly Hungary. Then, an ensuing discussion might had reviewed the relevance of the accumulated expertise to the conditions and circumstances in Iran.

The Environment and Human Rights

The second half of this century has brought two major changes in the social life: human rights and the environment were recognized as fundamental values. The 1972 Stockholm Conference linked human rights and the environment in the first principle of its declaration. The "right of environment" was thus formulated for the first time. It includes the right of all individuals to be informed of plans and projects which may deteriorate their environment, to create and accomplish their own projects, to participate in the procedure leading to a decision, and to dispose of adequate means of redress for the damage suffered or for the lack of respect of legal guaranties.

Public Participation

The heart of the "right of environment" is public participation, which necessarily includes prior information. For this reason, recent developments in international law stress the importance of public participation. It is advocated in the Rio Declaration and in Agenda 21 adopted by the Conference on Environment and Development (1992). It also can be found in the most recent international treaties, including the one on combating desertification.

Earlier, the role of the public has hardly been recognized and developed. It is a relatively new phenomenon in the whole process of decision making. Many countries, even in Europe, do not know how to develop and encourage "public responsibility", so that it might influence the process.

Public participation is a key term in this respect. In the case of desertification control, the public may play a particularly important role in the process by not only attacking somebody's actions, but directly and actively participating in the desertification control activities.

The governments, on the other hand, should not consider the public as an adversary but as an ally. The national plans of action to combat desertification, or similar documents, should be a result of the joint activity of the public and the government. Without such cooperation the plans of action are doomed.

The "public" - individuals or organizations who do not represent the government, is one of the nation's greatest resources for developing and implementing desertification projects, laws and policies. Farmers, non-governmental organizations, agricultural business groups, etc. are all members of the public. Individually, each member of the public brings a unique perspective to a desertification issue. Together, members of the public have more knowledge about their countries' natural resources and environmental problems than the government ever will. Their number alone make them more pervasive than the largest government agency. In order to ensure that sound decisions, actions and laws are made, all members of the public should have the opportunity to make their position known, to participate, if needed and possible, in the collective works in a field, and to challenge those decisions, laws and policies which fail to consider their views and actions.

Four basic principles of public participation can be formulated:

- The right of access to relevant information;
- The need of the problem awareness building;
- The right to participate in actions and discussions;
- The right to complain, appeal and sue.

Against this background, various non-governmental organizations combating desertification can be defined as:

1. a group of citizens (farmers) organizing grassroots activities to implement a desertification control project or to oppose it.;
2. an association of scientific experts providing the government with a neutral, non-partisan advice on a topic;
3. a coalition of industry or agricultural lobby representatives communicating their companies' views.

In many cases of the desertification control, the public may be confronted with complex issues. For public participation to be successful and effective, a sound and clear organization can be considered a precondition. Organization and cooperation are therefore prerequisites to successful public participation. As stated above, this can consist of a simple pressure group of local residents, or of a more official body, association, or foundation, and everything in between, provided that it is clear what aim is pursued and who is responsible.

Organization and cooperation are the means to acquire know-how in a group, to collect facts and data connected with the aim that is pursued, and to raise funds through membership fees or donations, but also to develop informative and educational activities. If organizations are successful in pursuit of these goals, they will also be in a better position to receive the government support.

Public Participation in Practice

A citizen or an NGO can identify various methods of participation that will work best for their needs. Public participation may be formal, meaning its form has been prescribed by a law, or informal, meaning the public decides independently the form of participation it would take. Often, the most effective participation in an environmental management combines both formal and informal methods. Even if laws ensuring public participation in environmental management or, more specifically, in the desertification control, do not exist, rarely are there laws explicitly prohibiting such participation.

To decide which methods will work best for each particular situation, a citizen or an NGO should answer the following questions:

- What desertification problem concerns you and why?
- How can you get more information about the problem?
- What objective(s), if achieved, will help to solve the problem and most benefit your community and country?
- What are the option(s) for pursuing your objective(s)?
- Which option(s) will you pursue?

Below are some comments related to these questions.

What desertification problem concerns you and why?

Whenever one is concerned about a desertification problem, one should try to ask the following questions: When and where does the problem occur? How widespread is it? What is the source of it? How does the problem affects you? Have you or anyone else been able to document the effects, and if so what are the findings?

How can you get more information about the problem?

Generally, the more information you have about a desertification problem, the easier it will be to convince other people and the government that the problem exist and that it deserves attention. The sources of information may be *the government, the local community, and business circles.* One should find out whether the government is required to give you certain information about the problem in question.

The IV Conference of European Ministers on Environment held in Denmark in June 1998, adopted and opened for signature the Convention on Access to Information, Public Participation in the Process of Decision Making, and Access to the Legal Protection on the Issues Related to the Environment[1]. Though the subject of desertification is not explicitly mentioned in the text of the Convention, and the Convention covers the territory of the UN Economic Commission for Europe, it may become useful for corresponding developments in other regions which might include Iran.

People in the local community can be a great resource for obtaining and compiling the information. One should identify other people and NGOs in the community in question who are concerned about the problem, have special expertise about it (environmentalists, biologists, engineers, soil experts, etc.) or are directly affected by the problem. The desertification issue of concern may relate to a privately-own company or other business circles. One has to find out its position in relation to the issue, whether it has a relevant information and is willing to share it.

What objective(s), if achieved, will help solve the problem and most benefit your community and country?

Based on the information obtained about the desertification problem, one has to determine the goals which should be achieved to help solve the problem. A basic recommendation is that one tries to participate and influence the process as early as possible. The further a project or a decision making process proceed, the harder it is to influence or alter its outcome.

What are the option(s) for pursuing your objective(s)?

When listing the options for a solution to a desertification problem, one has to think as broadly and creatively as one can. The following ideas can be considered:

- Organize the grassroot activities to solve the problem by action, with a permanent monitoring and maintenance afterwards (e.g. to plant trees and look after them, to build a canal and to keep repairing it, to install fences against moving sand and to look after them, etc.);
- Create a dialogue between the interest groups;
- Conduct a media campaign;
- Launch a public education and awareness campaign;
- Influence the actions and decisions of government officials;
- Initiate or participate in the decision making activities of the environmental NGOs;
- Use the courts, if necessary and if it is not contradicted to the laws of the country.

Which option(s) will you pursue?

Once the information is gathered and all the things one can possibly do to help solve the problem are listed, one needs to decide which options should be pursued to achieve the objectives. This decision is a matter of strategy. The advantages

[1] It is not an official translation on the Convention's title.

and disadvantages of each option should be listed. The cost of the option should be considered, the amount of time to be involved should be assessed as well as the impacts on the community. Does it make sense to pursue a variety of options at the same time instead of relying on any one option for success? Given the differences between countries and communities, different options may be appropriate for similar problems.

Public Participation in Environmental Issues in Central and Eastern Europe: The Political Process

Before the Second World War the countries of Central and Eastern Europe were quite different from the points of view of political system, the governance, economic development, history, national composition, culture, etc. Then, after the Second World War, during about 50 years, the developments in all these countries went on along the similar ways. It has lead to a number of common features in areas related to the environmental movement. The countries under reforms in other regions of the world might also have similar problems.

Below are some conclusions adapted from the publication referred to above in the footnote. It says that it is characteristic of all the Central and Eastern European countries that:

a) environmental issues are not considered on their own merits,
b) they are not high on the political agenda, and
c) the environmental administration has a very weak position in the government.

In this situation, environmental ministries and other environmental organs of the state need political support from the NGOs, the parties and the public. Environmental policies and strategies should be based on a national consensus, with some political compromise among the interest groups. In order to achieve the possible impact, the green movement and the public in general should be better organized, have a strategy for gaining public support, and create a priority list to focus on the most important strategic issues.

Apparently, the political process as related to the environment is very typical of not only the CEE countries but of many mid-income, mid-developed countries from other parts of the world.

Public Participation in Environmental Issues in Central and Eastern Europe: Impacts of the Past

It seems that the lessons learnt from the recent history of this part of the world might be useful elsewhere, for the countries going along the path of reforms.

In spite of the large differences among the CEE countries in economic, political, cultural and environmental situation, they have a number of similar issues formed as a result of the developments after the Second World War, and, in particular, after the crucial political changes over the last 10 years. These issues are mentioned briefly below.

The countries in question lack a participatory democratic tradition. In the recent past, where there was a single ideological solution to a problem, there was no need to build a consensus, only to "convince" dissenters. This perception persists. Many citizens still believe that it is futile to raise their voices, since they have no hope that they will be heard. The government representatives consider just few citizens, who dare to speak out, as obstacles to their work. The term "non-governmental" is sometimes understood as "anti-governmental", with subsequent actions by the authorities. On the other hand, many radical environmentalists view dialogue with government authorities as dissention from the cause and the fraternization with the enemy.

The previous political regimes in the CEE did not accept an existence of any imperfections in the system. Therefore, only in rare cases the environmental problems were recognized. It made virtually impossible for citizens to participate in any proceeding without government approval. It was not possible for them to demand and receive relevant information, or appeal the final decisions. The administrative mindset lingers on today and represents one of the most significant issues for the reform.

Under the centrally planning system, an average citizen did not feel that he or she had a role in helping the state to gather information and to make reasoned decisions. Without this participation, it was not possible to break down barriers against the free flow of information and to build institutions of participatory democracy.

Besides the lack of a participatory democratic tradition, the public lacks understanding of the role of law administered by a fair, professional, independent judiciary. Consequently, the public is reluctant to use legal participation mechanisms, even when such mechanisms are provided.

In some new nations there are naive expectations that they should simply vote in an election and then wait for the miracles to happen. In fact, the miracles do not happen without the active pressure exerted by the public on their elected representatives.

Building new institutions takes time and efforts. The new states (or the new democratic regimes) in their attempts to establish a functioning independent state give higher priority to such issues as national security, foreign policy, economic development, state governance, while paying less attention to the problems of environment, including the desertification. In this respect, a better balance of priorities should become one of the points for the reform.

Public Participation in Environmental Issues,

Including Desertification Control: The Grassroots Role

The grassroots movements play an important role in the developing countries, particularly in the rural areas. The expertise accumulated over centuries is crucial in defining the strategies in controlling desertification. New technologies integrated with the traditional management, require careful assessment of their impacts, limits of their application and possible damage caused by them. In this respect, the role of the public is crucial.

No less important are the leaders. The traditions of respect towards the old men (and women) in a village should not be dismissed as the elders might play a role of natural leaders.

For countries with strong religious feelings, a very influential role of the clergy as spiritual leaders cannot de overemphasized. They may play a crucial role as leaders in the desertification control.

Last, but not least, the role of school as an institution and the schoolteachers is also very important: the teachers are natural sources of new knowledge and the educated judgement. The students are future brains and hands of the rural society. The desertification processes evolve relatively slowly, so do the projects. The present-day boys and girls of the school age would grow more quickly than the desertification control does, forming, thanks to a proper education, a strong and conscious group of the grass-roots people who know their area, its problems and intimately understand possible strategies.

4

Desert Research and Control Desertification in Iran

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Abstract

After more than 40 years of executive programs and 3 decades of research activities for solving desert problems, a large quantity of reclimed desertic area has been ready for life of human communities. The most important experience is; to rational management of water, specially utilization of flood flows in arid regions is the key for solving the problems. Furthermore, sharing the people (who are the actual owners of the lands) , is the only successful way to desert sustainable rehabilitation. The paper presents some more information about the subject.

Geomorphology

Iran, the longitudinal section of a conch with a sort of hollow in the eastern part of the center, resembling a mother-of-pearl shell, lying on its back. This hollow in the center is formed by the different mountain ranges along the northern, western and eastern borders of the country.

The Alborz range on the north extends from west to east with its highest peak reaching about 6000 meters. The Zagros mountain range on the west extends right from the north-west along the west to south-eastern end, its highest peak reaching nearly 5000 meters. On the east the high plateau forms the edge of this hollow. One of the most peculiar geomorphic and geological features of these mountain ranges is that, whereas the taller ranges mostly consists of limestone and igneous formations, there is always a parallel low and auxiliary range, formed mostly of gravel and mud hills.

Thus the entire hollow of the Iranian plateau is surrounded by a series of gravel and mud hills. Generally there is far less precipitation on these mud hills than on the tall ranges. The soil loosend in these mud slopes by the perennial trampling of myriards of feet, is at the mercy of the elements. Early spring rains and hot and dry summer winds carry such loosened soil into the central basin. The scars left by the water erosion are visible in the shape of frightening gullies and innumerable rills in the mud hills. This transport of soil is greatly facilitated and accelerated by prevailing geomorphic conditions described above, since the ephemeral streams and drainage channels passing through the hills carry everything down to the plains during their fast descant. The flow of mud increases the arid and saline wastes in the plains. So, the soil salinity is a common problem for most of the interior plains of hollow because of salty minerals movement to the closed or semi closed basins. Moreover, ancient dried (evaporate) lakes have formed large saline and/or clayey areas in the lowest parts of basins which is named ”Kavir”.

Climate

More than 90 percent of the land area in Iran is classified as arid or semi-arid. Of the 164.8 million hectares of whole area of the country, the mean annual precipitation of the 87 million ha of the mountainous regions and 77.8 million ha of the plains areas are 365 mm and 115mm, respectively (Annon,1984).

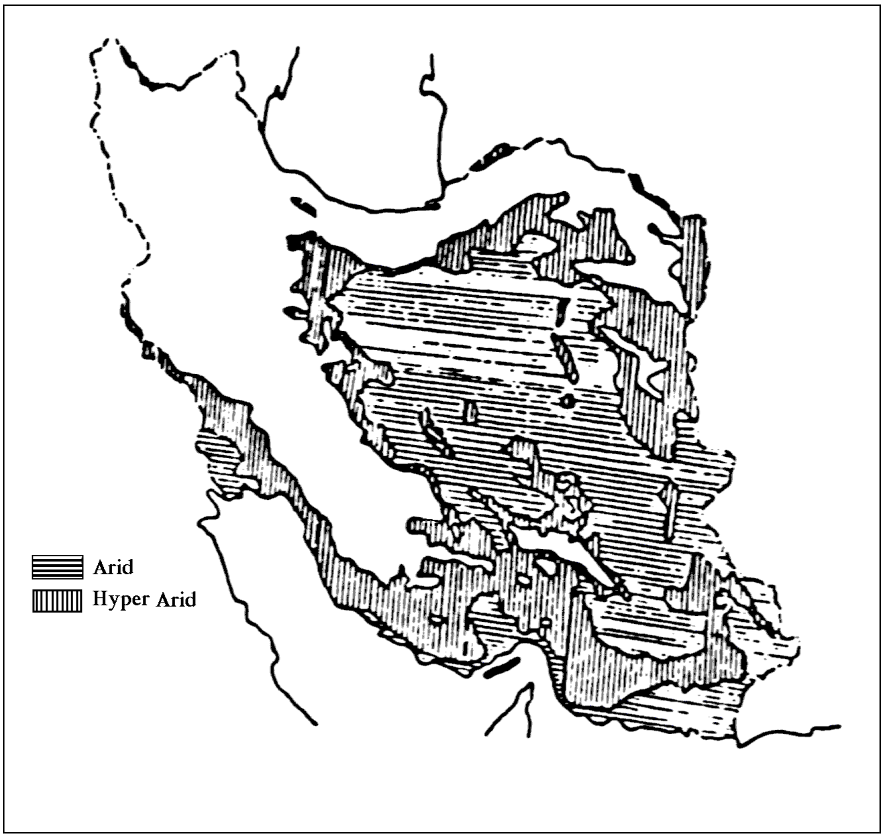

Figure 2: Distribution of arid climate in Iran

Approximately one-half of Iran's water supply comes from surface waters, with most of the remainder coming from groundwater aquifers which are significantly over drown. Therefore, drought is an ever present threat to most of Iran, (Figure 2).

Ironically, periods of drought are often punctuated by flood producing downpours that devastate the drought stricken people and their living things.

Distribution of deserts

Even though, there is a variation in reports on quantity of deserts areas in Iran, because of different definitions; some real estimations showed that, at the present the area of desert regions and sandy lands is estimated to be 34 million hectares (5 million ha active and 12million inactive sands and remain areas is salt accumulation lands, saline and alkaline soils, gravelly lands, etc.), and that of the poor and desertified rangelands which is 16 million, it reaches to 50 million hectares (Annon,1993). There is a great integrated survey to definition and mapping Iranian deserts, for getting actual numbers.

Executive programs

The first committee for soil and water conservation was established in 1958 in collaboration with F.A.O. This committee decided some measures to stabilize shifting sand dunes and in 1959 a small scale research project was put into implementation in an area of 10 ha in Khuzistan province. In 1965 another sand dune fixation project was carried out in an area of 100 ha in sot part of Khorasan. Because of successful results obtained from the accomplishment of the projects, it was immediately developed in other parts of the country, facing the same problems. These projects mostly consist of a) Biological operations; b)Physico-chemical activities.

Biological includes plantation of seedlings and cuttings, seeding, and enforcement of closures. *Haloxilon persicum, H.ammodendron, Atriplex lentiformis, A. conescence, Caliganum spp.,Artemizia spp., Tamarix hispida, T. katchy, Robinia psudo accasia, Eucaliptus kamaldulensis,*and some other drought tolerant species were used for sand dune fixation and deser trehabilitation.

Physico-chemical operations (for temporary stabilization of unstable soils and sand dunes) include petroleum mulch spraying, wind breaks, checkerboards, etc., which provide suitable conditions for plantation and/or natural regeneration.

Since the beginning of the sand dune fixation project up to now, more than one million hectares has been potentially under exploitation. Presently, The average biological production in the reclaimed land is 200 kgs and total annual production amounts to 200000 tons. Of the 8million ha has been organized for rehabilitation, and reclamation programs; 4 million ha are now under work.

The program for next 25 years (up to year 2025) is to manage 11 million ha of dessert and desertified area by the government and 12 million ha by private and social activities with cooperation of government by technical and fundamental aids and financial supports of banks. The rehabilitators will be owners of the reclimed areas in according to new lows.

Desert research activities

Through more than 30 years of Iranian desert research activities, a large quantity of research projects has been carried out for solving desert problems and to introduce and improvement measures for control desertification.

The most important result of 3 decades of desert research in Iran can be summarized as the concept of flood water utilization which is the key for combating desertification in most of the arid environments.

Iran and desertification

For better understanding the importance of water management in dry regions, here is a need to recognition the water cycle in Iran. According to published data of a 25 years period (up to 1994), the average accessible water in country is 125.3 billion m^3 (bcm) or 30.3% of total annual precipitation (413.2 bcm). Remain 69.7 is out of access because of evapotranspiration. 25% of accessible water, infiltrate directly and recharge the aquifers which supply about 55% of annual water needs, while 33 bcm of surface water provides the rest, (Table 2).

Table 2: Sub surface water balance in Iran

Recharge (bcm)			Discharge (bcm)		
Kind of recharge	**Volume**	**%**	**Kind of discharge**	**volume**	**%**
Evaporation from surface	4.02	7.1	Infiltration in highlands	17.455	34.3
Subsurface exit from country	0.955	1.7	Infiltration in plains	8.057	15.8
Drainage	6.008	10.6	Infiltration from surface flow	10.151	20
Well & Qanat	47.079	80.6	Infiltration after use	15.222	29.2
Total	58.062	100		50.885	100

Source: H.M.Arefi and M.Darvish (1996)

The volume of surface runoff which annually drains into outer and interior reservoirs adds up to 53 bm^3 if a substantial amount of this flow could be saved, a major portion of our water demands would be satisfied. Furthermore, according to reported data, there is a minus groundwater balance especially in the arid and semi-arid farmland regions. According to Table 3, the pressure of water consumption from good quality aquifers, seriously increased from 18.88 bcm in year 1977 to 149.4 bcm in 1994. (Figure 3). So, the movement of saline groundwater beneath the arable areas is expectable, and soil surface salinization is the obvious result.

In the same time, there is an acceleration trend in number of flooding through recent years (Figure 4), which is the obvious result of land degradation specially in arid regions. Use of flood water which is the common feature of arid regions of Iran, as the resource of artificial recharge of aquifers is a rational way to over come the problem. In addition, to being economically feasible and environmentally sound, flood utilization may be under taken with local traditional skills and experience, enabling desert communities to become self sufficient in water, food, forage and fuel.

Table 3 - Comprehensive water consumption of resources in Iran Well and Qanats

Year	**Numbers**	**Discharge**	**Discharge from unit**
1977	76489	18.8809	246.8
1982	93203	22.1403	237.5
1986	190237	38.5788	202.8
1990	249829	41.0285	164.2
1992	264434	43.154	163.2
1994	292478	47.079	161.0
Percent of change	282.4	149.4	-34.8

Source: H.M.Arefi and M.Darvish (1996)

Pilot project of flood spreading system

Pilot area is a 6000 ha sandy expanse located on the debris cone of the Bisheh Zard river in Gareh Bygone plain . The mean annual precipitation is about 150 mm,90 percent of which occurs between October and April. The mean annual evapotranspiration is estimated to be 2860 mm. There is a hot summer and cold winter temperature.

Eight flood water spreading system, ranging from 25 to 365 ha in area with a total coverage of 1365 ha, were designed and constructed between 1983 and 1987 on the intermediate zone of debris cone (Figure 5). The procedure used are a modification of those outlined by Quilty (1972). The systems serve as sedimentation basins and infiltration ponds for the artificial recharge of groundwater; and also as experimental plots for investigation range improvement, moving sand stabilization, afforestation, etc. (Kowsar, 1992).

Transformation of a desolate, sandy expanse into a verdant horizon is the most obvious result of the flood water spreading pilot effort. The expansion of irrigated fields in what was previously a water-short area is conveniencing evidence of the effectiveness of the measure. Increasing the amount of groundwater, decreasing of its salinity, prevention the flood hazards, is the other benefits. From Jan. 1983 through Feb. 1988 there were 21 floods of varying intensity and duration. It is estimated that a total of 38 million m^3 diverted by the system and 25 million m^3 were directed to reaching the groundwater under unimproved conditions, less than 10 percent of precipitation finds its way into the groundwater aquifers. In pilot area, grazing capacity has became 10 times and yield of farmlands reaches to two times more than the past.

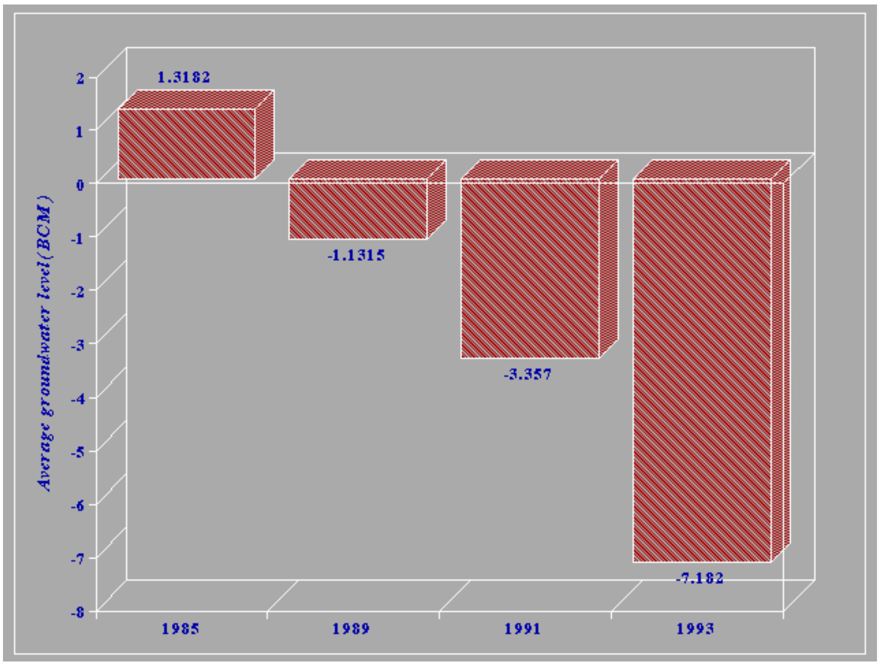

Figure 3: Trend in change of aquifer budget based on recharge and discharge data

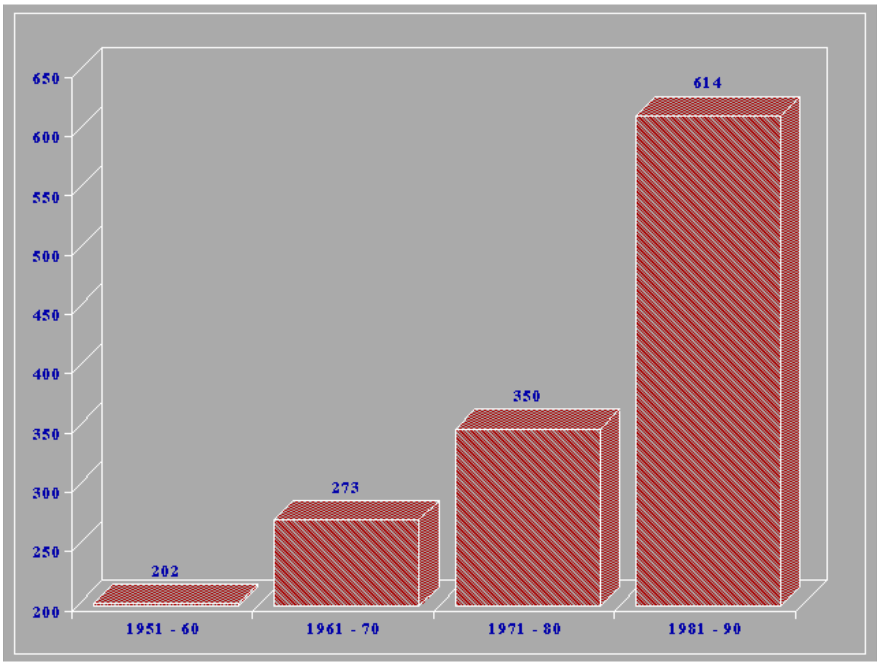

Figure 4: Number of flooding through recent 40 years

The project has been performed by A.Kowsar and its group of cooperators. In 1996recognized as the best watershed management project in the world by UNDP.

At present, the same projects has started in 20 sites of desert regions of country and handreds of young educated persons as well as the local people are being work at the projects. Most of the alluvial and piedmont plains of arid environments having floody rivers with coarse grain and deep aquifers, are suitable for this measure. In Iran, determined that near to 14 million ha of unarable lands can be change to farmlands by utilization of flood water (Arefi and Darvish , 1996).

New fields of research

As well as continuing previous activities, there is some other fields of desert research as follows;

1. Assessment and monitoring of desertification. This activity is performing as a national and integrated project using remotely sensed data and GIS, which will be complete and update by field investigations. Some general speaks say that there is a 1% trend of desertification in the country, but real data will produce at the end of project.

2. Use of new technics of plant breading in order to produce the most tollerant generation of desert plants.

3. Improvement and modification of useful and simple to use of water saving methods. For example there is a great project for utilization of clay pipes after especial processing in order to use as sub ground irrigation tools.

4. Ascertation the origin of sand dunes. The most effective sand dune fixation activity could be done in the area which is origin of the blown sands. Wind direction and speed analysis, study of sand morphology, finger printing of mineral composition; are the technical ways for recognition the origin of sand dunes.

Conclusion

Improper land use and drought are the principle agents of desertification. Reduced groundwater discharge, a variation of drought, is mainly due to over-exploitation of a limited resource; hence, it is partly man-made; therefore, man has the power to control desertification through proper utilization of land and water . This maybe partially achieved by harnessing the flash floods common to most deserts. Floodwater spreading is the key to desertification control in many parts of the world. This method has materialized in the Gareh Bygone plain, 200 km to the south-east of Shiraz, Iran.

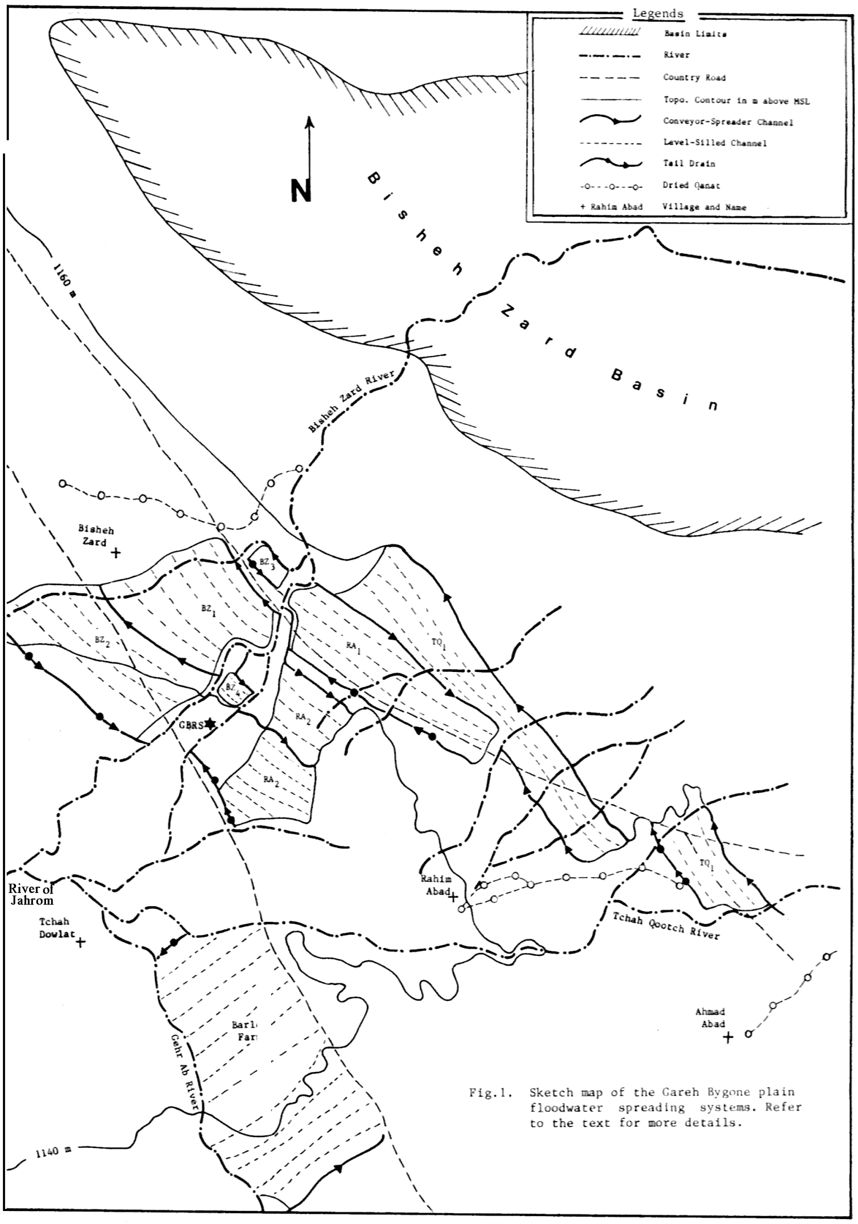

Figure 5: Sketch map of the Gareh Bygone plain floodwater spreading system

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Desertification Control: Recent Technologies in the Indian Context

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Introduction

Desertification is a major problem in the drylands of India, affecting the way of life for its inhabitants. The problem is more severe in the arid lands in the north-western part of the country, especially in the desert tracts of Rajasthan and Gujarat, as also in the states of Haryana and Punjab. Studies have been carried out at the Central Arid Zone Research Institute (CAZRI), Jodhpur, to understand the problem, its severity and its spatial distribution. These are summarised in Kar (1992, 1996a) and Faroda and Singh (1997). Over the past few decades CAZRI has also carried out researches for better technologies to counter the ill-effects of desertification. Venkateswarlu (1993), Gupta *et al.* (1997) and Faroda (1998) have provided summaries on these technologies. The present paper discusses some of these technologies and their utilities.

Wind Erosion Control

Wind erosion is a major problem in the Rajasthan part of the desert (containing the Thar or the Great Indian Sand Desert) where the higher average wind speeds, a dominantly sandy terrain, sparse vegetation cover and high human activities on the sand dunes and sandy plains lead to accentuation of sand blowing. It often leads to erosion of top soil containing precious little organic matter, damages to crop plants, burial of good agricultural lands and infrastructures, as well as disruption of transportation network. A number of mechanical and chemical methods are available globally for the control of wind erosion, but looking to the fact that this desert is highly populated and has a dominantly agricultural economy, rather than nomadic and pastoral one, many of the mechanical and chemical methods of control can not be implemented. So far, the large-scale wind erosion control measures in India have been sponsored by the Government. Farmers protect and manage their fields especially through crop residue management and fencing during critical periods. Economic evaluation of the benefits from Government-sponsored wind erosion control measures are not known. It is, however, estimated that if the Government is to continue this effort at the rate of Rs. 13,000 ha^{-1}, then at least Rs. 117,000 million will be required to cover the moderately and severely affected 8.74 million hectares area in western Rajasthan (Venkateswarlu and Kar, 1996). Two major activities of wind erosion control are sand dune stabilization and shelter belt plantation.

Sand dune stabilization

Studies at CAZRI have revealed that the sand dunes in this desert can be categorised into the old and the new dunes (Pandey *et al*., 1964). The old dunes are usually higher than 10 m. These were last formed about 10000 years back, and are naturally stabilised with potentials to support copious natural vegetation. These dunes have extremely low rates of movement, unless their ecology is disturbed by human action. The new dunes are mostly smaller than 10 m. These are forming now, are almost always bare of vegetation, and have a high rate of movement (Singh, 1982, Kar, 1993). Most sand dune stabilization programmes are directed towards the old dunes, so that the production potentials of these lands can be restored. The activities include (a) protection of the area from human and livestock encroachment; (b) creation of micro-wind breaks on the dune slopes, using locally available shrubs either in a checker board pattern or in parallel strips; (c) direct seeding or transplantation of indigenous and exotic species; (d) plantation of grass slips or direct sowing of grass seeds on leeward side of micro-wind breaks; (e) management of revegetated sites (Muthana, 1982; Harsh and Tewari, 1993).

Cultivation of dune slopes is a major form of land use in the more than 150 mm average annual rainfall zone. The dunes are largely owned by private farmers. Therefore, sand dune stabilization programme in these lands would succeed only with the participation of local population. Initially the dune stabilization programmes mostly involved the plantation of exotic trees and shrubs, but it was soon realised that the locally adapted species which can provide some economic return to the local population, are preferred by the villagers and, hence, they are not averse to protecting and managing such planted species, provided such plantation does not interfere with crop cultivation.

It is also increasingly realized now by the participants in the sand stabilization programmes that small shrubs and grasses are better sand binders than the trees. However, in most cases retention of a grass cover is a problem, especially because of uncontrolled grazing on the dunes and sandy plains alike. Bio-fencing, using locally non-palatable species, is a cheaper and more effective form of barrier. Unless it is demonstrated that biomass production from the shrub and grass cover on the dunes provides a better financial return to the owners of such lands, as compared to the *Kharif* crop cultivation, and unless the traditional mind-set of the villagers is tuned to such a message, there is less likelihood of shrubs and grass covers on dunes becoming a successful venture.

The agencies responsible for sand dune stabilization have their own limitations in carrying out the programme. For example, a number of reactivated hair pin parabolic dunes in the zone of very high wind erosion index in the desert are now being planted with trees and shrubs, especially *Acacia tortilis* and *Prosopis juliflora*, at the nosal part of the dunes. Only this small part is within the jurisdiction of the Government Forest Department. The rest of the area of any such dune belongs to the farmers nearby, who practice dry farming, often using tractors instead of country plough along the dune slopes, and open grazing during rest of the year. The natural shrubs on the dunes provide fuelwood to these villagers. Faced with such a scenario, the department attempts to develop a 'forest' cover in the land within its own jurisdiction. However, the relative paucity of a ground flora in the area of development and the non-availability of the long upwind parts of the dunes for revegetation programme go severely against the concept of controlling sand control from the dunes (Kar, 1996b). With increasing pressures on the soil and vegetation resources of the dunes each summer, the sand continues to move at an accelerated pace from the dune slopes, and accrete over to the nosal part of the dunes and then move forward along narrow, artificially created corridors of faster wind flow through the belts of planted trees and avalanche downslope, thus helping the dunes to prograde (Kar, 1996b).

The tree, shrub and grass species, suitable for stabilization programme, are described in Table 4.

Table 4. Plant species suitable for sand dune stabilization in Thar desert (after Venkateswarlu, 1993)

Annual rainfall zone (mm)	**Trees**	**Shrubs**	**Grasses**
150-300	*Prosopis juliflora, Acacia tortilis, A. senegal*	*Calligonum polygonoides, Ziziphus nummularia, Citrullus colosynthis*	*Lasiurus sindicus*
300-400	*A. tortilis, A. senegal, P. juliflora, P. cineraria, Tecomella undulata, Parkinsonia aculeata, Acacia nubica, Dichrostachys glomerata, Colophospermum mopane, Cordia rothii*	*Ziziphus mauritiana, Z. nummularia, C. polygonoides, Citrullus colosynthis*	*Cenchrus ciliaris, C. setigerus, L. sindicus, Saccharum munja*
400-550	*A.tortilis, P. cineraria, P. juliflora, A.senegal, Dalbargia sisoo, Ailanthus excelsa, Albizzia lebbek, P. aculeata, T. undulata, D. glomerata, C. mopane*	*Z. mauritiana, Cassia auriculata*	*C. ciliaris, C. setigerus, S. munja, Panicum antidotale*

Presently there is hardly any good and totally acceptable solution to the problem. To the land holder, the dune is the plank of his economic well being. With time, it is becoming increasingly difficult for him to keep the land fallow, even for a year. Therefore, he is willing to regularly cultivate the land and gamble with nature for growing crops and at the same time accept some degradation and consequent dune movement, rather than to leave the land for fencing and for less lucrative proposals like growing grasses and horticultural crops (Kar, 1996b; Venkateswarlu and Kar, 1996). The suggestion that the upper slopes and other vulnerable parts of the dunes should be left out of the cultivator’s plough is difficult to put to practice. There is no such law. It is also utopian to suggest to the development agencies to formulate ‘appropriate stabilization programmes’ in the so-called ‘source areas’. Most of the development agencies, including the agencies whose infrastructures are affected (e.g. the railways and the road maintenance departments), have insignificant areas of land at their disposal and much less resources and expertise to provide a long term solution to the menace of sand deposition. What is needed, therefore, is a set of cheap and acceptable solutions for both the private land holders and the development agencies. Given the complexities of situation in which sand movement takes place in the dunefields the solutions will be more location-specific (Kar, 1996b).

In the drier western part where large tracts of less accessible sand dunes occur, and where most of the dunes are not being held privately, with consequent very little grazing pressure, aerial broadcast of pelletized seeds of *Lasiurus sindicus* grass and suitable trees and shrubs have been tried successfully (Shankarnarayan and Kumar, 1986). Such areas should be protected from biotic interference and aerial seeding continued for four to five years, so that a good plant population is ensured.

Shelterbelt plantation

Erection of shelterbelts along the boundaries of crop fields help to reduce injuries to the tender seedlings from sand blasting and hot desiccating winds. Wind velocity at the lee of shelterbelt is reduced in the 2H to 10H distance and soil loss by about 76 per cent. Usually a three row wind break of *Acacia tortilis*, *Cassia siamea* and *Prosopis juliflora* as the side rows and *Albizzia lebbek* as the central row is suggested, but shelterbelts of *A. tortilis* perform better in reducing wind velocity than those of *P. juliflora*. Shelterbelts also reduce the loss of moisture from fields in the lee of shelters. At least 14 per cent higher soil moisture and 70 per cent more grain yield of pearl millet were recorded in the lee of shelters, as compared to that in the areas without shelters (Gupta *et al*., 1997).

Experience suggests that across-the-wind plantation of a 13 m wide tree belt, grown in pits and interspersed with 60 m wide grass belt, provides the best results. Establishment of micro-shelterbelts in arable lands, by planting tall and fast growing plant species like castor bean on the windward side, and shorter plants like vegetable crops in the leeward side of tall plants helped to increase the yield of lady's finger by 41 per cent, and of cowpea by 21 per cent, over the control (Venkateswarlu, 1993). In spite of such good results the shelterbelts in arable lands are not very popular with farmers, because in many cases the trees put hindrance to agricultural operations and inter-field movement. It is now suggested to plant trees on field bunds across the direction of wind (Venkateswarlu and Kar, 1996).

Other methods of sand control

Plantation of trees and shrubs at every location is not always beneficial. In some areas such plantations lead to more of sand depositional problem. For example, highways in the drier western parts of the Thar get more problems of sand drift where road side plantation along both sides of the roads obstruct the passage of sand-surcharged summer wind in the sandy plain areas. Sometimes the tree rows and the fences to protect them, even on the downwind end of the road, create new problems where none existed before (Kar, 1988). The fences attract more sand during summer and a sand ridge is created along the road. The best way to solve the problem is to allow sand to move across the road. The hard surface of the road acts as a zone of faster grain transportation and, hence, if the surroundings of the road are cleared of structures which reduce the wind velocity and arrest sand, the rest of the problem is easily solved by the road itself (Kar, 1992; 1994).

Construction activities within the desert often lead to some sand reactivation which, in due course of time, threaten the structures constructed. In order to minimise such hazard it is desirable to follow some precautions during the construction activities. Kar *et al.* (1994) suggested some mechanical measures of protecting the sandy terrain from sand blowing after the construction activities related to the laying of a gas pipeline in the dry western part of the desert. These included back-filling of the dug-out material in such a manner that gravel percentage is more near the surface, relative compaction of the surface so that it behaves as a zone of faster grain transportation, and levelling of all undulations along the route so that these do not attract sand accumulation. In the deflated interdunes between linear dunes protection measures like compaction of the back-filled material in the trench, first with a mat of *Panicum turgidum* grass and then with a layer of *kankar* will provide greater resistance to the high wind in the narrow interdune corridors and along the flanks of the dunes. As far as practicable, ground flora including the small shrubs, should not be uprooted, but may be cut or scrapped. This will help in regeneration of the vegetation (Kar *et al*., 1994).

Controlling new dunes

The new dunes are devoid of vegetation and are currently forming. Stabilisation programme on such dunes need to be taken up more carefully. Studies in many deserts have indicated that it is much wiser and economical to avoid the paths of barchans, rather than to interfere with their natural movement. Biological control of such dune has not met with much success, but the chemical stabilisation methods like oil spray have met with some success. However, once the surface is breached by wind a huge amount of sand becomes suddenly available for reworking and the problem multiplies (Watson, 1990). The oil spray is costly and may spoil the land permanently in countries like India where even the barchan slopes are put to monocropping of pearl millet whenever there is monsoon rainfall. Under such conditions it may be worthwhile to attempt a reshaping of the dune, or to stabilise the dune horns by simple mechanical means (e.g. spreading gravel, dry shrubs, logs etc. on the horns and crest, or putting large boulders) so that its optimum aerodynamic form is disrupted and the barchan is forced to degenerate into other less dangerous forms (Kar, 1996b). However, such techniques do not have permanent success. Moreover, the barchans are not some isolated dunes in the desert plains. They usually occur in a long series. Therefore, immobilization of one or two barchans, or disrupting their aerodynamic shape may be of little consequence when new barchans start arriving at the site and increase the sand load there It is more sensible and economical to let the barchans pass rather than to tamper with their form, unless these pose great danger to some existing structures (Kar, 1994, 1996b).

Soil and Water Conservation

The wetter parts of the arid zone and the semi-arid areas are more vulnerable to water erosion. To counter crusting of soil and its subsequent erosion from the agricultural fields a number of practices have been suggested. These include contour bunding (low rainfall area) or graded bunding (medium to high rainfall area), contour tillage, contour sowing, etc. (Singh, 1990; Dhruva Narayana, 1993). In the black soil areas ridge and furrow system may help to reduce the problem of waterlogging, while in the hard pan soils deep ploughing at 3-4 years' interval will ensure better infiltration and root growth. Mixing crop residues and organic matter with light textured soils help to increase the soil moisture and crop yield.

In the areas where gravel form a significant part of the surface soil volume, but the subsurface is less stony (e.g. Saurashtra upland and Kachchh peninsula), periodic tillage may reduce the danger of water erosion, enhance moisture conservation and ensures better soil drainage. This is one of the reasons why farmers in the fringes of the uplands in those areas mix gravel with heavy textured black soils, while in the uplands they practice occasional tillage.

On the non-arable lands a grass cover ensures minimum soil loss, but not the cultivated fallow. Small and medium gullies can be reclaimed through clearing and leveling of gully bed, followed by construction of contour bunds and check dams, and providing of pipe outlets and ramps with suitable grasses. Deep and closely spaced gullies are not always easily accessible. Gully plugging, planting of grass species like *Dichanthium annulatum* on gully heads and sides, and plantation of tree species like *Prosopis chilensis*, *Acacia nilotica*, *Dendrocalamus strictus*, *P. juliflora*, etc. help to control erosion (Dhruva Narayana, 1993).

Cropland Management

A number of management practices are available for management of croplands in the drylands. Many of these counter land degradation and improve the crop yield. Few such practices are highlighted here.

Minimum tillage

Tillage of land at regular interval usually ensures healthy crop growth. In the sandy soils of arid region farmers normally practice deep tillage after every 3-4 years. It reduces the clod percentage in the surface soils, but encourages wind erosion. Tillage can also cause hard pan development below the depth of tillage, and crusting due to loss of soil structure (Papendic and Parr, 1997). Reduced tillage is, therefore, recommended for such areas and summer tillage is discouraged. Although Papendic and Parr (1997) advocate no-till farming for the best management of the soil, a limited tillage after the first monsoon showers has been found to be ideal in our desert (Gupta, 1993; Gupta *et al*., 1997). In experimental plots production of mung bean, clusterbean and cowpea increased with the limited tillage of one disking and sowing in a loamy sand soil under an average rainfall regime of 300 mm (Gupta, 1993). In a sandy soil the tillage needs to be further reduced.

Strip cropping

Strip cropping (or lay farming), consisting mostly of a strip of crops, followed by another of grass or shrub with fodder value, has been found to be useful for wind and water erosion control. Plants for the strips are chosen so that they do not compete with each other for moisture, nutrients, etc. The width of strips depends on the types of soil and crop. In the sandy loam of arid areas the strips may vary from 6 to 30 m. At CAZRI Farm, Jodhpur, strips of *Lasiurus sindicus* grass and *Ricinus communis* (castor) between two rows of *Kharif* crops helped to reduce wind erosion and increased the crop production, while at Bikaner 18-20 years old perennial grass strips of *Lasiurus sindicus*, *Cenchrus biflorus* and *Panicum turgidum* not only reduced wind erosion, but also helped to form surface crusting which bound the soil particles (Gupta *et al*., 1997). In the semi-arid areas the system helps to arrest water erosion and stabilize the production system. A width of 7.8 m was found to be optimum. Sorghum and pearlmillet crops were found to be compatible with *Leucaena latisiliqua* as fodder crop rows (Singh, 1990).

Management of Permanent Pastures and Rangelands

Permanent pastures are most degraded and most neglected in our desert. Many permanent pastures do not have any basal plant cover. Destruction of natural vegetation and encroachments have increased so much on these lands that the original plant communities have been replaced by poor communities (Kumar, 1998). In order to revert the process the development sites need to be protected from encroachments, for which appropriate legislation and villagers' participation are needed. It is also to be realized that different landforms (habitats) support different communities, and that the duration of enclosure for development of vegetation in different habitats will be different (Shankar, 1983). Grasses like *Lasiurus sindicus*, *Cenchrus ciliaris* and *C. setigerus*, as well as multipurpose trees and shrubs like *Prosopis cineraria*, *Ziziphus nummularia*, *Capparis decidua* and *Acacia nilotica* may be grown after some soil working. The improvements can increase the carrying capacity of an average permanent pasture from 2.5 sheep ha^{-1} to as much as 4.5-6.9 ha^{-1} sheep in sandy soils and 9.0-13.8 ha^{-1} sheep in loamy sand soils (Abrol and Venkateswarlu, 1995). Farmers may be encouraged to grow grasses and small shrubs in the short and long fallow lands.

Management of Waterlogged and Salt-affected Areas

Much of waterlogging and salinity-alkalinity hazard is associated with wrong irrigation planning. Some glaring examples are from the command area of the Indira Gandhi Canal, and the command areas of small and medium-irrigation tanks in the desert. The problem can be partly countered by vertical and horizontal subsurface drainage, as has been done in parts of the alluvial soils of Haryana and black soils of Karnataka (Abrol and Gupta, 1990; Rao and Singh, 1990). Lining of canals, judicious use of canal water and soil management are necessary to arrest further degradation of land. Irrigation with high-RSC groundwater has also spoiled much area in the central and southern parts of the desert. The soils can be reclaimed by the addition of gypsum. The requirement of gypsum has now been standardized (Abrol and Gupta, 1990). With proper choice of crops only the upper 15 cm of soil needs to be amended by gypsum. Usually the crops which can withstand excess moisture conditions, can tolerate sodicity. For highly degraded illite-rich soils of Haryana 14-15 t ha^{-1} of gypsum can start rice-wheat rotation, in which the cultivation of rice further improves the soil (Abrol and Gupta, 1990). Near Jodhpur, irrigation with water containing 2.5-7.5 me L^{-1} RSC reduced the yield of chillies and cumin by 50%, but plantago and lucerne continued to withstand the adverse effects (Dhir, 1977). A variety of crops have since been grown successfully with such high RSC water in the desert of Rajasthan, especially through gypsum treatment of the soil. The major crops include Wheat, Mustard, Barley, Cumin, Turnip and Sugar beet.

Rehabilitation of Mine Spoils

Mine spoils are becoming a source of land degradation in the arid lands of India, although the area covered under such degradation is still negligible. One of the major constraints in rehabilitation of mine spoils in arid regions is the very poor status of plant nutrients in the overburden/ mine dump. Higher pH, and exchangeable sodium, magnesium, sulpher and phosphorus, as well as salinity-alkalinity build up are the other constraints in many mine spoils (Saxena and Chatterji, 1995). Revegetation of the mine spoils is, therefore, very challenging. CAZRI attempted to revegetate a limestone and a gypsum mine spoil area to the south and east of Jodhpur with some degree of success. Saxena *et al.* (1997) listed the suitable tree, shrub, and grass species for rehabilitation of different kinds of mine spoils. For example, gypsum, bentonite, Fuller's earth and clay mine areas can be rehabilitated with species like *Prosopis juliflora*, *Salvadora persica*, *Acacia tortilis*, *Albizzia amara*, *Parkinsonia aculeata*, *Dichrostachys nutan*, *Capparis decidua*, *Desmostachya bipinnata*, *Cenchrus ciliaris*, etc. Since direct sowing of seeds provide very poor results in the arid areas, it is now advised to transplant 6 to 9 months old saplings, raised in poly-pots. Development of micro-catchments with 5% slope to ensure run-off to single row of plants, and other soil conservation practices like ridge and furrow system and half moon structures, helped to grow shrubs and grasses with about 90 per cent success (Gupta *et al*., 1998).

Conclusions

In concluding the review on desertification control technologies being tested and developed at the Central Arid Zone Research Institute, Jodhpur, it may be worthwhile to provide a holistic view of the programme and the philosophy behind it.

The densely populated desert of India has a dominantly agricultural economy. Much of the land is privately owned, and is under cultivation. Therefore, researches on desertification control technologies here put more emphasis on vegetative control of any particular problem, so that the rural population gets tangible economic benefits out of the control measures being suggested, and become interested in becoming a partner in the control of degradation. Wind erosion control gets more emphasis because it is the single largest problem. Several alternatives for vegetative control of moving sand, involving different mixtures of trees, shrubs and grasses, are now suggested to the farming communities. Improved varieties of crops have been developed and improved farming techniques have also been evolved, which help in better management of the crop lands. For controlling degradation of the rangelands, salt-affected lands, water-eroded lands, mine-spoils, etc., different packages of practices have been evolved. Once the technologies are known, these are tested in farmers' fields, and the economic benefits from the practices are worked out. The successful technologies are disseminated to the villagers for adoption. The process is a continuous one, and the technologies are being updated regularly.

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6

Combating Desertification in China

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Introduction

Desertification is one of most serious environmental and social-economic problem in the world, which has been suffering China for a long time. Desertification brought about environmental deterioration and land degradation, which caused heavy losses of economy. Therefore, it is very necessary to carry out project for combating desertification. According to research and practices for nearly 20 years, we consider that *the desertification is land degradation mainly resulted from interaction between excessive human activities and vulnerable environment* (Zhu Zhenda et al., 1989) The causes leading the land to be desertified may be of varied description, but there are two most important factors can be recognized what we called both ‘natural factor’ and ‘human factor’. The combining actions of those factors are the major causes for sandy desertification, and the human factor is more important than the natural one. So what we have been thinking that it is high possibility to combat desertification just based on the fact that we can manage the human impacts on the process of desertification, because we nearly can do no thing to change the natural impacts. During last 5 decades, the desertified land has expanded continually in the China, which total area has reached over 861,600 km^2 by end of 1980's. But some successful models of combating desertification have improved that where the reasonable landuse has been adopted over some years, the sandy desertified land has reversed and can be use again for more effective farming or grassing. Actually, where some preventing and combating measures have been adopted over decade, the desertified land has decreased. For example, according to the remote sensing monitoring result of the Mu Us Sandy Land, the desertified land has decreased from 32,590 km^2 in 1987 to 30, 650 km^2 in 1993, about 280 km^2 had been controlled annually (Wu Wei,1997).

Although the reversing value was rather low compared with its expanded areas in the North China, only about 10% of total spread desertified land, the successful models have illustrated that the desertification can be controlled through appropriated measures. What we need are the confidence and action.

Status and process of desertification

Desertification/land degradation is recognized as environmental and social-economic issues, and attracts attentions from all over the world. Most of the areas to be subject to the desertification are suffered from high pressure of population and intensive human impacts. In China the main types of desertification can be classed as follows: sandy desertification caused by wind erosion, land degradation by water erosion, soil salinization and other land degradation caused by engineering construction of residential areas, communications, coal mine and oil field, etc.

According to the conception of desertification in China, the total desertified land had reached to 861,600 km^2 by end of 1980's, accounting for 8.97 % of the total land of China. Table 5 shows the areas of desertified land, which caused by different process in China.

Table 5: Areas of desertified land by different process in China

Types of desertification	Area (km^2)	% of total
Wind erosion	379,600	44.1
Water erosion	394,000	45.7
Salinization	69,000	8.3
Engineering construction	19,000	1.9
Total	861,600	100.0

Sandy desertification through wind erosion

In the North China the main land degradation is sandy desertification caused by wind erosion, which covers about 379,600 km^2 and mainly distributed in the arid and semi-arid zones where the annual rainfall is below 500 mm. In those areas the land surface is mostly composed of sandy and gritty deposition. Drought season beings synchronously with wind season so that the spread of sandy desertified land will occur immediately so long as the land surface is disturbed by human activities.

On the basis of extensive field investigation and remote sensing data of different period, we established a preliminary degree classes and index system of sandy desertification and developed a suitable method for remote sensing monitoring and assessing on sandy desertification. The results indicate that during last 5 decades the sandy desertification in the North China has been caused mainly by irrational human economic activities, and the growth rate of desertified land has being increased decade by decade like as the annual spread area has increased from 1,560 km^2 of during 1950's and middle 1970's to 2,100 km^2 of between middle 1970's and late 1980's, to 2,460 km^2 of among late 1980's and middle 1990's. From the viewpoint of property, the development during 1950-1970 had been characterized mainly by dune-field formed because the moderate(M) desertified land had developed to very severe(VS) one, while in recent decade it had been characterized by serious wind erosion in new reclaimed land and rangeland because of over-cultivation and over-grassing. The sandy desertified land in the North China are mainly distributed in (a) agro-pastoral areas in the semi-arid region - about 40.5% of total sandy desertified land, (b) desert steppe areas in the semi-arid region - about 36.5% and (c)marginal oases and lower reaches of inland river in the arid region - about 23%. View the situation as a whole, the degree of desertified land has become more serious as the results of development through slight to very severe degree. According to the statistics of desertified land areas with different landuse purposes, the human impacts of contributing to sandy desertification in the North China were as 25% of over-cultivation, 28% of over-grassing, 32% of over gathering firewood and 8% of mis-used water resources and 1% of engineering factors, occupied 94% of causes for the sandy desertification. With the human impacts the limited rainfall and dynamic wind also played a key role, especially during drought.

Desertification through water erosion

This kind of desertification is soil loss through water erosion, which is the most serious land degradation in China. By a rough estimate, annual soil loss caused by water erosion reached to about 5 billion tons, of which about two fifths come into the seas (Zheng Du,1998). According to a national-wide investigation, there were about 1.53 million km^2 to be affected by water induced soil erosion at the beginning of 1950's, but increased to 1.79 million km^2 of 1990's (accounting for 18.6% of the nation's territory), of which about 394,000 km^2 had been desertified by water erosion. Most of those desertified lands distribute eastwards of the boundary from Da Hinggan Ling - Yin Shan - Helan Shan to eastern rim of Qingha - Tibetan Plateau.

Salinization

There are about 20% of total 100 million hm^2 farmland of China have been more or less threatened by the salinization at present, and about 69,000 km^2 land has been salinized by the end of 1980's in China, which mainly distributed in the arid and semiarid regions of the Northwest China and subhumid regions of North China Plain.

Desertificatin caused by engineering construction

For last 20 years, a new type of desertification has spread very quickly with some large-scale projects like as development of oil field and mining, construction of residential area and communication. A preliminary study indicated that it covers an area of 19,000 km^2, which mainly expanded through wind and water erosion.

Principles for combating desertification in China

Based on the summary of research and practice on combating desertification for many years, we would like to suggest that the overall strategic idea on sustainable development carried through to combat desertification in China should follow the guiding principle of "taking prevention first, carrying out overall planning, conducting integrated prevention and treatment, adopting measures suitable to local conditions, strengthening management, and laying stress on efficiency" and implement the following policies.

1. Taking prevention first. Attention should be paid not only to combat the existing desertified land, but even more important to the prevention of potential desertified land such as to adopt prevention actions to light degraded pastureland and light soil eroded land, enforce supervision and monitoring and minimize desertification resulting from environmental deterioration caused by irrational human activities.

2. Using key affected points as combating basis to promote work in the entire area, such as in combating water erosion induced desertification, small priority watershed should be taken as a unite (point) to undertake comprehensive management and popularize the work from the unit to large areas. For combating wind erosion induced desertification, priority township should be taken as a unit to promote the work in different batches step by step.

3. Adopting measures suitable to local conditions and identifying preventive facilities according to type of hazard. Corresponding measures were taken according to local physical, social and economic conditions.

4. Integrating combating with development and utilization. Desertification combating should be closely combined with economic development, eco-environmental improvement should be integrated with improvement of local people's living standard, combating should be used to ensure development and development should be used to promote combating. For instance, according to the local eco-environmental features favorable either for desertification combating or favorable for economic development, the principle of "protective forestry, commercial animal husbandry and self-sufficient farming" has been suggested to the farming-pastoral areas which experiencing the sandy desertification.

5. Harmonized ecological benefits with social and economic benefits. When the three benefits are in inconsistency, the need of ecological benefits should be satisfied for it concerns the overall long-term benefits and concerns the sustainable development of desertified area and the immediate economic benefits should not be taken into account at expense of environmental benefits. For instance, in the process of present large-scale afforestation for sand stabilization and of reclamation of desertified areas for grain production, attention should be paid to prevent environmental deterioration from drop of ground water table. However, in the specific operational process, efforts should be made to promote ecological and social benefits via economic results.

Status of combating desertification in China

It is evidence from the above analyses that the land desertification in China has led to a heavy loss of land resource, which is affecting sustainable economic development in farming-pastoral, pastoral, dry farming areas in the North China and hilly areas in the South China. The Chinese Government attaches very importance to combat desertification, so far substantial work has been done and certain achievements and experience have been gained. So it is very necessary to evaluate the status and existing problems of combating desertification in China, analyses examples and summarizes experience in combating desertified land in different types and formed under different natural conditions so as to provide scientific basis for the formulation of national action programs in combating desertification in China.

Gradual perfection in policy and management measures

Relevant legislation work has been quickened since the 1980s
As stipulates in Article 19 of Law of Environmental Protection of the People's Republic of China issued on 26 December 1989, ‘measures should be taken to protect eco-environment in exploiting and utilizing natural resources’; in Article

20, 'people's government at various levels should strengthen protection of agricultural environment, prevent soil pollution, land desertification, salinization, impoverishment, swamp, ground subsidence and prevent and control vegetation devastation, soil and water loss, water source exhaustion, species extinction as well as the occurrence and development of other phenomena concerning ecological disturbance.

Soil and Water Conservation Law of the People's Republic of China was reviewed and carried through at the Standing Committee of the National People's Congress on 29 June 1991. In this special law on prevention and control of soil and water erosion, aspects concerning principles on soil and water conservation, soil erosion prevention and supervision, soil erosion control, role of government and public in soil and water conservation, and legal obligations were stipulated in detail.

Item 1 of Article 19 of *Forest Law of the People's Republic of China* implemented on 1 January 1985 stipulates, 'prohibit destroying forest for reclamation and destroying forest for quarrying, sand and earth mining as well as other actions related to forest destruction'.

Other relevant Laws can be listed as followings:

- Grassland Law of the People's Republic of China implemented on 1 October, 1985.
- Law of Mineral Resources of the People's Republic of China implemented on 1 October, 1986.
- Land Management Law of the People's Republic of China issued on 29 December, 1988.
- Law of Agriculture of the People's Republic of China issued and implemented on 2 July, 1993.

Gradual intensify management on combating land desertification

Relevant administration agencies concerning desertification control have been established in China, administering work to combat desertification from different aspects, such as the division in Department of Nature Conservation within NEPA with responsibility of administering work on land degradation/desertification control. For the sake of tackling land desertification problems in a comprehensive way, eco-environmental impact assessment of construction projects was strengthened and, work on ecological demonstration plots aiming at sustainable development in desertified areas was carried out. The Office of Sand Control was set up in Ministry of Forestry in the 1970s. In order to strengthen engineering construction of 'Three North' shelterbelts, the Bureau of Three North Shelterbelts was established under the ministry and corresponding institutions concerning desertification control and shelterbelts construction were also established in various relevant provinces and regions.

With regard to grassland operation and management, grassland administrative stations with a total staff of over 10,000 have been set up in major pastoral provinces, prefectures and counties throughout the country.

Major achievements in combating desertification in China

Following the UN Desertification Conference in 1977, the Leading Group Office on Environmental Protection under State Council (predecessor of Notional Environmental Protection Agency), in cooperation with the Chinese Academy of Sciences (CAS), entrusted the Institute of Desert Research, CAS and other units to carry out studies on desertification in China. Research results of various field teams and experimental stations as well as practical experience of local people were scientifically summarized. Then entrusted by international organizations of UNEP, FAO and ESCAP, over dozen training courses and seminars were jointly organized by NEPA and CAS, the areas covered including the North and South China. In addition, experts were sent to Ethiopia, Tanzania and Mali to give lectures or coordinate and guide work on desertification prevention and control. UNEP, CAS and NEPA set up an International Center for Research and Training on Desertification Control with assistance of the Institute of Desert Research in Lanzhou in 1987. Meanwhile, monitoring and mapping of causes and status of desertification in the North China and its trend of development was carried out systematically. Based on extensive investigations and studies on typical controlled areas, experiences of difference control models were summed up, a desertification combating system by combining prevention and control with development was proposed.

In order to quicken the pace in sandy desertification control in recent years, the centre government compiled Main Points on National Sand Control Project Planning in 1991- 2000, worked out plan target of combating 666.7 x 10^4 ha of desertified land within 10 years. So far, 20 key counties, 9 experimental districts and 22 demonstration bases related to national Sand Control project have been included in the national economic development program and in the progress of implementation. During the Eighth-Five-Year Plan period (1991-1995), 375.9 x 10^4 ha of land related to the project got controlled in a comprehensive way.

Up to mow, the first and second phase work concerning the Three North Shelterbelts system project has been completed. As a result, 1851 x 10^4 ha of land were forested with a forest coverage increased from 5.05 percent to 8.2 percent, more than 4 x 10^4 ha of 'virgin land' were turned into green woodland, 130 x 10^4 ha of sandy desertified land were transformed into farmland, grazing ground and orchard, 12 percent of the sandy desertified land were tackled and 10 percent of the sandy desertified land were put under control, over 1100 x 10^4 ha of farmland were protected with shelterbelts, 893 x 10^4 ha of grazing ground were rehabilitated, resulting in a grass yield increase of over 20 percent. Agricultural eco-environment of one third of the counties in the Three North shelterbelts tends to change toward a benign circulation. According to report from page 1 of China Forestry on 5 September 1996, the aerial sowing forest and grassland area for sand control reached 100 x 10^4 ha, they play a tremendous role in against wind and sand dune stabilization. In 1958, pilot project on aerial sowing to Sand Control was initiated in Yule of Shaanxi Province in China, and 1988, the results began to be used for extensive production, at an annual expansion rate of 70 x 10^4 ha, recently at 10 x 10^4 ha. Apparent ecological, social and economic benefits were gained.

According to stipulations of the Law of Grassland, Chinese government at various levels strengthened protection and management of grassland resources, strictly prohibited discriminatory reclamation, excavation and grazing, practiced the combination form of State, collective and individual, and quickened the pace in grassland rehabilitation and control of grassland degradation. Statistics revealed that aerial sowing grassland and artificial ameliorated grassland totaled 1175.7 x 10^4 ha and grassland fenced, 823.3 x 10^4 ha in the country. Remarkable achievements were obtained in 49 grassland and animal husbandry integrated demonstration projects organized by the State as focus of attention. Up to the end of 1994, artificial sown grassland area totaled 563.8 x 10^4 ha, opening up a new way development of livestock farming and eco-environmental protection in arid, desertified and soil eroded areas.

As the Chinese government attaches importance to soil and water conversation work, the desertification through water erosion (soil erosion) has been effectively controlled and eco-environmental and agricultural conditions have been improved. At present, 25 stretches of national key soil erosion control areas have been identified, water and soil conservation projects been carried out in 7 large river basins and mountains, rivers, farmland, forests and roads been tackled in a comprehensive way in more than 10,000 seriously eroded small catchments. Consequently, a total amount of 67 x 10^6 hm^2 of soil eroded area was controlled, a great many water storage and water preserving projects were built, annual average soil loss was dropped by over 1.1 billion tons and water preserving and holding increased by 18 billion tons in the country. In soil erosion comprehensive control areas on the Loess Plateau, 15 x 10^6 hm^2 were tackled, 30 percent of the eroded areas were controlled in different degrees and annual sediment delivery into the Yellow River reduced by over 0.3 billion tons. According to report from the article "Tremendous Changes Resulted from Soil and Water Conservation in China" carried on of Science and Technology Daily on 5 September 1996, since 1983 the State has selected 8 stretches of seriously eroded areas including Wuding River, Sanchuan Ruver, Huangpu River, upper reaches of Liuhe, Xingguo County, Dingxi County, reservoir area of Gezhouba and upper reaches of Yongding River from 7 major drainage basins of Yellow River, Haihe River, Liaohe River, etc. as key areas for soil erosion control. Up to now, satisfactory results have been gained in tackling problems concerning mountains, rivers, forests, farmland and roads in key areas under unified planning and in comprehensive way in light with the principle of bringing scale efficiency into play and tackling in continuous stretches. Within the 13 years, soil eroded area reduced by 33.2 x 10^4 hm^2, forest and grassland area increased 239.8 x 10^4 hm^2, per capita income in concerned areas exceeded 600 yuan, and over 1,500,000 people got rid of poverty.

Major problems existing in combating desertification in China

Viewing generally in light with ‘Environmental Protection in China’, problems such as inadequate forest area, grassland degradation, land desertification, etc. still exist in China, therefore, further strengthening protection of eco-environment and biodiversity is still an important task confronting the Chinese government.

Legislation is incomplete and enforcement system of law is imperfect.
Except the Law of Soil and Water Conservation, which is a special law on soil and water loss (related to water erosion induced desertification) prevention and control, other relevant laws and regulations on desertification combating are scattered in many other laws. The urgent task is to make the Law of Combating Desertification and relevant specific stipulations to coordinate relations of resources development and desertification combating. Another serious problem is negligence of laws and regulations and enforcement system is imperfect.

The rate of desertification combating lags behind the rate of development
Since the founding of the People's Republic, work on combating various types of desertification has been carried out and greater achievements have been gained. However, in a long period of time, as no effective measures have been adopted to control artificial impacts and prevention has not been put on the No.1 position, though desertification development has been changed in reverse in partial areas, taking the country as a whole, the phenomenon of ‘combating in points but disrupting on entire area; combating while disrupting; and disrupting first followed by combating’ was very serious. The rate of desertification control lags behind the rate of development, and the desertified area is still expanding. In sandy desertification control, up to the end of 1988, the afforested area mainly for desertification control thus preserved covered 10 x 10^6 ha for the whole country, making 10 percent of the sandy desertified area have been controlled. However, the trend of desertified area expansion had not only been constrained but became aggravated.

Short of sufficient funds to combat desertification
China is a developing country, as economic growth exerts great pressure on funds, the State input to desertification combat is limited. What is more, because of severity in desertification extent, vastness in expand, and ‘too much debt owed’ in history, only substantial input is devoted can the problem be solved. Desertification usually occurs in poverty-stricken areas, hence non-governmental mobilization and accumulation of funds is also difficult in desertified areas. Shortage of funds to combat desertification in China, the same as in other developing countries in seriously desertified areas on the globe, has multiplied the difficulties in tackling the desertification problem.

Typical experience in combating desertification in the North China

With regard to content, the essence of desertification combating is to improve the degraded land conditions by rehabilitating productivity of the already desertified land, how to reverse the degradation process of the ongoing land desertification and how to prevent the development of the potential desertified land; and to make land resources being sustainably utilized and bring even greater benefits. Although the desertification has expanded in China as a whole for last decades, many efforts have reversed about 10 percent of the sandy desertified land in the

North China and much more in the South. Some effective examples can be shown as following:

Hotan County of Xinjiang
Combating desertification around oasis in extremely arid region

Hotan Oasis, sandwiched in between Yurungkax River and Karakax River at southwestern margin of the Taklimakan Desert in Xinjiang, where annual average precipitation is only 34.8 mm with evaporation as high as 2564 mm. According to the natural conditions, the fundamental way combating sandy desertification is to set up sand-protecting plantation centered around the oasis and to stabilize oasis ecosystem by rational utilizing water resources of inland rivers. In this connection, the following measures are identified:

1. Undertake new water conservancy projects. Making full use of water resources of Yarungkax and Karakax rivers had formed a complete irrigation system with trunk canals. As a result, small scale farming with irrigation system was realized for 80 percent of the cultivated land.

2. Built complete sand-protecting plantation and windbreak forest system centered around oasis. Forest reservation was adopted in the semi-fixed areas at the periphery of the oasis to preserve natural vegetation. A 358-kilometer-long trunk forest belt of the sand-protecting plantation and windbreak forest system, 100-300 m wide, was built encircling the fringe of the oasis. The woodland made of 40.2 % coverage in the oasis.

3. Stabilize moving dunes and level individual dunes. For stretches of dunes, warping by diverting flood water was practiced on interdune lowland for woodland; and the dune surface was fixed by sand breaks made with reeds and wheat straw.

The adoption of above measures led to an environmental improvement, a drop of wind velocity over fields protected by forest grids by 25 percent and sand-bearing content in wind-drift sand by 40-60 percent in contrast to open space. Economic efficiency as also apparent. The total output of cereals, cotton and oil-bearing crops increased by 1.17, 1.16 and 2.31 times respectively, per unit area grain yield increased by 3.3 times and per capita income by 7.5 times in the county compared the case in the early 1990s with that of the end of the 1970s.

Yulin City of Shaanxi
Combating sandy desertification in western part of semi-arid farming-pastoral areas

Yulin City is situated in northern part of Shaanxi Province, where 70 percent of the annual precipitation (414.6-mm) is concentrated in July, August and September. It is one of the seriously desertified areas in China. In light with sandy desertification dominated by wind erosion, a ‘belt, patch and grid’ combined sand and windbreak system was recommended to be established.

1. By using conditions of relative high ground water level and better water regimes in the interdune lowland within the desertified area to stabilize shifting sand; meanwhile, stabilized and semi-stabilized dunes were enclosed to facilitate plantation.

2. Protection network dominated by narrow forest grids was established on dune encircled farmland distributing on river terraces and floodland of lake basins; along with measures such as enclose fixed and semi-fixed dunes to facilitate planting on the edges of floodland in combination with shrubby grass plantation, to form a farmland protection system.

3. Aerial grass sowing in combination with artificial enclosure to facilitate plantation was adopted in vast expanse densely distributed with high moving dunes. The preservation rate is generally 40-50 percent; the highest may reach 70 percent.

4. In areas abound in rich water resources, water diversion to disperse sand for soil amelioration was applied. As a result of transformation moving dunes along west bank of Yuxi River west of Yulin city into farmland or new urban district, the area of Yulin City in 1990s has been enlarged 8.5 times in comparison with in 1949.

5. As a result of the adoption of aforementioned measures, the vast expanse of sandy desertified land was separated and encircled by green ecological breaks, forest coverage increased from original 1.8 percent to 37.6 percent in 1994, 3,400 km^2 of shifting sands were stabilized, 1,000 km^2 of farmland were protected with forest grids, over 660 km^2 of farmland were added in desertified areas, 106 km^2 of water surface of lakes or reservoirs in interdune floodland were used to raise fish, 1530 km^2 of grazing ground were rehabilitated and improved. Both ecological and economic benefits were gained. For example, in Qinhe Township west of Yulin city, sandy desertified land decreased from pre-treatment 56 percent to post-treatment 13 percent in the 1990s and per capita income increased by 241.5 percent in 1995 than previous 10 years.

Naiman Banner of Inner Mongolia

Combating desertification in eastern semi-arid farming-pastoral area

As a huge ecological system, Horqin Steppe Region has varied conditions of eco-environment and complex relations between ecology, environment and human impact. Due to the unfavorable natural conditions, the eco-system is very fragile and it is much stable for grassland-livestock raising than drylands-farming. But along with the growth of population and development of cropping agriculture for the last 100 years, it is impossible to renew the original one again. Up to the present, the eco-system already has became a dry-land agricultural eco-system, which shares the cropping, animal husbandry and forestry as dominant composition and has much complex structure and function. Although the productivity is higher than before, the new eco-system is unstable. The process of desertification is the major result. So it needs great efforts to enable it reach a new stability for sustainable development.

Many good results show clearly that land desertification could be controlled when some necessary measures have been token. Based on the analyses of eco-environmental, economic and social benefits between before and after desertified land had been brought under control in Xinglongzhao District, Naimanqi, as a good example, we try to evaluate the desertification control in Horqin Steppe Region. The area of Xinglongzhao District is about 53,000 ha, which was a fine pastureland until 1950s. But it was degraded because of over-cultivation, over-grazing and over-collection of fuelwood.

The desertified land had expanded to over 15,700 ha up to 1974, which resulted in the deterioration of the ecological environment, decrease of grain production and reduction of livestock output. The process of desertification hindered seriously the development of the local economy and the improvement of living standards of the people. Since 1976 the local government and masses implemented a project to combat desertification for improving the environment of production. This project has achieved success and the main targets are showed in Table 6.

Table 6: Effectiveness of combating desertification in Xinglongzhao, Naiman (1974-1994)

Land type	1974	% of area	1994	% of area	Change
Desertland	15,700 ha	29.62	2,100 ha	3.96	86.62 %
Woodland	777 ha	1.47	25,840 ha	30.10	19 times
Farmland	4960 ha	9.36	6,900 ha	13.02	39.11 %
Other parameters -					
Grain yeild	2,790 t		13,110 t + 10,320 t		+3.7 times
Unit grain yeild	562.5 kg/ha		1,900 kg/ha + 1,337.5 kg/ha		+2.4 times
Rangeland Capacity	124,200 sheep unit		152,200 sheep unit + 2,800 sheepunit		+22.5 %
Income/ person	80 yuan		1,120 yuan + 1,040 yuan		+13 times

The project has prevented the desertified land from spreading over more areas, which is very important since the prevention cost is much lower than the controlling one, as well as a large area of desertified land has been rehabilitated. It brought about a coordinated advance in economy, society and the environment, and made considerable headway on the ecological, economic and social benefits.
Desertification is a complex process caused by human impacts and natural factors. For a sustainable development in regions affected by the process, prevention and remedy of desertification is an arduous task which should and must be accomplished because of the human existence and can be accomplished since the effect of some theories and practices for combating desertification have been proved fully.

Hetian Town in Changding County of Fujian
Combating water erosion induced desertification in humid hilly areas

Hetian Town of Changding County, located at upper reaches of Dinghe southwest of Fujian, used to be known for its picturesque scenery over 100 years ago and became a representative of water erosion related desertification in hilly areas of southern as a result of human impact and natural erosion. In mid 1980s, eroded area accounted for 44.7% of the total land area, of which above moderate eroded area made up 78.9% of the total eroded area, including plane erosion, 34.5%, gully erosion, 15.8%, and heaving induced, 49.7%. They generally happened on badland, stony slopes and gravel landforms on low hills of 20-80 m high with dissection density, 0.25-0.30. in addition, sandified cultivated land also made up 4 percent of the affected farmland by accumulation of granitic weathered coarse sand due to flood scouring.

Water and soil erosion control has began as early as in the 1940s in Hetian. Since the founding of the People's Republic, massive prevention and control was carried out following the principle of scientific experiment and research in combination with local peoples' practice. In order to popularize the mass movement in combating desertification, a number of demonstration plots aiming at different conditions were set up.

1. As for stony slopes with topsoil being washed off, the Guanxintang Experimental Plot was set up at the upper reaches of Bashili River. The model of a vegetated cover consisting of various tree species (e.g. silk tree, *Lespedeza bicolor*, *Amorpha fruticosa* and *Robinia pseudoacacia*) planted in high density and with a mixture of forests and shrubs was developed. Observations indicated that soil erosion module dropped by 94.8 percent compared with pre-control, and soil organic matter increased 5 times.

2. As for severely eroded red earth developed on granitic hill slopes, the mixed forest model dominated by *Acacia mearnsii* plus *Robinia pseudoacacia* and *Amorpha fruticosa* was developed. It functions as a temperature regulator to prevent high temperature hurt to plants because the maximum daily temperature variation was 17.9 ºC inthe forest in summer and outside was 36.1 c. Contents of nitrogen and organic matter increased greatly due to nitron fixation of nodule bacteria of the plant and decomposition of fallen leaves.

3. As for highly eroded barren terrains with dense gullies, a model of a multi-type, multi-layer vertical plantation system including afforestation, grass planting and fruit tree cultivation for prevention and control in combination with development was developed at Chiling. According to the model, grass was planted on hilltops, *Acacia mearnsii* was planted on hill slopes, fruit trees were planted at foothills and in places where water is available, and fishpond was opened. As to old and pinon pines remained on hill slopes,

measures were taken to promote the growth of the trees. Fruit trees like peach, plum, hawthorn and kumquat were planted at the edge of forest belts. Economic crops like peanuts and citron daylily were interplanted. After treatment with this model, the amount of soil eroded reduced by 92 percent and soil organic matter increased 0.6 time.

4. Low mountains and hills subjected to water erosion induced desertification were generally closed, after 5 years desertified area reduced by 14.3 percent. An important aspect to ensure implementation of desertification combating program is preferential policy formulation and strengthening organization and management. For instance, measures were taken to cope with coal supply and subsidies, popularize energy-saving cooking stove and build methane tanks. As a result, land pressure was reduced by firewood gathering, vegetation was protected and and combating results were consolidated. Meanwhile, propaganda was strengthened on law of environmental protection, forestry law, and law of soil and water conservation, relevant agencies concerning desertification combating were strengthen and perfected. With regard to organization and management, the measure of who made contributions in combating who gain was practiced, and responsibility system concerning combating and management was set up under contracts and in a planned way. Therefore, responsibility, rights and benefits were unified and combating, management and utilization were integrated. After adoption of aforementioned measures, the vegetation coverage increased from below 10 percent pre-treatment to over 50 percent and soil erosion module reduced from 5000-12,000 t/km^2.a to 449-695 t/km^2.a. Desertified area reduced from 26.2 percent to 21.6 percent and per capita income increased by 260 percent in 1990 than pre-treatment. Environment was also improved.

Tangbeihe in Xingguo County of Jiangxi Province
Combating water erosion induced desertification humid granitic hilly areas

Tangbeihe watershed in Xingguo County of Jiangxi Province, located to south of Xingguo, is a small tributary of Pingjiang River. The entire watershed is composed of coarse granites with loose weathered horizon ranging from several to dozens of meters andis liable to be eroded after vegetation destruction. Annual average precipitation is 1371.9 mm and is unevenly distributed with 73% concentrate in March to August. Except alluvial plains, the watershed is mostly composed of granite hills and their weathering product, i.e., red earth. Vegetation was seriously damaged due to afforestation, tea plantations at the expense of forests and firewood gathering. Most of the low mountains and hills in the middle and lower reaches were barren, subjecting to serious water erosion. in the watershed, 70.4% of the land were affected by soil erosion, 98% of the mountains were subjected to erosion. Of which badland and desertified stony slopeland occupied 58.1%, or 82.5% of the eroded area.

According to the actual situations, the following measures were taken.

Table 7: Effectiveness of combating desertification in typical areas in China

Representative Regions	**Annual rainfall (mm)**	**Features of desertified Land**	**A***	**B ***	**C***
Pingchuan, Linze County, Gansu	117	Dune mobilization around oases, sand dune enchroachment	56.4	9.4	154
Yaole Dianzi in Naiman Banner Inner Mongolia	360	Sandy grassland wind erosion, Dune mobilization and dune enchroachment in farming - pastoral area	77.0	25.0	126
Qinhe Township Yulin,Shaanxi	415	Farmland surrounded by dunes on valley terraces and lake basin flats in semi-arid areas	56.0	13.0	242
Zuocheng in Yanjin,Henan	600	Dune and sandland in ancient yellow River beds and flooded splays of sub-humid area	48.6	2.7	178
Shibangou in Baihe ,Shaanxi	799	Badland, stony slopeland and ground surface desertified by water erosion on mountains	21.7	4.7	335
Renli, Suining Sichuan	993	Purple sandatone and mudstone eroded hills	41.08	1.55	373
Xiadian,Dawu Hubei	1150	Water eroded badland and stony slopeland on granitic gneiss hills	18.8	7.2	197
Dashan, Hengnan,Hunan	1287	Sandstone and sandshale hills with badland and ston slopeland	54.9	7.6	86
Malinhe,Wuhua Guangdong	1443	Granitic hills dominated by badland and collapse erosion	64.6	9.5	98
Mengpuhe Puding Guizhou	1450	Sand hill desertified limestone hilly areas	36.6	5.9	155
Fuling, Jixi Anhui	1534	Granitic hills dominated by badland	56.6	3.1	580
Tangbeihe Xingguo Jiangxi	1593	Granitic hills covered badland, ground surface broken subjected to be water eroded	82.4	7.2	272
WeishanNingx-iang, Hunan	1580	Granitic hills dominated by badland	45.8	3.5	230
HetianChang-ding, Fujian	1636	Granitic hills with badland and stony slopeland to be serious water eroded	26.2	21.2	260

* A - Desertified land / total area (%) before combating desertification
* B - Desertified land / total area (%) after combating desertification
* C % of increase income/person between before and after combating desertification

1. Build various types of field works for soil and water conservation so as to create conditions for quickening vegetation rehabilitation. For instance, bamboo joint contour trenches were mainly built on slopeland over 25 degrees, table land (terrace) with reversed gradient was mainly constructed on slopeland of 15-25 degrees, while level terraces were built on gentle sections of foothills.

2. Select appropriate tree species and grass species for afforestation and allocate tree species properly. Native tree and grass species with high adaptability such as *Pinus massoniana, Liquidambar formosana, Schima superba, Aleurites fordii, Quercus,* and *Lespedeza bicolor*, were selected and good varieties of grass such as *Staria vidiris, Paspalum thunbergii*, were introduced. Fruit trees and firewood were normally planted above halfway up the mountains such as *Pinus massoniana, Liquidamber formosana, Schima superba, Quercus* and *Lespedeza bicolor* so as to form a multi-species, multi-layer and high density vertical structure. Economic forests and timer forests such as *Aleurites fordii, Camellia oleifera, Cunninghamia lanceolata* and *Paulownia fortunei* were planted below halfway up the mountains or at foothills.

3. An essential guarantee to accelerate vegetation rehabilitation and combat desertification is to integrate combating with management and to practice forest reservation. After hillside enclosure and afforestation, vegetation coverage increased from less than 10 percent to 50-60 percent.

4. An important measure to stop vegetation destruction is to provide solutions to domestic energy demand in rural areas. Such as to build methane tank, popularize fuel saving stoves and plant shrubs like *Lespedeza bicolor* and *Arundo donax* at four sides of the house for quick solution of firewood.
5. After treatment, soil erosion was mitigated, desertified area dropped to 5.04% of the watershed area and per capita income increased 272%.

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7

Can Desertification Trends be Reversed in West Asia and North Africa?

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Introduction

The Concept of Desertification

Desertification has come to the forefront of global concerns, as demonstrated in the number of international conferences and conventions, most recently, the Convention to Combat Desertification. The Convention defines desertification as a process of land degradation resulting from various factors including both climatic variation and change and human activities. Land degradation occurs in the forms of impoverishment and depletion of vegetative cover, loss of biophysical and economic productivity through exposure of the soil surface to wind and water erosion, and through salinization and waterlogging leading to deterioration of physical, chemical and biological soil properties.

The drylands of the world are considered the most threatened by desertification. Comprising hyper-arid, arid, and semi-arid regions with annual moisture deficits greater than 50%, the drylands are estimated to cover 34% of the earth's surface. Drylands are associated in the popular view with desertification, partly because of the association of the term with hyper-arid environments and partly because of recent attention to the phenomenon of sand dune encroachment in agricultural areas. Although invasion by moving sand is a particularly dramatic form of desertification, relatively few people have been affected and the focus on arresting sand movement has, unfortunately, detracted from the more important and widespread issue of general degradation in drylands, of which desert encroachment is only a small part. In this regard, it should also be noted that more humid environments can also be affected by desertification through deforestation and subsequent erosion of soils.

It is estimated that some 9 million square kilometers of the world's drylands have been turned into unproductive deserts in the past half century, directly affecting the livelihoods of some 80 million people. FAO (1995) estimates that today half the world's irrigated land is so badly salinized or waterlogged that crop yields are reduced. Some 1 to 1.5 million hectares, mostly prime agricultural land, is newly subjected to salinization each year. The continual acceleration of vegetation loss through salinization and human removal not only depletes the biodiversity, but it also reduces the ability of the natural environment for carbon sequestration, with the consequent long-term effects of global warming and climate change.

Although some desertification is attributable to natural causes (long term climate change, droughts, and localized weather events), most instances can be attributed to human activity. Drylands are characterized by limited availability of arable land, limited and highly variable rainfall and scarcity of water resources. The demands placed on land and water resources by rapidly expanding populations, through agricultural intensification, urbanization and industrialization have combined to intensively exploit these natural resources. The principal direct causes of degradation in the drylands are:

- Removal of vegetation through cutting and uprooting trees and shrubs, plowing previously uncultivated and marginal land for annual cropping, poor soil management practices following harvest, overgrazing natural rangelands, and

- Intensification of cultivation using inappropriate cultural practices that degrade soil fertility and encourage erosion and through overuse of irrigation and poor drainage, leading to rising water-tables, waterlogging and salinization

Assessment of Degradation

Investment in reversing degradation/desertification, whether in research, technological interventions, or national policies, requires knowledge about the state of the land (the degree and extent of degradation), including what forces affect productivity, whether productivity is declining under present management, and whether degradation can be reversed and productivity restored. Whether investment is warranted by a particular government, or in a particular location, depends on the outcome of this assessment and also on consideration of what may be the costs of not investing in reversing degradation.

New tools for the 21st Century

Newly developed tools such as remote sensing, GIS, and computer-assisted expert systems can contribute to the planning and implementation of concrete measures to combat desertification that also greatly improve dryland productivity. Capitalizing on the positive sunshine and temperature aspects of dryland environments, the provision of water for irrigation allows the economic production of crops and other agricultural products on lands reclaimed from the desert areas. Reclamation often requires heavy investments in earth moving and irrigation infrastructure construction. That such efforts are feasible is demonstrated in Egypt, where almost 1 million hectares have been reclaimed from the desert. In other areas, non-conventional sources are needed. Desalinizing seawater using innovative energy sources such as solar power, tidal movement, or even bio-gas offers interesting opportunities for development in areas without renewable sources of surface or groundwater.

Since heat, moisture stress, and salinity are the major abiotic constraints to vegetative grown in arid and semi-arid environments, enhancing the ability of introduced plant species to withstand these constraints is a major concern in reclamation and rehabilitation efforts. Genetic engineering and other biotechnology tools offer considerable promise, together with improved conventional plant breeding methods. At the same time, there is need to develop appropriate land and water management techniques to prevent erosion, fertility loss and salinization so that the production system becomes sustainable.

Desertification in West Asia and North Africa (Wana)

Root Causes: Interaction between Social and Economic Change and Limited Environmental Resources

The vast area broadly defined as West Asia and North Africa (WANA) stretches from Morocco in the west to Afghanistan and Pakistan in the east, and from Turkey in the north to the Arabian Peninsula in the south. It constitutes the single largest contiguous dryland region in the world. The region has only limited natural resources suitable for agricultural use. Rainfall is erratic in space and time; only a few favored spots receive enough precipitation to be classified as humid or sub-humid, and the length of rainfed growing period is almost everywhere less than 180 days. There are few permanent rivers, and much of the area is mountainous with shallow and infertile soils. The majority of the land consists of arid deserts that bisect WANA from west to east, from the Sahara in Africa to the Thar desert of southern Pakistan and the Karakum on the northeastern Iranian frontier. Only 14% of the land area, to the north and south of the desert zone, is deemed suitable for rainfed cropping, with much of this only appropriate for extensive land use practices. Despite its dryness, WANA is an important center of biodiversity. Many of the world's major food crops, pasture species, herbs and medicinal plants originated either in the Mediterranean and continental climates (winter rainfall) to the north of the desert arc or in the semi-arid tropics (summer rainfall) lying to the south of the deserts.

Demographically, WANA has one of the fastest population growth rates in the world. In the early 1960's the total population stood in the region of 200 million people, by 1990 the figure had reached 470 million, and it is projected to approach 930 million by the year 2020. The struggle to feed the rapidly expanding population has been a major strategic concern of almost all the countries in the region. Despite heavy public and private development investments, the amount of land and water resources available for agricultural production has not kept pace either with population growth or consumer food demand. By 1990, only Turkey was a net food exporter, and the rest of WANA combined constituted the single largest food importing region in the developing world, and the regional food self-sufficiency ratio has continued to fall by an average of 1% per year (El-Beltagy, 1997; Nordblom and Shomo, 1995). While agricultural production failed to keep pace with demand, rising incomes derived from other sectors of the economy, particularly in urban areas, have triggered a change in consumption patterns towards greater emphasis on meat and milk products, fruits, and vegetables. In order to meet the ever rising costs of living, farmers and pastoralists have responded to these changing demographic and economic circumstances by seeking to intensify production through greater exploitation of their limited resource base of soil, water, and natural vegetation.

Across WANA are locations where it is possible to utilize surface and underground water resources to intensify agricultural production through irrigation. In the past 30 years, governments have invested heavily in large-scale irrigation works to capture and manage surface flows from the few perennial rivers. National projects have been supplemented by individual farmer investments in drilled wells which tap underground water supplies. By 1991, about 35% of total cropped area in the region was under irrigation. However, sustained productivity through irrigation development is threatened by over-exploitation and poor management of water application and drainage, leading to declining water quality and depleted aquifers, often resulting in salinization and loss of soil fertility.

In the higher rainfall areas receiving more than 400 mm, intensification has typically followed a pattern of increased inputs, diversification, and attention to higher value crops. A major trend has been the spread of permanent crops, particularly fruit and nut trees and vines, with a 64% increase in the area devoted to these crops in WANA in the past 30 years. It is in these more favored, higher potential areas that intensification poses the least risk of desertification, although soil erosion on slopes and hilly land is a persistent problem.

The threat of desertification is greatest in the zone lying approximately between the 100 and 400 mm rainfall isohyets. This area represents about 80% of the land area outside the hyper-arid desert environments of WANA. These semi-arid areas have been regarded historically as marginal for human existence and the population pressure has been relatively low, although they have always been an important support and natural resource for the extensive small ruminant production systems of the region. Traditional systems of extensive cereal cropping and pastoralism in these areas of marginal productivity were well adapted to the physical environment and its constraints, but they are no longer adapted to the evolving circumstances in which intensified exploitation of the limited resource base of land and natural vegetation is an economic imperative for the local population.

The areas most threatened with desertification represent two distinct land use patterns. Lying approximately between the 200 mm and 400 mm rainfall isohyets is an area traditionally used for extensive cereal cultivation combined with animal production. Recent intensification here is marked by increased annually cropped area, pushing the frontier of cereal cultivation into drier and drier areas and poorer and poorer soils while, at the same time, drastically reducing the area under annual or longer-term fallows. Much of the estimated 9% increase in total WANA annual cropped area has occurred in these marginal agricultural environments. Plowing for cultivation has removed natural vegetative cover, destroyed potential use as rangeland, and reduced biodiversity (Rodriguez, 1997). In years when rainfall is not sufficient to produce a cereal crop, the expansion of the cultivation frontier has resulted in significant wind erosion and depletion of the soil resource. Complete removal of crop residues following harvest in order to feed livestock leaves the soil surface exposed to wind erosion and further degradation.

Below about 200 mm of annual rainfall are vast areas, used as permanent pasture and rangeland, where precipitation is insufficient for arable agriculture. In these areas intensification has simply been increasing grazing pressure with more animals using the range for longer periods of time. The total small ruminant population in WANA, now is about 400 million sheep and goats, many of which are based in the rangelands and adjacent cereal producing areas. Movements of livestock within the rangelands in the past were regulated by seasonal availability of water and forage; they could stay on the natural pastures only as long as grazing and water were available. Water for livestock, rather than seasonal vegetative cover, was the main factor determining the duration of the grazing season. The modern use of vehicular transport by sheep herders has disrupted the traditional grazing cycle and effectively intensified the exploitation of natural grazing. The additional mobility provided by vehicles means that animals can be transported quickly over long distances to take advantage of new pasture. In addition, the ability to transport water to the herds enables them to longer stay in any given area. Thus, early grazing and overgrazing are common. In effect, the range is subjected to larger numbers of animals for longer periods of time each year than ever before in history.

Approaches to Reversing Desertification in Wana

Research Strategy and Agenda

Arresting, and perhaps reversing, desertification in the extensive marginal agricultural and rangeland areas requires a whole range of different strategies to develop more appropriate biophysical technologies and production techniques and associated socio-economic institutional arrangements and policy actions. ICARDA, which has a world-wide responsibility for research and human resource development for sustainable agricultural productivity in sub-tropical and continental dryland environments, has been tackling the issue of desertification through an array of research efforts in collaboration with national program scientists. The goal of the research effort is integrated management strategies incorporating appropriate technologies for agriculture in the drylands that satisfy the triple requirements of increasing production, sustaining the natural resource base, and satisfying the needs and capabilities of the human population that will use them.

The essential research problem is to devise better methods of management of the land surface and its vegetative cover that are technically feasible, socially acceptable, and sustainable. ICARDA has developed simple and easily applied methods to measure soil erosion effects in the drylands in order to quantify factors promoting erosion, test simple methods available to farmers to control erosion in their lands and identify the areas at risk of desertification. Satellite imagery is being used by ICARDA to identify erosion-prone areas. The methods include use of a computer program that takes user-identified sample areas of known type (e.g., wind-eroded units) and generates statistical criteria that are then used to identify similar areas on the wider satellite image. Developing these techniques and the maps they produce allows estimates of the magnitude of degradation while simultaneously permitting assessments of present and future impacts of rehabilitation efforts.

Over the last four years, ICARDA has undertaken germplasm collection in the desert- margin zones to safeguard valuable legume species from genetic erosion and disappearance through overgrazing or cultivation of former rangelands. The germplasm from these areas is often highly drought- and salinity-tolerant. Over 250 accessions have been collected from desert margins below the 300 mm isohyet in Jordan, Tunisia, Libya, Pakistan (Baluchistan) and Morocco. They are presently under rejuvenation and evaluation by national program and ICARDA scientists.

The agenda for developing sustainable systems of land use that can reverse the effects of desertification can be conceived as a matrix along two axes: resource management and production systems. Within the cells of the matrix are located individual activities addressing specific degradation problems with their biophysical sustainability and socio-economic concomitants. The resource management axis is based on the recognition that, everywhere in the drylands, water is the most constraining resource. Reversing the process of desertification requires making the best use of water available from different sources.

Best use may often include the conjunctive (or complementary) use of different water sources, since each source has its special problems. The sources include rainfall, surface flows (perennial and intermittent), groundwater from shallow (rechargeable) and deep (fossil) aquifers, and unconventional sources such as de-salinization plants. Water management is distinguished by two themes: direct use of rainfall at the time and place where it falls and indirect use of captured and/or stored water. This latter theme includes rainfall capture through water harvesting and storage either in the soil profile or in reservoirs and water that is stored by nature in aquifers and river basins.

Table 8: Research Matrix

Production Systems	**Water Resource Management**		
	Direct Rainfall	**Water Harvesting**	**Surface and Ground Water**
Rangeland and Pastures	Rehabilitation, grazing management and shrubs	Micro-catchments for shrubs	
Rainfed Agriculture	Legumes in rotation and soil surface management	Micro-catchments for tree crops	
Irrigated Agriculture		Reservoirs for supplemental irrigation of crops	Water use efficiency and optimization of productivity

The production systems' axis reflects predominant land-use patterns in the drylands: rangeland grazing, rainfed farming, and irrigated agriculture. Each cell within the matrix combines a water management strategy with the production and utilization of vegetation in an integrated and sustainable way. Soil conservation and management are addressed within each cell of the matrix, as appropriate. There are additional aspects of specific importance to desertification in a number of cells. For example, at the intersection of direct use of rainfall and rangeland are located concerns with the *ex situ* and *in situ* conservation of dryland biodiversity of wild plant and animal species. Similarly, at the intersection of river and groundwater use and irrigated cropping are the issues of combating salinization and waterlogging. The discussion of research progress that follows is organized according to the matrix as represented in table above presented.

Range rehabilitation using direct rainfall

Rainfall is the most precious of renewable natural resources. However, only a tiny fraction of rainfall becomes usable soil moisture: only 1-10% of the rainfall that falls in the drylands ends up in the tissue of natural vegetation and crops of economic significance. Most of the water is lost through surface runoff, deep drainage, evaporation from the soil surface and deep cracks, and transpiration by weeds. Techniques must be found to reduce water losses and so increase the moisture available for vegetative growth.

On rangeland, proper grazing management and other measures are essential to preserve sufficient vegetative cover to capture rainwater in the soil profile, prevent serious runoff, and efficiently utilize the water infiltrated into the soil. Research here is concerned with the re-establishment and maintenance of suitable natural plant cover and devising systems that balance animal productivity with rainfall capture.

Efforts to increase the productivity of rangelands and to reverse resource degradation have been carried out in many parts of the region. Measures include fencing off and/or reseeding degraded rangeland to allow it to regenerate, planting of fodder shrubs or trees, and the introduction of appropriate systems of grazing management. However, many of these measures have been applied without regard for resource users' current strategies, economic efficiencies, and integrated strategies. ICARDA recognizes that many of these techniques have a role to play in reversing desertification in rangelands, but they must be applied in an integrated manner well adapted to local environmental, social, and economic circumstances. Closing off grazing land may have positive effects on the regeneration of certain types of vegetation, but protecting the land for too long can have negative effects on productivity by favoring the development of more vigorous, but unpalatable, species that supplant more valuable species such as certain annuals. Grazing, if properly managed, is a positive contributor to the improvement of rangeland productivity. Reseeding or encouraging self-regeneration with native species is also valuable in rehabilitating the degraded rangelands. ICARDA has developed a pitting machine through which the re-establishment of native vegetation can be enhanced. The machine makes pits breaking through the hard surface or sub-surface crust typically found in degraded calcareous soils in WANA; seeds are deposited in the pits where rainwater can collect and moisture conditions favor their successful germination and growth.

Palatable shrubs and trees can provide important fodder reserves while stabilizing the soil surface and reducing wind erosion in degraded rangeland areas. However, attempts to establish plantations of fodder shrubs or trees have not always been successful, due to mistakes in plant density, size of areas planted, inadequate choice of species, etc.. Failure or poor performance of shrub plantations can often be attributed to the poor ecological adaptation of selected species that are unable to regenerate by natural reseeding and eventually disappear. Inappropriate grazing management, particularly in protected plantations, means that shrubs and trees may attain a size where they are either unpalatable or ungrazable.

ICARDA, with its partner the Steppe Directorate of the Syrian Ministry of Agriculture and Agrarian Reform, has been evaluating the use of *Atriplex* spp and *Salsola* spp. for rehabilitating rangeland in areas receiving less than 200 mm. Livestock performance, biodiversity and shrub growth are being measured on improved and native rangelands under different grazing regimes. The data collected will be used to construct models of environmental, vegetation and management interactions for application both in Syrian conditions and elsewhere. ICARDA has conducted similar work with the Arid Zone Research Institute in Quetta, Pakistan that shows promising results with *Atriplex* spp.

For successful use of fodder shrubs and trees, detailed studies are needed to identify appropriate and well adapted species and their agronomic requirements. ICARDA is coordinating a CGIAR system-wide initiative on *Production and Utilization of Multi-purpose Fodder Shrubs and Trees* with other CGIAR centers (ICRISAT, ILRI, and ICRAF) and the national research systems of WANA and the African Sahelian countries. The objective of the initiative is to improve the production and utilization of feed resources in a sustainable manner. Attention is focused on the identification of shrubs and trees adapted to the harsh environments of areas of low rainfall and shallow, often crusted, soils, together with the appropriate management of these species and their integration into existing livestock production systems. In addition to being important feed reserves for livestock on the rangelands, shrubs and trees serve as windbreaks to control soil erosion and as a source of fuelwood for the pastoralists.

Within the cultivated marginal drylands, there are many areas where soil is too shallow, stony or sloping to be used for cultivation. These areas are generally intensively grazed by small ruminant flocks based in the farming villages. Overgrazing is a pervasive problem and severe soil erosion is commonplace. Research conducted at ICARDA on these lands over the past decade has demonstrated that an annual application of a small dose of phosphate fertilizer (25 kg P_2O_5 per ha) can increase the productivity of these lands and reverse the process of degradation. Application of phosphorus in P-deficient land encourages the establishment of legumes and increases the carrying capacity for grazing. In addition, reseeding using native forage legumes such as annual medics and trifoliums has been effective. ICARDA has developed simple, hand operated machines that collect native pasture species seeds, and their use has been demonstrated to farmers. Through a participatory research approach with village communities, phosphate application and reseeding, when combined with appropriate grazing times, has proven to be an effective package of technologies for reversing degradation at a number of different sites in Syria and Lebanon.

Improving Direct Use of Rainfall in the Driest Cropped Areas

Expansion of the cultivation frontier into the rangelands bordering the desert, together with replacement of extensive fallows in previously established cropping areas by continuous cereal monocropping, for livestock feed, have been major contributors to declining soil fertility and wind erosion. One way of combating degradation resulting from cereal monocropping is the introduction of adapted forage legumes, such as vetches (*Vicia* spp.) and chicklings (*Lathyrus* spp.), into the farming system. These crops are indigenous to the Mediterranean basin and can augment soil fertility when properly managed in rotation with cereals. The crops have the additional benefit of multiple-use options: they can be used for green grazing during winter, harvested for hay in the spring, or for grain and straw at full maturity. The high nutritional quality of the plants is of great value to small ruminant flocks dependent on degraded range vegetation and cereal crop residues. Increasing forage production in areas adjacent to rangelands may have a positive impact on the rangeland vegetation by reducing local problems of quality feed supply and allowing the deferment of rangeland grazing until vegetation has reached the growth stage most suitable for grazing.

ICARDA has assembled extensive collections of vetch and chickling species, evaluated them for environmental adaptation, and made selections of types with superior agronomic characters suitable for dryland cropping systems. A number of ICARDA vetch and chickling selections have shown excellent performance in the low rainfall arable farming areas of the northwest coast of Egypt. They are also becoming increasingly popular with farmers in the critical low rainfall barley production zones of Syria, Lebanon, Jordan, and Iraq.

The challenge in dryland rainfed crop production is to coordinate the use of water-efficient cultivars, crop rotations and land management to increase biological and economic output per unit of water. The development of drought-tolerant, or more water-use efficient cultivars, particularly through the advances made in biotechnology and genetic engineering, contributes to this goal. At least equal contributions may be achieved from improved soil, crop and cropping system management. The objective is to integrate the use of water-efficient cultivars, crop rotations and land management in a sustainable production system that increases biological and economic output per unit of water. Water-use efficiency in rainfed agriculture depends on the maintenance of a permeable surface and the establishment of crop canopies that maximize productive transpiration relative to losses through weeds and surface evaporation. Well-timed tillage operations, in some cases including contour ridging or mulching, combined with skilled, locally adapted crop husbandry may double the percentage of water used productively.

Water Harvesting and Irrigated Agriculture

In many locations, direct rainfall is insufficient for crop growth and increasing the amount of water available through water-harvesting techniques is the most appropriate way to ensure sustainable production and to reverse desertification. Water harvesting concentrates rainfall by allowing and encouraging it to run off catchment surfaces in a controlled way and then storing the harvested water for subsequent use. Water may be stored in a number of ways: small dams, cisterns, shallow aquifers, or in the soil profile. It is then made available to a target crop, shrub, or tree.

Water harvesting has deep historic roots in the WANA region. Many ancient systems, long fallen into decay ,need to be revived and adapted for use in the modern world and new systems more adapted to modern social and economic circumstances devised. This is not easy. Developing the right system and adapting it successfully to local conditions is rarely straightforward. An inevitable degree of unreliability in supply requires careful choice of target crops. Moreover, water harvesting systems will not be maintained unless they command the full confidence of their users. Using land as catchment often involves opportunity costs and may adversely affect current users, and it may have important environmental implications. Intercepting run-off flows higher up in larger catchments may have hydrological, social and economic consequences for downstream users.

Water-arvesting techniques may be grouped into two categories. Techniques that directly supply water to target crops and store water not immediately transpired in the soil profile around the root zone may be considered micro-catchment techniques because the catchment area is small and no artificial storage structures are required. The other category are macro-catchment techniques that concentrate run-off flows and store them in prepared reservoirs for subsequent application to the target crop. The application of stored water can be considered a form of supplemental irrigation, in the sense that the harvested run-off water is used to supplement the rainfall that directly falls on the target crop. The choice of technique and target crop depends on local circumstances, including topography, soil type and depth, rainfall characteristics (amount, distribution and variability), and run-off coefficients. ICARDA and its national partners are following a combined strategy in water-harvesting technique decision-making. Research is being conducted in selected sites in a number of countries in developing and refining individual water harvesting techniques and establishing their performance parameters. At the same time, on a much broader geographic scale, remote sensing and GIS technologies are being applied to assess and select suitable areas for large-scale water harvesting applications within the drylands of WANA. Digitized sets of satellite images, topographic information, soil types, vegetation, hydrology, and meteorology are combined with specific water harvesting techniques to provide an expert system for decision making for large-scale development investments.

A decade of work in Jordan and Syria has demonstrated that micro-catchment techniques such as contour ridges for fodder shrub and pasture production has great potential for revegetation and combating degradation in rangelands. Where rainfall is less than 150 mm, micro-catchments economically support almond, pistachio and olive trees without supplemental irrigation. In the same area, water harvested and stored in small earth dams was used for the seasonal production of field crops. Rainfall use efficiency can be very high using properly designed and managed water harvesting systems. Overall system efficiency for small basin micro-catchments in Jordan reached over 86%. If the system is ill-designed and not properly managed, the efficiency drops to about 7%. These results reinforce the importance of combining technology development with the perceptions, needs, and capabilities of the land users who will implement water harvesting (Oweis, 1997).

ICARDA is the convening center, within the CGIAR, for an ecoregional research programme in *On-Farm Water Husbandry in West Asia and North Africa*, linking scientists from ICARDA and national programs in WANA and established recently to focus precisely on these issues. The research programme addresses four main themes:

- Description and analysis of indigenous systems (past and present), with particular focus on the human dimension.
- Development of methods for appraisal of sites for water-harvesting potential.
- Optimizing the utilization of the harvested water.
- Disseminating new techniques to land users.

Although supplemental irrigation using harvested rainwater may be the only way of ensuring annual harvests of field crops in the driest cultivated areas, modern supplemental irrigation can play a much wider role in sustaining water resources. Using groundwater from shallow aquifers to supplement rainfall during the growing season has always been a widespread phenomenon throughout WANA. Over the past half century, however, new technologies have increased the capacity to extract, move and use water, resulting in use exceeding supply in many areas. In fact, the popularity of well irrigation is so great that in many locations water extraction is exceeding recharge, and many shallow aquifers have been depleted to the point of exhaustion. Over pumping goundwater in coastal areas leads to the intrusion of sea water and salinization of soil. Sea water intrusion is of particular concern in Libya, Oman, and Yemen. The challenge in maintaining, and perhaps restoring, vital groundwater resources, and thereby ensuring sustained production improvements, is to use the available water to the highest degree of efficiency possible.

ICARDA has a substantial program of supplemental irrigation research targeted to agricultural areas receiving between 250 and 500 mm of annual rainfall. Research has concentrated on improving water-use efficiency in supplemental irrigation by determining the optimum amount of water to apply across a range of environmental circumstances rather than achieving the highest possible yields. Maximizing yields usually results in overuse of water per unit of production. Judicious application of small amounts of supplemental irrigation in Syria when rainfall does not exceed 250 mm showed that 200 mm of irrigation applied at the proper time increased the grain yield of wheat from 0.5 ton/ha to 4.0 ton/ha. When rainfall exceeded 500 mm, 70 mm of supplemental irrigation improved wheat yield by over 1.5 ton/ha. It has been found that the water use efficiency of supplemental irrigation is much higher than full irrigation in low rainfall areas. A cubic meter of supplemental irrigation water produced on the average over 2 kg of wheat, whereas under full irrigation a cubic meter of water produced only 0.5 kg of wheat.

In long-established irrigated areas and in newly reclaimed irrigated lands throughout WANA there are serious degradation issues. To a greater or lesser extent, these lands are threatened by changes in water quality and quantity, rising water tables and salinity, increased disease incidence, and pollution of soil and water from heavy use of chemicals and fertilizers. Moreover, FAO estimates that as much as 60% of water diverted or pumped for irrigation is wasted through leakage, system faults, and misapplication. Through its Nile Valley and Red Sea Regional Program, ICARDA has joined in partnership with the Egyptian national program to implement a research project designed to address resource management and sustainability issues in the long established and newly reclaimed irrigated areas. A number of sites, each selected for representative environmental conditions and identified resource degradation threats, have been established for a series of long-term trials and on-farm resource management studies.

Conclusion

Desertification is a reversible process, but action must be taken immediately to reverse the process in areas where the threat is greatest before the process reaches its conclusion and there is no longer the chance of recovery. In the drylands of WANA and the arid and semi-arid zone has the highest priority because it is here that removal of natural vegetation and inappropriate cultivation methods are degrading and depleting valuable and limited biological, soil, and water resources at the fastest rate.

ICARDA is firmly committed to addressing and seeking to reverse desertification in the drylands through research to develop sustainable agricultural systems that integrate crop and animal production, appropriate resource management practices, and the needs and capabilities of the human population. ICARDA and its national and international partners are working together to utilize the scientific and technological tools available to achieve this objective. The research effort is producing an array of applicable and proven approaches to combat desertification, including rangeland rehabilitation, grazing management, farming systems development, water harvesting and on-farm water husbandry practices. As we move into the 21st century, the future looks promising, so long as the research effort is sustained.

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8

Soil Desalinization and Land Reclamation in Iran

A case study : Khuzistan Province

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Introduction

Land degradation is one of the most restrictive factor on world wide food production. In arid and semi-arid regions, apart from the water and wind erosion of valuable top- soils due to overgrazing and deforestation, the main factor contributing to land degradation and desertification is soil and water salinization. Salinization is the increase in concentration of total dissolved solutes in water and soil bulk solution. Soil and water resources can be salanized naturally by physical and chemical processes or by human activities (secondary salinization).

Secondary salinization is as old as the history of irrigation. The well known case of secondary salinization happened in Mesopotamia where the civilization establishment and development was based on irrigation farming and the main crop cultivated during the early days was wheat. Overirrigation along with improper management of irrigation facilities, poor soil internal drainage condition, unsuitable quality of irrigation water and lack of drainage facilities lead to accumulation of salts in irrigated lands. In response to these changes wheat was replaced by barley which is more salt - tolerant. By 1700 BC the cultivation of wheat had been abandoned completely (Ghassemi et al. 1995). Change of cultivation pattern lead to more and more salinization of land and water resources. Consequently, in the later millenniums the salinity of resources reached such levels that barley would not grow and the civilization of Summer and Akkad became depopulated and decadent. Other historic evidence from several parts of the world emphasis on the role of human- induced salinization on downfall of the civilizations.

Large scale irrigation developments, that come back decades ago, promoted soil and water salinization as well land degradation, particularly in arid and semi-arid zones. Now day, about 77 million hectares of cultivated lands are salt- affected to varying degrees from secondary salinization. Therefore, sustaining and preserving productivity of the current 230 million hectares of irrigated lands and 1475 million hectares of dry land agriculture is the basic concept. A typical example of irregular large scale irrigation developments is the Amu Darya and Syr Darya rivers in the Commonwealth of Idependent States(CIS) which diverted from the Aral sea for the development of irrigated lands in 1950s. Due to these huge diversions its level dropped about 13m and its area decreased by 40 per cent between 1960 and 1989 (Ghassemi et al. 1995). The Aral sea still is shrinking and this fully degraded the ecosystem and caused health hazards and climatic changes in the region.

Secondary salinization is predominant in arid and semi- arid regions. The countries affected by this phenomenon include: The United States of America, Argentina, Brazil, Chile, Peru, Australia, Thailand, China, India, Pakistan, Iran, Iraq, Turkey, Syria, Egypt and Spain. Table 1 provides global secondary salinization distribution in the world's irrigated lands.

Table 9: Global estimate of secondary salinization in the world's irrigated lands.

Country	**Cropped Area (Mha)**	**Irrigated Area (Mha)**	**Share of irrigated to cropped area (per cent)**	**Salt affected land in irrigated Area (Mha)**	**Share of salt –affected to irrigated land (per cent)**
China	96.97	44.88	46.2	6.70	15.0
India	168.99	42.10	24.9	7.00	16.6
Commonwealth of Independent States	232.57	20.46	8.8	3.70	18.1
United States	189.91	16.10	9.5	4.16	23.0
Pakistan	20.76	16.08	77.5	4.22	26.2
Iran	14.83	5.74	38.7	1.72	30.0
Thailand	20.05	4.00	19.9	0.40	10.0
Egypt	2.69	2.69	100.0	0.88	33.0
Australia	47.11	1.83	3.9	0.16	8.7
Argentina	35.75	1.72	4.8	0.58	33.7
South Africa	13.17	1.13	8.6	0.10	8.9
Subtotal	**842.80**	**158.70**	**18.8**	**29.62**	**20.0**
World	**1473.70**	**227.11**	**15.4**	**45.4**	**20.0**

Source: Ghassemi et. Al (1995)

Salinity in Iran

The overincreasing salinity of land and water resources is one of the most important problems in Iran's agriculture. The main factors on contributing to the salinity of soil and water resources of country include: high potential evapotranspiration, poor soil internal drainage condition, low rainfall and its improper seasonal and regional distribution, topographic situation creating closed and semi-closed basins, surface and subsurface drainage networks scarcity,overirrigation, irrigation with unsuitable water (surface and groundwater) and improper design, construction and management of irrigation facilities.

This factors lead to formation of vast saline and sodic soils which is distributed mostly in the central plateau, east and southwest parts of the country. However, some scattered regions in the north parts of the country suffer from the salinity and sodicity to varing degrees. It is believed that the total area of saline and sodic soils of Iran to be estimated about 24 million hectares or 15 per cent of the surface area of Iran (Pazira and Sadeghzadeh, 1998). Irrigation has predominant effects on the secondary salinization of land resources in the country. Considerable areas under the modern constructed dams have gone out of cultivation due to overirrigation, waterlogging and salinity problems (Bybordi, 1989). Consequently, the need for design, planning and construction of drainage networks has been recognized in nearly all modern irrigation projects. Also, in some irrigated as well as non-irrigated lands desalinization operations must be performed which is commonly time consuming and very expensive.

This paper presents an attempt to introduce some empirical relationships to quantify soil desalinization and land reclamation in Khuzistan provinc which is located in the southwest of Iran.

Methods and Materials

The selected site has typical condition ; the soil ranges from highly saline to highly saline-sodic and has heavy texture. The saline groundwater table is also shallow. Lowering of the groundwater table by means of open drains to a depth of 2.5 meters enables the determination of tile drain spacing which is essential for salt leaching as well as salt balance management. Subsurface drainage design was done for tile drain spacing of 25,50, 75, and 100 meters, all with 100 meters length. To compare the effect of tile drain spacing on soil desalinization and reclamation, 4 levels of depth of leaching water, i.e., 0.5, 1.0, 1.5 and 2.0 meters were applied in the same replication. Large size plots were designed. The top soils of the plots were plowed. Experiments were done on a field in which the tile drain spacing were different. Soil sampling depths and procedures, rate of water application and the water redistribution period were just the same. The soil salinity data obtained before and after leaching for eight different soil depths were used to calculate the mean depth values of soil segments from 0.5 to 2.0 meters down. The same statistical method was used to examine the obtained data. It can be seen that as the depth of leaching water or the ratio of leaching water to the depth of soil increases, the salt leaching rate also increases, specially in the topsoil layers. Also, the rate of salt leaching within the soil profile increases with an increase in depth of leaching water. However, in general, the mean depth values and the obtained results are nearly the same.

The salinity will be reduced only to a special rate (i.e.,Min ~ ECe = 2.0 dS/m) either under high or low application of leaching water. Therefore, it can be concluded that the reclamation requirement will be strongly related to the initial soil salt content and soil physical conditions rather than increase in depth of leaching water. Furthermore, it is worthy to use a unit depth of leaching water per unit depth of soil segment as the reclamation requirement and continue the salt leaching by irrigation through the principle of leaching requirement if leaching of soluble salts from the soil profile is our target. The calculated drain spacing may be suitable, but for waterlogging control and salt balance purposes the drain spacing may vary from 25 to 100 m in the region.

Soil Desalinization

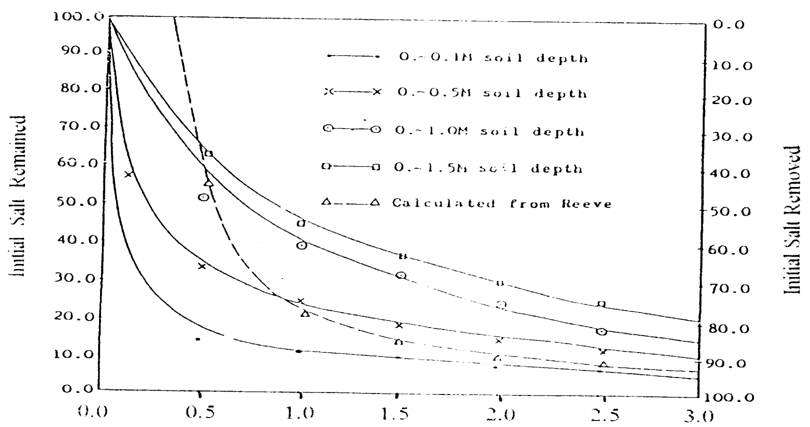
The principle of desalinization consists of leaching out the soluble salts downward, specially from the top soil layers,using leaching water application as well as irrigation. Naturally, the percolated water contains much salts which should be removed by establishment of subsurface drainage systems, if the groundwater table is high. The presence of high saline water table causes the soil internal drainage condition to be insufficient and poor.

The data for soil salinity obtained before and after leaching experiments, were averaged for each treatment. The leaching curves with respect to soil desalinization at soil depths 0 - 0.1, 0-0.5, 0-1.0 and 0-1.5 meters are shown in Figure (6).

For similar experimental data Reeve (1957) has suggested to replace (Dlw) by (Dlw/DS), in the form of an empirical hyperbolic relationship as follows :

$(Dlw/DS) = (EC_i / 5EC_f) + 0.15$ .... (1)

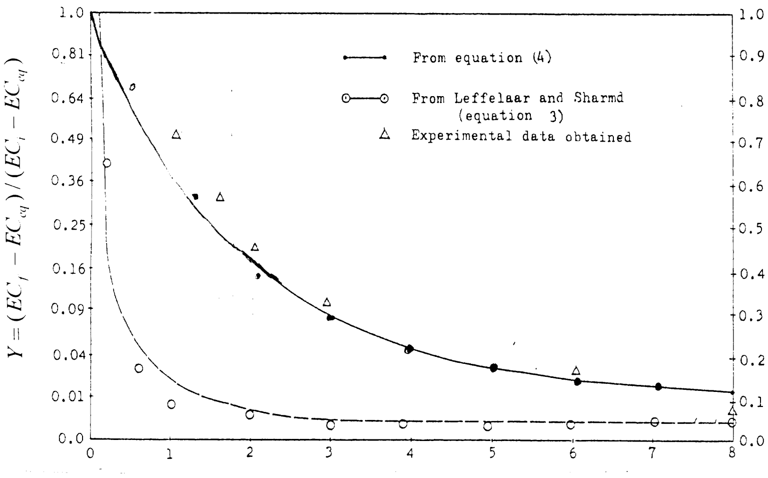
In which Dlw is the depth of leaching water(cm, or m), DS is the depth of soil (cm,or m), EC_i is the soil salinity (ECe, dS / m or salt %) before leaching and EC_f is the soil salinity (ECe, dS / m or salt %) after leaching.



Depth of Leaching Water (Dlw) in Meter

Figure 6: Relation between soil salinity and depth of leaching water

In the case of DS= 1.0 meter, Eq.(1) was used where the results are given in Figure (7).



Depth of leaching water per unit depth of soil(DLw/DS)

Figure 7: Desalinization leaching curve

From the results, it could be seen that this equation can not be fitted to the leaching experimental data of Khuzistan province soils,because the natural conditions, initial salt content of soil and heaviness of soil texture, were different from Reeve’s experiments.

Van Hoorn (1973) and Leffelaar & Sharma (1977) reported opposite results using Eq. (1), even with rather the same soil texture (sandy loam to silt loam). However, from Figure (7) it can be seen that as the depth of leaching water increases, the rate of salt leaching also increases, specially at the top soil segments., (i ; e ;0.1 and 0.5 meter). As a result of this, the surface of bare experimental plots were plowed before leaching water application. In general, considering the soil segments of 0.5 and 1.0 meter as the top and sub soil layers, application of one unit of leaching water per unit depth of soil (two pore volume) decreases the initial salt content of the respective soil layers to 78% and 60%, respectively.

Desalinization Leaching Curve

The leaching graph could possibly show the relationship between soil EC i ,

EC f and Dlw, as well as (EC_f -EC_{eq}) / (Ec_i -EC_{eq}) and Dlw, in which EC_{eq} represents the salinity or electrical conductivity of soil extract obtained after salinity of that has come to an equilibrium under specified local conditions. Based on the relationship suggested by Reeve (1957), the following equation can be derived:

$$\frac{(EC_f - ECeq)}{(EC_i - ECeq)} = A(DS / Dlw) + B \quad .... (2)$$

where A and B are experimental constants. Leffelaar and Sharma (1977) used these empirical hyperbolic relationships in their treated cases (sandy loam to silty loam soils) as follows :

$$(EC_f - EC_{eq} / EC_i - EC_{eq}) = 0.062(DS / Dlw) + 0.034 \quad (3)$$

The value of EC_{eq} of Khuzistan soils in this report was found to be 2.0 dSm^{-1} in top soil layer (in traditional farms with good soil drainage conditions). This value, as mentioned by Dieleman (1963), depends mainly on evaporation, drainage conditions, and salinity of irrigation water (EC_w). If this value is subtracted from EC_f and EC_i , the relationship between (EC_f -EC_{eq}) / (EC_i- EC_{eq}) and depth of leaching water becomes independent of salinity of leaching or irrigation water, existing drainage and evaporation conditions. The graphs that result from using the former relationship are determined by the soil characteristics.

The case study was conducted in summer season, when there was no rainfall and the rate of evaporation was excluded. In other cases, the depth of water which was needed for moistening the soil layer, was obtained by subtracting evaporation and adding rainfall. For soils which were used in this study ,the data of Figure (7) were used and attempt was also made to express the results using equation (3). The derived equation is as follows ;

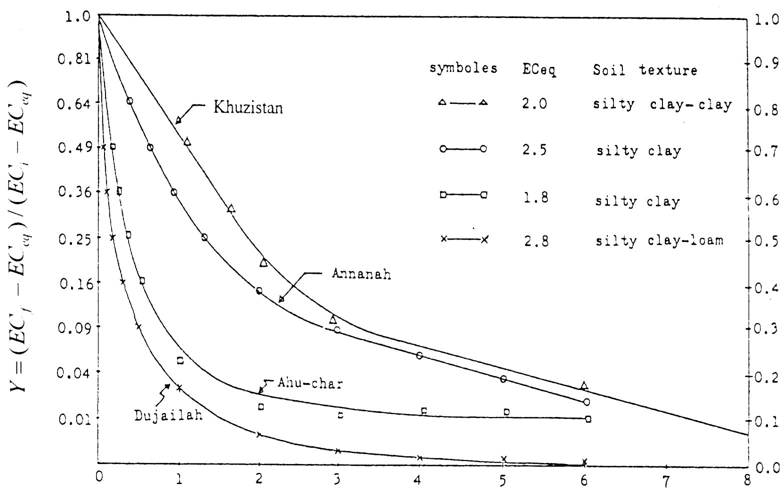
$$(EC_i - EC_{eq})/(EC_f - EC_{eq}) = 0.0761(DS / Dlw) + 0.023 \quad (4)$$

The results of calculation based on Eqs. (3) and (4), and the experimental data are presented in Figure (7).From this, it can be seen that Eq. (4) fits accurately to the experimental data. However, equation (3) does not fit the experimental data obtained from this area, because of the heaviness of soil texture.

Comparison of Other Experimental Data

There are some theoretical models that predict the leaching curve such as the Glueckauf theory of column operation as applied to the soil by Van der Molen (1956), leaching theory of Dieleman (1963) and many numerical methods, as one was introduced by Tarkeltoub and Babcock (1971). Since there are some limitations as regards to their applicability to heavy and very heavy textured soils, the comparison was avoided. Comparison to other experimental desalinization leaching curves obtained in Iran (Khuzistan and Ahu- Char) and Iraq (Annanah and Dujailah) is presented in Figure(8). The data of Annanah and Dujailah were from Dieleman (1963), those of Ahu- Char experimental station were prepared by Van Aart and Osterkamp (1968) and those of Khuzistan experiments are from author’s research works.

From Figure (8) which shows a comparison between desalinization leaching curves for Khuzistan soils and those of Ahu- Char, Annanah and Dujailah soils, it will be shown that the leaching process on Khuzistan soils seems to be difficult, as compared with Ahu- Char soils in Iran and Dujailah in Iraq. It must be said that, experimental desalinization leaching curve is valid only for the initial salinity ranges through the soil profile. The values (electrical conductivity of saturated extract) for Ahu - Char, Dujailah, Annanah and Khuzistan soils were 30-140, 40-100, 20-60, and 65-80, respectively. This is the reason why the initial salt leaching was less effective for Khuzistan and Annanah soils as compared to other soils.



Depth of Leaching Water Per Depth of Soil (DLw/Ds)

Figure 8: Desalinization leaching curves for the Khuzistan soils

Another reason for less effectiveness of leaching on Khuzistan soils, which is characterized by heavy and very heavy textured soils, is that the leaching water which passed through the large pores (cracks, which were in the soil column and/or had developed quickly on soil surface during the redistribution period) had only a minor effect and hence decreased leaching efficiency.

Application of Salt Leaching Curve

Leaching practices and programming can be conducted in some different ways. The main difference in the leaching methods depends on whether application of leaching water will be done on bare soil or it will be programmed by cropping systems. Consequently, selection of appropriate method for soil salt leaching not only depends on soil physico - chemical properties, but also on social and economical aspects. However, based on mentioned considerations, a specified reclamation procedure seems to be advisable. Moreover, the use of leaching curves will enable us to arrange the various steps of accurate planning in relation to reclamation water requirement as well as the time needed for completion of reclamation procedure.

Conclusions

Studies on the salinity problem in Iran, in general, and Khuzistan plains in detail were considered in this research. As it could be pictured soil salinity, sodicity and waterlogging problems are the main causes of deterioration of the irrigated lands and crop yield reduction in Iran. It is important to note that extension of irrigated area by means of construction of storage and diversion dams caused serious problems and deterioration of the irrigated lands in the country. This deterioration was enhanced when the groundwater table was relatively shallow ; capillary action and upward movement of water from saline groundwater table made the soil completely unarable. To reclaim such a potential productive lands additional water was needed for leaching process. Since water was not available each year a noticeable area is shifting out of cultivation. A typical example of such problems happened in the area of the Khuzistan plain; the details, causes as well as the solution of the problems are presented. In reclamation process of the saline, and saline - sodic soils,some approaches such as subsurface drainage networks planning and construction, salt leaching operations and amendments application must be recognized and utilized. Good soil drainage conditions, effective irrigation and proper cropping systems are important to improve and maintain the productivity of the reclaimed irrigable lands. Continuous inspection is needed for irrigation of reclaimed lands ; if any problem happens, the solution should be studied. Still much more research works are needed in this respect.

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9

Aquifer Management : A New Approach to Soil and Water Conservation in the Deserts of Iran

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Abstract

Desertification, if continued at the present rate, will take most of the world's cropland out of production in the 21st century. Clear cutting of forests for industrial and fuelwood, and later conversion to cropland, destroys another life support system. Plowing of the rangeland to replace the desertified cropland completes a vicious cirlce. However, there is a hope. Aquifer management, which is based on the artificial recharge of groundwater (ARG), not only replenishes the empty aquifers on the debris cones, but builds soils that will be used for growing food, feed, fiber and fuelwood. Harnessing annually 42 km^3 of floodwater to recharge aquifers under 14 million ha (mha) of the ARG systems will provide water for irrigation of 6 - 8 mha in the deserts of Iran while providing employment for 4 million people.

Introduction

The United Nations Conference on Environment and Development (UNCED) adapted the following definition of desertification at Rio de Janeiro, Brazil, in June 1992: "Desertification is land degradation in arid, semi-arid. and dry sub-humid areas resulting from various factors, including climatic variations and human activities" (Anon., 1997). Soil erosion annually takes 5 - 6 million hectares (mha) of cropland out of production (Doos, 1994). Salinization makes 2 mha of irrigated land unfit for agriculture every year (Umali, 1993). These, plus the land made useless for crop production due to compaction, inundation, toxification, burial by the moving dunes and conversion to airfields, roads, building sites etc., annually amount to 14mha. Assuming that cropland of the world covered 1444 mha in 1990 (FAO, 1992), therefore, man will be out of most of the present cropland before the arrival of the 22nd century. Clear cutting of forests, to the tune of 13.4 mha a year (FAO 1992, 1993), principally for conversion to cropland, is an exercise in futility. This also happens to untold mha of rangeland which are put under the plow but left to nature after a few years due to erosion and loss of fertility. In conclusion, human activities are making *wastelands* out of our irreplaceable life support systems.

More importantly, as a net importer of food, feed and forest products Iran will be most affected by the outcome of land degradation on the global scale.

As we are approaching the 21st century water is taking a prominent position in geopolitics. And we, in the Middle East, will be at the cutting edge of the conflict. As water is the most precious resource in drylands, it is logical that we should manage our meager water resources properly to be able to live comfortably in the near future. And since groundwater supplies about 60 % of our water requirements its prudent management is of paramount importance.

Debris Cones: The Habitat of Ingenious Desert Dwellers

It is greatly to the ancient Persians' credit that they chose the debris cones for living. They not only benefited from the permanent and temporary springs which issued from the apices of the cones, but spread the nutrient rich floodwaters on their permeable land irrigating their crops while simultaneously replenishing the underlying aquifers. The artificial recharge of groundwater (ARG) lead to the invention of qanat, the most appropriate technology for water collection and delivery in the deserts underlain by the coarse - grained Quaternary alluvium. The very low gradient of the qanant tunnel, about one in thousand, in sloping cones facilitated the construction of underground aqueducts at different levels, each draining the upstream aquifer and recharging the downstream one. These highly efficient systems irrigated the fertile alluvial fans.

The flood-irrigated fields are actually the sedimentation basins (SBs) and recharge ponds (RPs) of the ARG systems. As soon as an SB or an RP is filled up with the suspended load it is converted into a cropping field irrigated with floodwater. Thus, the farmers add to their holdings as the time goes by. It is obvious that soil building is a natural outcme of the ARG, the most practical and the least expensive method to reclaim the drastically disturbed land.

The Alluvia of Iran: An Astronomical Wealth

The geological setting and climate of the Iranian Plateau are conducive to the ARG and discouraging to the construction of large dams. The deposition of thick argillaceous lacustrine layers during the Miocene and Pliocene ages, and the filling up of the basins with alluvial deposits during the Pleistocene age, formed the Central Plateau aquifers which may be up to 400 meters (m) thick (Stoecklin, 1965; Issar, 1969). The gypsiferous marls of the Miocene age make the basins in the Zagros Mountain Ranges impervious. These basins are filled up with the coarse - grained, calcareous alluvium and chert which may hold water of good quality for millenia. The very same tectonic movements that formed our mountain ranges are still continuing today, but at slower rates. The damsites in the defiles are mostly formed by faults, some of them active. Moreover, outcropping of the highly erodible Miocene formations in the watersheds produce enormous sediment loads which eventually fill up the man - made reservoirs in a relatively short time, and make the large dams useless. The mean annual evaporative demand of the deserts in Iran is about 3m; therefore, an enormous volume of the precious water is wasted from the surface reservoirs. These, and the very great expenses incurred during the study and construction phases, make the large dams uneconomical for most of the land of Iran.

According to the latest survey this country is blessed with 43 mha of debris cones, alluvial fans and colluvial soils suitable for the ARG. Assuming that the average thickness and specific yield of these potential aquifers are 100m and 10%, respectively, they may store 4300 km^3 of water, 10 times the mean yearly total precipitation of Iran. The entire volume of the reservoirs built in Iran in the modern times is less than 30 km^3. The average cost of $1m^3$ of space behind large dams is $0.20 at the current official exchange rate. Therefore, the present value of the space in the aquifers, if utilized for water storage, is 860 billion dollars. The total cost of the ARG system construction on this 43 mha is approximately 3.5 billion dollars. Considering that the benefit: cost ratio of an ARG project implemented at the Gareh Bygone Plain in southern Iran was 20 (Bakhtiar et al. 1997), the real financial rewards of aquifer management come into focus. It should be emphasized that the losses of life and property due to floodings, the enhancement of environmental quality, such as carbon sequestration, and other intangible benefits were not included in arriving at the B:C ration of 20. Could these items be quantified and added to the benefits the B:C ratio would have certainly risen.

Floodwaters and coarse - grained alluvia of good quality are two of the most precious treasures for the desert dwellers.

Gareh Bygone Plain : A Reclaimed Desert

An ARG project, which was implemented during the 1983-1986 period, coveres 1365 ha of a 6000 ha sandy desert in southern Iran. Fixation of the moving sand through deposition of the suspended load in the SBs and RPs has virtually eliminated the dust storms on the site (Kowsar, 1991, 1992). The nutrient rich sediment in eucalyptus stands have provided a fertile soil for growing flood-irrigated cereals (Table 10).

Table 10: Selected physico - chemical properties of the 0-30 cm soil of the Gareh Bygone Plain Artificial Recharge of Groundwater Project site.

Soil property	**Control**	**Flooded For 6 years**
Sand, %	73.2	23.0
Silt, %	14.5	60.0
Clay, %	12.2	17.0
Saturation, %	23.4	61.0
Organic C, %	0.17	2.06
Total N, %	0.034	0.208
EC, mmhos cm^{-1}	0.47	1.40
Available K, ppm	156	250
Available P, ppm	4.5	45.6
$CaCO_3$, %	38.28	38.00
pH (saturated paste)	7.96	7.50

Eucalyptus camaldulensis Dehnh., planted at 3x3m spacings, yielded 7.765 m^3 of wood per ha per year at the age of 8 (Kowsar, et al. 1996). The number of irrigation wells has increased 10-fold to 120, and the area of irrigated farm has increased 20.7- fold to 3482 ha (Kowsar, 1998). The yearly yield of the indigenous forage has increased 11- fold to 900 kg per ha; however, the fodder yield of plots planted to *Atriplex lentiformis* (Torr. Wats.), *Acacia salicina* (Lindl.) and *A.cyanophylla* (Lindl.) has increased more than 30-fold. Barley production on the reclaimed sand irrigated with floodwater has ranged from 1.0 to 2.3 tons per ha per year with the growing season rainfall of 153 to 313 mm, respectively (ibid). Water salinity, as measured by electrical conductivity, has decreased from 20 to 69%. The average honey yield of 20 beehives kept at the site was 14.5 kg for a 4 month period during March - June 1997; however, the average yield of beehives of two commercial growers were 10.0 and 8.5 kgs for a 30 and 45 day periods in the spring of 1997, respectively.

A detailed proposal has been submitted to the government of the I.R. Iran to implement the ARG projects on 14 mha of the most suitable aquifers, annually recharging 42 km^3, providing adequate water for the irrigation of 6 - 8 mha of cropland, while planting the SBs and RPs to fruit trees, industrial and fuelwood, forage, cereals, etc., and providing employment for 4 million people.

Epilogue

Aquifer management is the prudent utilization of two usually wasted resources, floodwaters and debris cones. It is only through the intellingent utilization of the natural resources, mainly soil and water, that man may continue to live on the planet earth for the foreseeable future.

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Desertification Assessment and Control

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Desertification: Assessment and Control

Combating desertification requires assessment and monitoring of the type and severity of land degradation in the drylands, a determination of the causes of the land degradation which has occurred, and the selection and application of appropriate actions to counter the problem. None of these three exercises is easy or uncomplicated. The principal reason for the difficulty is that desertification, as was shown long ago, is not a simple technological problem. Controlling water erosion of soils, for example, is a well-understood technical process. Determining why agriculturalists do not act to stop erosion is a complex social and economic question for which there probably are no readily available explanations (Stiles, 1995). Neglect of these non-technical factors by project planners and managers is not necessarily due to ignorance or lack of appreciation of their importance. Most of the reluctance or inability to consider them arises from the time demands and the presumed complexity of doing so.

Assessment

Assessment of "desertification" as a whole (the sum of one or more individual land degradation processes, such as vegetation degradation, water erosion, wind erosion, salinity, etc.) is of little use. Maps of desertification can have educational value but cannot be used by planners to propose control projects. Planners need to know the severity of each degradation process because control of desertification demands, first and foremost, control of each process affecting the land. These land degradation processes include, in addition to the major processes mentioned above, such environmental problems as soil structure deterioration, lowering of groundwater levels, pollution of groundwater supplies, loss of soil fertility, heavy metal and pesticide contamination in soils, and other damages to land productivity.

Desertification Status

Assessment of the status of desertification (land degradation) processes is essential for a village, district, region, or nation to make informed decisions on the financial and labor investment that should be made in its control. The scale at which assessments are made largely determine their accuracy. At the village level, people commonly do not possess quantitative data on the impact land degradation has had on the well-being of the community. Nevertheless, the older farmers, pastoralists, and merchants usually will have a reasonably good idea of the degree to which land damage has affected the welfare of the villagers. Also, they know what land is in good condition and in poor condition. Local languages frequently have specific words to identify soils having different levels of productivity (Krupenikov, 1992).

The structured informed opinion technique (Dregne, 1989) for mapping land degradation can be useful at the detailed scale of a village. Successful use requires participation of a representative group of villagers, not just the opinion of the village chief. Collecting good judgmental information is no simple task. Sending out a questionnaire, only, is not going to provide estimations that are comparable and based on the same assumptions. The end product of a land degradation assessment for the drylands is a map showing the location, extent, and severity of each significant land degradation process (erosion, salinity, etc.). From those maps, a map of desertification can be constructed, if desired.

Working with local people to assess the impact of land degradation is generally considered to be essential to the success of field projects. After all, the beneficiaries-to-be of a project usually have the greatest to gain and the most to lose. Assuring that these people do participate actively and effectively in the planning and execution of projects requires commitment, patience, a tolerance of contrasting views, and knowledge of local social and environmental conditions by whatever agency takes the lead, whether it be a government department or a non-governmental organization (NGO). Communication is the key.

Desertification Maps

Desertification (land degradation) maps become less accurate as the size of the mapped area increases. Maps at different scales serve different purposes, also (Table 1). Global, continental, and national maps of desertification or of desertification processes are useful to inform people about the general status of land degradation in the drylands and to call attention to the presence or absence of a major environmental problem. They have less value in detailed project planning at the catchment (watershed) and village levels. Desertification control is site-specific, meaning that even though general principles of control of land degradation processes are well-known and widely applicable, deciding what trees to plant and what the shape of terraces should be depends upon local environmental conditions.

Informed opinion appears to be the best available procedure for constructing small scale maps (national, continental, global). At the village (community) and watershed scale, however, informed opinion is not enough; actual field information is essential. Effective project plans simply cannot be made on the basis of opinion. Opinion can be useful for a first attempt at assessing the severity of any individual degradation process. The second vital step is data collection on past and present land and productivity conditions. Land degradation assessment in the state of New South Wales in Australia is an excellent example of small-scale map presentations for decision-makers (Graham et al., 1989). One of the rare national maps of soil degradation is in a report from India (Sehgal and Abrol, 1994).

Costs

At all assessment scales, estimates of the cost of each desertification process should be made. Those costs, optimally, would include on-site (farm field) and off-site (downstream) damage done or income foregone. Decision-makers usually are interested in knowing the location and severity of land degradation. What really gets their attention, though, is the cost of the damage done, first, and how much it would cost to stop and reverse the process, second. In Australia's state of New South Wales, one of the very few large-area estimates of on-site damage done by major land degradation processes–expressed as income foregone annually–has been made (Aveyard, 1988). To considerable surprise, the most costly kind of land degradation was soil structure decline (soil compaction). Prior to the cost determination, water erosion was believed to be the principal degradation process. Table 12 presents a summary of the Australian analysis. Canada conducted a similar survey for the nation for soil degradation (Science Council, 1986).

Table 11: Impact of scale on use of desertification maps

Scale		**Example**	**Use**
Relative	**Numerical**		
Very large	> 1:1000	Village	Setting priorities and planning field projects
Large	1:1000 to 1:10000	Catchment	Setting priorities and planning field projects
Medium	1:10000 to 1:50000	Region	Setting Priorities
Small	1:50000 to 1:1000000	Nation	Approximate location and severity of land degradation
Very small	< 1:100000	Continental and global maps	General information on desertification

Table 12: Costs of Land degradation on Cropland in the Murray-Darling Basin, Australia

Degradation Process	Annual value of production foregone (US$)
Soil structure decline	$108,500,000
Shallow watertables	29,300,000
Acidification	18,900,000
Water erosion	3,800,000
Dryland salinization	300,000
Wind erosion	90,000

**Adapted from Aveyard, 1988.*

Off-site costs of land degradation are much more difficult to estimate than on-site costs. For that reason, no country other than the United States appears to have made studies of off-site damage costs, and that was for soil erosion, only. Ribaudo et al. (1989) produced the figure of $7 billion as the average annual off-site damage cost of water and wind erosion. The authors analyzed the cost of damage done by soil erosion to recreational facilities, reservoir capacity, navigation, commercial fishing, floods, and other facilities. There are wide differences of opinion on how the damages should be calculated.

Monitoring

Monitoring land degradation would be done, desirably, as part of the data collection process before final decisions are made on setting priorities for new projects. Monitoring land changes over time is required in order to determine land condition trends: whether conditions are becoming worse, better, or staying the same. Such monitoring rarely has been done before a project has begun. Once a project is underway, monitoring land condition changes becomes one way to evaluate project effectiveness. Ideally, indicators of change should be quantitative, sensitive to small changes, small in number, and simple to measure. Finding indicators that are unambiguously related to a certain land degradation process or to desertification in general is difficult.

Most indicators are indirect. For example, crop yield decline may be due to soil salinity but may also be due to other problems, such as insect infestation, that have nothing to do with land degradation. Crop yield, then, is an ambiguous indicator that must be analyzed cautiously to avoid confusing a coincidence with a cause. One of the very few unambiguous indicators of land degradation is salinization of irrigated lands. As soil salinity increases, yields of farm crops invariably decline. The rate of decline depends upon the salt tolerance of the crop.

It is critical that monitoring be done over a long enough period of time to truly assess meaningful trends in land degradation. For irrigated lands, three years of monitoring may be adequate to measure trends in salinization and waterlogging. Rainfed cropland monitoring of wind and water erosion probably gives significant results in five years. Rangeland monitoring, by contrast, may require 20 to 40 years to establish range condition trends. It takes longer in drier rangelands than in wetter rangelands to identify trends.

Indicators

Indicator monitoring is a scale-dependent process. Numbers of massive dust storms occurring annually can be a useful indicator of wind erosion trends over large areas. It has no value as an indicator of conditions around a single village. Similarly, measuring the advance of gullies each year or two has meaning at the village or watershed level but is completely impractical as a large-area indicator. A report by Hammond et al. (1995) gives a highly instructive analysis of the selection and aggregation of environmental indicators. The recommendations of the authors are directly applicable to land degradation indicators. The major conclusion is that decision-makers and the public need highly aggregated indicators that, at the final stage, are few in number. This means that data collection may involve a large number of indicators but the final presentation should be a few aggregated indices that are easily understood and can be compared in order to determine trends. The Hammond et al. example called for aggregation of much primary data into 20 indicators that are combined to produce four highly aggregated indices. Those indices would provide the principal published results of the exercise. The use of maps to show spatial differences in land degradation is strongly endorsed, recognizing that degradation seldom occurs uniformly across a landscape or region.

International Cooperation

While each nation would focus its data collection and analysis efforts upon degradation processes of most concern to it, having a common core of indicators for all countries would greatly strengthen international cooperation against a shared problem. Deciding what that common core would be can only be done by the countries concerned. Before that core can be selected, countries would need to decide what data are needed and how much a country is able and willing to collect.

Causes of Land Degradation

There are two classes of causes of land degradation in the world's dryland. The direct cause is mismanagement of the land (human activity). The indirect causes of the mismanagement may be many: land tenure arrangements, export-import policies, political acts, drought, poverty, poor advisory services, little or no problem-solving research, population pressures, etc. Combating desertification and developing a sustainable management program depends upon removing both kinds of causes. Usually, the indirect causes are socioeconomic and not easily changed. They also tend to be the basic causes, mismanagement being only a symptom of deeper problems. By far the greatest challenge in combating desertification is to determine what the most important indirect causes of desertification are and, then, to find ways to correct the problems. It is a time-consuming and difficult process, at best.

Combating Desertification

Techniques for combating desertification are, in fact, practices to control the several desertification processes that, in the aggregate, represent desertification. The major processes are vegetation degradation, water erosion, wind erosion, salinization of soils, and soil compaction. Locally important processes consist of heavy metal pollution of soils and groundwater, pesticide contamination, lowering groundwater levels, and some other damaging changes in land quality. Reclamation procedures for each of these degradation processes are well-known. The principal problem in using the procedures is that they are site-specific in their application. Just knowing the general principles is insufficient because each site is unique, in one way or another. Soils, climate, and land slopes are the variables that must be known in order to devise effective control methods. Local applied research is the source of information needed to find suitable practices for each site.

Advanced Technology

Computers and satellites have brought development of two new technologies that are especially valuable in combating desertification. Satellites have made possible global positioning systems (GPS) that can locate an object on the earth's surface with unprecedented accuracy. That accuracy permits repeated sampling of, for example, sites where vegetation changes are being monitored. The great utility, in this case, is that permanent markers do not have to be placed at sampling sites. GPS enables data to be collected in exactly the same spot year after year even in remote uninhabited areas.

The second significant technology utilizing computers is vastly improved Geographic Information Systems (GIS). It is now possible to use desktop computer software to stack images of any maps and analyze them singly or in any combination. GIS overlays greatly facilitate construction of maps that combine such different maps as those of population, road systems, location of crop and forest lands, etc. in a way not previously possible. As with any study of maps, the results are only as good as the quality of the maps. Poor maps provide poor information. Assessment of desertification risk is the major contribution of GIS to combating desertification.

Satellite imagery holds great unrealized promise in inventorying environmental conditions, especially land degradation features. The promise is yet to be fulfilled but progress continues to be made as satellites capable of higher and higher resolution (detail) are developed. At present, colored images are immensely valuable to show landscape associations over large areas. They still are unreliable for assessing land conditions in small areas, whether it be plant composition changes under grazing pressure or erosion damage. For analysis of any satellite imagery, ground checking (getting ground truth) is generally indispensable. High cost of satellite images is a deterrent to their use.

Aerial Photography

The most useful aerial photography to use in assessing ground conditions is low-level (e.g., 3,000 m) photography from airplanes. Excellent preliminary surveys of land conditions, including desertification, can be made using low-level photographs. Their big advantage is their large scale. The cost for surveying a village or watershed area commonly is not high but they become prohibitively expensive to purchase and analyze when hundreds of photos are needed for large areas. As with satellite images, extensive ground checking must be done.

Conventional procedures for combating desertification are effective when properly used. Since most reclamation projects involve a degree of trial-and-error, it is wise to begin with improving small areas. The cheapest and most effective methods can then be selected for application in larger areas.

Conclusions

Assessment of the current status of desertification in a country is the crucial first step in understanding and correcting the problem. National assessment maps are needed by planners and decision-makers to establish priorities for desertification. Every country government must decide whether priority for funds will go to education, health, road construction, industrial development, or to other pressing problems. In the absence of reasonably good information on the cost of the damage land degradation does and the cost of repairing that damage, intelligent decisions cannot be made.

Combating desertification in the field is, in the final analysis, a local effort. Only the local people are in a position to know what can be done that is socially and economically acceptable to them and will be continued after the initial project ends. Most people are more interested in short term benefits than in saving land for the future.

Monitoring desertification indicators is required if the effectiveness of control activities is to be measured and changes made, where necessary. Monitoring, unfortunately, must be a long-term activity if it is to provide needed information on land degradation trends. Donor agencies dislike sponsoring long-term projects such as monitoring. Support, then, probably will have to come from local and national resources. That will not be easy to obtain. Indicators will have to be few in number, highly informative, and simple to measure. While the direct cause of desertification is mismanagement, indirect factors such as government policies and poverty usually are the root causes.

Advanced technologies for helping assessment and monitoring of desertification can be of great value. Computers and satellite images have nearly revolutionized natural resource data collection methods. Those tools, though, are expensive to use and do not substitute for on-the-ground studies and for deciding how to meet the site-specific requirements of land reclamation.

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11

Eolian Sand Dynamics and Protection Against Sand Drift and Moving Dunes

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Sand encroachment is one of the serious problems facing the various human activities in deserts and around deserts. Since about fifty years, several irrational development activities are responsible for the increase in the magnitude of sand encroachment : overgrazing, denudation of vegetation cover and all the disturbances of the fragile arid ecosystem. Actually, many new technics are perfected because it is necessary to protect fields under cultivation, roads or even cities, such as Nouakchott, the chief town in Mauritania (Salama et al, 1991) against sand encroachment. But, in spite of increasing basic knowledge (Anderson et al, 1991) , we dont have a clear understanding of all the factors controlling eolian processes in general and sand encroachment or dune behaviour in particular.

How is it Possible to Combat Against Sand Migration ?

In deserts, except during the short rainy spells, sands become dessicated, and shift as soon as wind speed exceeds about five meters per second, which is considered as the fluid threshold. Quickly, a thick cloud of saltated sand particles moves over open areas, rising 50 cm to 1 meter above the ground. It is a serious task to protect cultures as well as buildings of any kind against sand drift.

All the sand transportation studies indicate that, among the three processes of wind blown sand drift, saltation process represents the principal mode of sand movement. Roughly, three quarters of the transport rate are by saltation and one quarter by creep, as shown both by field measurements and by wind tunnel test curves (Chen Weinan et al, 1996). The total distribution of transport rates is a function of height.

The turbulent structure of the wind is significant in the aerodynamic entrainment of grains since the curves of wind speed and sand transport are nearly parallel (Hardisty et al, 1993). Several studies and theorical models of the saltation have been published, in particular on the higher portion of the sand trajectory (Werner, 1990) Because of the vertical wind profiles, grains in saltation receive momentum from the wind and deliver it to the bed at a rapid rate. (Haff and Anderson, 1993).

Another important parameter for sustaining the grain cloud equilibrium is the grain/bed collision (C. Anderson, 1987; Werner and Haff, 1988). Collisions, of course, are recognized as being an integral part of the wind blown sand system (Anderson and Haff, 1991). The shear stress has been calculated by the computer simulation : the total stress is found from summing both the wind and airborne grain stresses . There is a remarkable complementarity between those two stresses within the grain layer. (Mc Even and Willetts, 1993).

Mac Ewen and Willetts (1991) constructed full saltation models which follow the system from its start to steady state saltation where a stationnary state of flowing grains is reached. That is shown in their curve of the total mass flux against time.

Consequently , the basic problem is to disrupt this steady state of the cloud of grains in transit .

A way of preventing or stopping this mechanism is by modifying the wind/ground interface, if it is possible :

- to spray different soil conditionners, such as bitumen, lubrication oil etc... But these surface treatments have different costs, durability and efficiency, and seem unlikely to have any large field diffusion (De Boodt and De Vleeschauwer, 1981)

- to mulch with synthetic staples or plant material (for instance : culms, brushwood)

- to promote the growth of microorganisms which may form rigid crusts, which increase the resistance of sand to entrainment by wind. Phototrophic microorganisms play an important role in stabilization of moving sand in coastal dunes (Van den Ancker et al, 1985).

An other way is by increasing the surface roughness :

- by spreading, on the sandy surface, worn out fishing nets to prevent the saltation and to encourage the natural vegetation to grow.

- by carrying to the sand dunes, loamy soil collected superficially so that it is rich in grass seeds . If rainfall is sufficient it favours the growth of weeds and grasses which fix the sandy surface. But , this way is very expensive.

Vegetation plays a vital role within the surface roughness. In semi-arid areas, if the moving of men and livestock is stopped, the entire surface may be covered with a range of different herbaceous and shrub species after 3 to 6 years.

The former dunes disappear and the fixation may be considered as complete. Natural regeneration is the most effective and economic method of control, as it was shown, for instance, in Southern Tunisia with the spatial evolution of some barchans, changed in nebkas within two years (Khatteli, 1996)

When roads or railroads must be protected against sand drifts, three methods consist in accelerating the speed of sand motion and getting sand downwards of wind : profiled embankment , Venturi deflectors or artificial pebble pavement :

- ***by profiling embankment :*** many researches in wind tunnel show that the speed of the wind can be altered by changing the streamline profile.To this end, the slope steepness must be lightly inclined towards the wind direction, in order to increase the speed of wind as far as its direction is not too variable. On the base of physical studies, the ideal slope steepness would be about one sixtieth

(Maergner, 1990).But how long the road might be protected depends on the volume of rising sand.

- ***if the volume of moving sand is too large***, a deflector can be built upstream on the wind trajectory and tilted leeward, in order to accelerate or divert sand fluxes by Venturi effect and to prevent down stream sand deposits. (Oulehri, 1992) Nevertheless, this method is very expensive.

- ***the wind speed can be also accelerated by the effect of an artificial pebble pavement*** on eolian sands (Oulehri, 1992). Erosion and transport increase as a result of scour around the roughness elements. The wind has two effects :
  - the scouring affects the rate of eolian sand transport by changing the surface roughness and, thus, modifying the pattern of wind flow close to the ground
  - the pebble pavement also improves the efficiency of grain rebound trajectories over a hard surface. Gradually, it will make it impossible for wind to accumulate sand. This method is very effective for destroying sand dunes on the windward side of an area which has to be protected.

Several field experiments and wind tunnel studies showed that the effects of pebble concentration are initially enhanced for the lowest coverage and followed by a continuous decrease in transport with increasing coverage up to an inversion point. Behind this point, the effect of increasing surface cover changes from enhancement of transport to protection. This reaches zero at some point well before 100 per cent. The percent cover at which the inversion point occurs, increases with increasing diameter of the roughness elements (Davidson-Arnott et al, 1997).

Used tyres can serve as a substitute for pebbles which often are not to be found in the sandy areas.

Another Method : Modifying the Wind Characeristics by Setting Up Wind Breaks

Pratically, it is possible to stop the bulk of saltated sand with fifty centimeters high wind breaks, since ninety per cent of the sand grains are located in the zone 10 to 50 cm above the ground. There are several ways to prevent sand accumulation in front of an area to be protected :

1. **By erecting brush-wood fences, perpendiculary orientated against the dominant wind :** The aim is to slow down the wind speed. Sand rising up against the set of fences, is associated with the continuous self-burying of the fences within the sand deposits, generated by its own functionning. When the fences are covered by moving sands, a new fence should be erected over the

previous buried wind break. Finally a counterdune, 10 - 15 meters high, will be created between the wind and the gardens. This method, carried out everywhere in the deserts , has four disadvantages :

- if the counterdune is not well-maintained by renewing of fences, there is a constant risk of burying the gardens by overflow of the large amount of accumulated sand. In the Tafilelt region (S.E. Morroco), a palmgrove was partially buried by sand in 1977 and a new counterdune was erected in 1980. (Abrou, 1991)

- the counterdune is a serious obstacle to the connections between the palmgrove and the outside, for instance roads or water channels.

- practically, every two years, all the process must be repeated : palms or thorny branches or all other wood stakes are quickly consumed by termites

- the removal of this woody material impoverishes the bushland which becomes more vulnerable to desertification.

That is why other raw materials are, more and more, used as sand filters :

- worn out plastic perforated linen strips mounted on grids. If they are U.V resistant, they have a greater longevity (several years), compared to only two years for vegetal fences. They are 5 to 10 times cheaper than other artificial screens.

- perforated asbestos cement plates. They have even a greater longevity and efficiency. Theoritically , the cement plates can be reused but it is illusory. There is a serious increase of purchase and transportation costs, paid in foreign currency.

2. By drawing up a square set of wind breaks for trapping more and more saltated sand

This another technique, more effective than the counterdune, makes use of a net-work of fences in the form of a checkerboard grid, at such close intervals as to block any serious movement of the sand. Belts of squares are elongated in parallel with item to be protected: road, village etc... When the sands are fixed by mechanical devices, planting with drought resistant tree species would be suitable. But it is difficult for people to supply water through the square set of wind breaks.

If the amount of sand drift is too large, the square pattern is fully covered up by sand deposits. After a few years, a new device should be prepared. Such a solution is heavy and very expensive.

3. By simultaneous tree planting and sand fixing: the BOFIX system

The BOFIX system has been under experiment in Mauritania since 1993 where the annual rainfall average is about 50 millimeters (Meunier and Rognon, 1995). Because of a drastic lack of near surface water for roots, only trees can have access to a wet zone at depth . Tree planting and hedging by fences are simultaneous to increase the wind break efficiency.

The growth of the trees is accelerated by two ways :

- by protecting the young trees, owing to a plastic sheet covering a grid cylinder. It protects it against the wind and hungry cattle and constitutes an individual greenhouse. Transpiration vapor, kept within the plastic chimney, creates a favorable humid environment leading to a fourfold growth increment

- by supplying water directly into the ground, thanks to a tank, made with six recuperated plastic bottles, one liter and half each. This tank is linked with a funnel bottle. So water loss, either through evaporation or lateral diffusion, is removed and water comes down in depth along a vertical wet column which guides the roots directly to the damp zone. In sand dunes, this damp zone is located at about 5-6 meters depth. So, before 8 to 10 months, plant water supply is taken in charge by the deep water table it-self.

So, a double result is obtained with regard to trees :

- their growth speed is accelerated by 2 or 3 (2.5 to 3 meters per year)
- their water independance is established after 8 or 10 months

Trees, surrounded by cylinders, are planted 3 meters apart, and completed with lines of grid which is hang with a woven linen strip. Parallel lines of grid cylinders are oriented perpendicularly to one or two dominant winds. Each following year, a new tree line is planted, each time 10 meters further up stream of the wind.

This same step by step procedure is applied until the extinction of the sand source . It leads to fix sand horizontally and to plant trees which can bring some profit to the inhabitants.

A Strategy of Dune Control

The increase of development activities requires more and more protection against shifting dunes. Their rates of movement range between 8 - 10 meters by year for the large dune and about fifty meters by year for the smaller ones. The higher is the dune, the shorter is its rate of advance . For instance, in Southern Tunisia, two small barchans, 2 m high, moved about 50 m a year in 1992 -93 (Khatteli, 1996).

Barchans, shaped by an unidirectional wind, migrate on a long distance down wind. They are very dangerous dunes; for instance :

- along the southern Morocco coasts, barchans extend perpendicular to the prevailing N. NE trade wind, through a road way, two towns, a harbour and a mining convoyer (Callot and Oulehri, 1996)

- in the Middle Mauritania, where a very important rail road for iron ore transport is always in danger of sand encroachment .

There are some strategies of dune control, but they are not very efficient : the dune control requires some further researches, in particular concerning the avalanche process and the modelization of dune motion.

1. Avalanching is the fundamental mechanism to explain the shifting of mobile dune.

In course of time, the barchan evolves from a protodune to its proper shape by spreading out wings and by setting the avalanche talus on the active slip face .

Avalanches generally start close to the crest of the dune, where saltated sand accumulate . These sands are lacking in structure as snow drift. When the upper slope comes near an angle called maximum angle of stability, the slope is destabilized, so that the avalanching progresses downwards, leaving deposits as a long narrow sandy tongue, that lies conformably over the former underlying deposits (Kocurek and Dott, 1981; Savage and Hutter, 1991)

This behaviour is very different when sand is moist and cohesive

2. Modelling is the only way to understand the physics of dune dynamics and to control their behaviour.

Howard et al (1978), then Wippermann and Gross (1986), Fisher and Gladies (1988) or Stam (1987) proposed the first mathematical models leading to a much deeper understanding of the physical processes involved in the barchan behaviour. Barchans, of course, are too large for any wind tunnel experiments. But all the processes of dune displacement (climbing ripples, grain flow or grainfall, wings spreading etc...) could be got together in a three dimensional model. This model would be essential to test each new technique for controlling dune behaviour.

For instance, it is now possible to plant trees as wind breaks, even on moving barchans by means of the BOFIX method... on condition that any appreciable humidity, stored within the dune, would be available.

Barchans can be considered in aerodynamic equilibrium when they move forward conserving their size and shape. On the windward face, the dune body normally constrains the wind flux to become divergent. But a barchan can easily be destroyed by setting a pattern of wind breaks convergent on this gentle windward slope. These wind breaks constrain the divergent wind flows to converge. An incision can appear in the middle of the barchan and a windgap develop and destroys the dune . But it is necessary to test this method with a computer model

Longitudinal dunes are the most wide spread in tropical deserts, in response to two diagonally blowing alternating winds. Those winds cause oscillating slip faces and sand deposits alternate on both flanks, as is evidenced by cross bedding (Lancaster, 1982; Tsoar, 1983; Greeley and Iversen, 1985). The growth rates of these dunes decrease with increasing dune length and dune height because much more sand, blown along the dune body, is trapped.

In Mauritania, at present, only the crestal section of these dunes is active.It is possible to prevent the normal evolution of longitudinal dunes, using longitudinal tree lines and wind breaks, on both sides of the crest. Gradually, two counterdunes will be erected. The dune height increases and its capacity for downwind extension decreases. Morever, some oblique wind breaks are set up on the dune flanks for protecting them against strong wind deflation .

At the scale of a complex belt of longitudinal dunes, in the Trarza sand sea, in the Middle Mauritania for instance, the seaborne trade wind and the harmattan are the two prevailing winds . It would be possible to put in a curved wind break, which could constrain both winds to destroy, each other ‘s effects. The method could be applied at each point of the longitudinal dune origin, where the strongest winds blow.

Therefore, owing to the BOFIX system, it is now possible to plant trees as wind breaks, following methods specific to each dune type . But each method has to be tested, thanks to a model adapted to each dune shape.

In conclusion, there are actually more and more sophisticated ways to combat sand encroachment. In the future, the coordination beetwen fundamental and pratical aspects of the control measures should be seriously considered.

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Symposium: Programme

Monday, 12 October 1998

09:00 – 09:05 Recitation from Holy Koran

09:05 – 09:25 Opening statement
H. E. Mr. Hamid Kalantary
Deputy Minister
Ministry of Jihad-e-sandegi and
Head of Forest and Range Organization

09:25 – 09:35 Statement by
H. E. Mr. Hama Aiba Diallo
Executive Secretary, UN Convention to
Combact Desertification UNCCD

09:35 – 09:45 Statement by
Dr. Jamal Ahmad,
FAO Representative in
Islamic Republic of Iran

09:45 – 10:00 "U. N. University and its Role in Desertification"
Prof. Iwao Kobori
United Nations University

10:00 ~ *Visit to combacting desertification activities in Kashan and Isfahan*

Tuesday, 13 October 1998

Full day field trip

Wednesday 14 October 1998

09:00 – 09:05 Greetings by
Eng. S. A. Rezae
General Director of Technical Brueau for
Combacting Desertification

Panel 1 – Panelists: Dr. Kowsar, Dr. Kobori and Dr. Zehtabian

09:05 – 09:20 "Two Basic Rools to Combact Desertification"
Dr. A. P. Koohafkan
Chief, Soil Resources, Management and
Conservation Services
Land and Water development Division, FAO

09:20 – 09:40	"Iran's Agriculture and Salinity" *Dr. H. Siadat* *Soil and Water Research Institute, Iran*
09:40 – 10:10	"Public Participation in Combating Desertification" *Prof. G. Golubev,* *Faculty of Geography,* *Moscow State University*
10:10 – 10:30	Conclusion
10:30 – 10:50	Coffee Break

Panel 2 – Panelists: Dr. Koohafkan, Dr. T. Wang and Dr. Arzani.

10:50 – 11:00	"Iran's Role and Activities in the Elaboration and Implementation Processes of CCD" *M. Jabari,* *Ministry of Foreign Affairs* *Islamic Republic of Iran*
11:00 – 11:20	"Desertification and Modern Communication Technologies" *Dr. Charles Lilin* *FAO*
11:20 – 11:50	"Study of Soil Salinity in Deserts Based on Field Observation – Remote Sensing and GIS" *Dr. M. Zehtabian* *Chief of Center of Desert Research*
11:50 – 12:10	Conclusions
12:10 – 14:00	Prayer and Lunch Break

Panel 3 – Panelists: Dr. Dregne, Dr. Siadat and Dr. Glubev

14:00 – 14:20	"Study of Qualitative and Quantitative Aspects of Wind Erosion and Sedimentation in the Yazd–Ardakan Watershed" *Prof. H. Ahmadi* *Tehran University*
14:20 – 14:35	"Combating Desertification in Tunisia: Process and Control Techniques" *Dr. Hiucine Khattelli* *General Director, Institute for Arid Zones*

14:35 – 14:50 "Desert Research and Control Desertification in Iran"
Mr. M. Pakparvar
Research Institute of Forests and Range Lands

14:50 – 15:05 "Combating Desertification in Indian Conditions"
Dr. A. S. Faroda
Director, Arid Zone Research Institute, India.

15:05 – 15:30 Conclusion

15:30 – 16:00 Coffee Break

Panel 4 – Panelists: Dr. Ahmadi, Dr. Rognon, Dr. Khatteli and Eng. Kholdbarin

16:00 – 16:15 "Combating Desertification in China"
Dr. Tao Wang
Deputy Director, Institute of Desert Research
People's Republic of China

16:15 – 16:30 "Reversing Desertification Trends in West Africa and North Africa"
Dr. M. Tahir,
Leader, ICARDA Country Team, Tehran, Iran

16:30 – 16:45 "Desertification Problem in Russia"
Prof. G. Golubev
Faculty of Geography,
Moscow State University

Thursday, 15 October 1998

Panel 5 – Dr. Kowsar, Dr. Sh. Mahmoudi, Dr. Lilin, and Dr. Pazira

09:00 – 09:20 "Iran's Natural Resources: Policies and View Points"
Mr. Seyed Ata Rezaei
General Director,
Technical Bureau of Combating Desertification,
Forest and Range Organization, Iran

09:20 – 09:40 "Global Network on Integrated Soil Management for Sustainable Use of Salt-Affected Soils"
Dr. Koohafkan,
Chief, Land and Water Development Division,
FAO

09:40 – 10:00 “Soil Desalination and Land Reclamation in Iran”
Dr. Pazira and Dr. Sadeghzadeh
Soil and Water Research Institute, Iran

10:00 – 10:10 “Use of Saline Water and Soil for Forage, Vegetable Oil, Rubber and Paper Production”
Mr. Asfia,
Forest and Range Organization, Iran

10:10 – 10:30 Conclusion

10:30 – 11:00 Coffee Break

Panel 6 – Panelists: Dr. Kobori, Dr. Koohafkan, Eng. Rezaei

11:00 – 11:20 “Sowbags Come to the Rescue – A Friendly Pest Saves a Desertification Control Project”
Dr. Kowsar,
Fars Research Center for Natural Resources and Animal Husbandry, Iran

11:20 – 11:40 “Eolian Sand Dynamics Protection Against Sand Drift and Moving Dunes”
Prof. P. Rognon,
Dept. of Geodynamics
Université P. & M. Curie

11:40 – 12:00 “Desertification: Assessment and Control”
Prof. Harold Dregne
International Center for Arid and Semi Arid Land Studies
Texas Technical University

12:00 – 12:15 “Study of Soil Salinity in Deserts based on Field Observation, Remote Sensing and GIS”
Dr. Alvy Panah

12:15 – 12:40 Conclusions

12:40 ~ Prayer and Lunch

Symposium: Report of Proceedings

Zafar ADEEL, Ph.D.
Academic Programme Officer
Environment and Sustainable Development
The United Nations University

Monday, 12 October, 1998 (Tehran-Kashan-Esphahan)

Morning: Opening Session of the Symposium. An opening statement was made by Mr. Hamid Kalantary, Deputy Minister of Jihad-e-Sazandegi, who also serves as the Head of Forest and Range Organization (FRO). FRO served as the host organization on the Iranian side. Other speakers who made opening comments included the following:

- Mr. Hama Arba Diallo, Executive Secretary UNCCD
- Mr. Gamal Ahmad, FAO (Iran)
- Prof. Iwao Kobori, UNU

The speakers emphasized various aspects of desertification in Iran and globally. The challenges and strategies for combating desertification were outlined. Prof. Kobori provided an outline of UNU's activities in the area of combating desertification and indicated willingness to further collaboration with all relevant organizations in the area.

Afternoon: Trip to Esphahan. En route visited the project station outside Kashan. The project station is focused on combating desertification. The primary mechanisms of combating desertification include:

1. Sand dune fixation by planting (seeds and seedlings) of weather-hardy shrubs.
2. Sand dune fixation by petroleum mulching.
3. Reclamation of land for agricultural use by providing pumped groundwater.

We also visited a village at the outskirts of Lut Desert. This village is sustained through agricultural activities on reclaimed land. We also visited a traditional, but abandoned, mechanism of water storage called Qanat.

Tuesday, 13 October, 1998 (Esphahan-Tehran)

Morning: Meeting at the office of Director of Natural Resources Department (Ministry of Jihad-i-Sazandagi). He informed us that the efforts in the Esphahan Province in Iran are being managed by his office. These include the following:

Land type	Total	Under Management
Arid areas (for combating desertification)	23,000,000 ha	1,000,000 ha
Rangeland	6,600,000 ha	1,200,000 ha
Forest Area	100,000 ha	28,000 ha

The director informed us that his office develops the design of management approaches for desertification areas and the execution of the plans is performed by general public. The management programmes are typically initiated through public interest. Additionally, the Iranian government has made significant improvements to the infrastructure, including construction of roads and provision of electricity, in these rural areas. This allows villagers to sustain their economy through agricultural acitivities.

Visit to the project station for combating salinity problems (about 20 km from Esphahan). The rehabilitation project was started approximately 20 years ago. The primary mechanisms were:

1. Planting seeds and seedlings of plants which are resistant to high salinity levels.
2. Lowering of water table through pumping.

Afternoon: Excursion trip to historic Esphahan.

Wednesday, 14 October, 1998

Morning: Symposium Technical Session

Dr. Koohafkan: Introduced the two software tools developed by FAO for analyzing and evaluating desertification problems. SOTER is a soil and terrain digital database, which includes patterns of land use, morphology, slope, and soil categories as GIS layers. WOCAT is a database of soil and water conservation technologies that have been successfully applied in the field. Both tools are available as CD-ROMs and through the FAO web site.

Dr. Siadat: Provided an overall summary of desertification and land degradationan problems in Iran. He also presented an overall budget of water resources available to Iran. About 30 million hectares in Iran are uncultivated due to lack of water resources, which equals about160 billion cubic meters.

Dr. Golubev: Discussed the general concepts related to public participation in efforts for combating desertification. He outlined four general principles: access to relevant information, problem-awareness building, public participation in activities, and the right to complain, appeal and sue. The UNCCD and Agenda 21 particularly emphasize public participation. Different “members” of public include: farmers, action groups, associations of scientists, and the industry.

Mr. Jabari: Provided another general overview of desertification problems in Iran. He highlighted Iran’s contributions and participation in international treaties related to desertification.

Dr. Lilin: Emphasized the importance of institutional and macro-economic issues when dealing with desertification problems. He proposed to develop resource centers to alleviate this problem. These resource centers would contain information databases which could be used by scientists, policy-makers and general public. New analysis tools and national/regional guidelines should also be developed by these resource centers.

Dr. Zehtabian: Provided an overview of the research activities undertaken by the Center of Desert Research at the Tehran University. The project site at Kashan is managed under their organization.

Afternoon: Symposium Technical Session

Dr. Ahmadi: Provided a general overview of issues related to wind erosion in desertified areas. He presented a model developed at the University of Tehran called PSIAC. The model takes into account lithology, geomorphology, wind speed, soil texture, density of vegetation cover, soil moisture, and land use. The description of various model input variables was provided in detail.

Dr. Khatelli: Provided a general overview of desertification problems in Northern Africa, where up to 90% of the area is affected by desertification (72% affected by wind erosion). He described the activities of a research station dealing with wind erosion issues in Tunisia; the station contains a wind tunnel and sand trap to study particle movement. He provided the example of sand dune fixation in Northern Tunisia using mulching from crop residue. He also described use of mechanical fences to combat wind erosion. Finally, he provided results from a comparative study of various plowing techniques to quantify their impact on soil loss and cereal productivity.

Mr. Pakparvar: Presented an overview of the negative trends in the water budget for Iran. This could be compared to an increasing number of floods in the country. He attributed the increase in frequency of floods to increasing land degradation. He presented results from a study in the Gansar Plain, where up to 50 observation points were used to monitor the decrease in water table and changes in soil chemistry.

Dr. Faroda: Presented two technologies for combating desertification in the Thar Desert in India, which comprises 32 million hectares. The first set of technologies were related to sand dune stabilization. These included protection from human and livestock encroachment, creation of micro-windbreaks, direct seeding of trees, plantation and management of grasses and shrubs. He emphasized that the success of sand dune fixation depends on planting shrubs instead of trees, public participation, development of locally-adaptive plant species, and providing financial incentives. The second set of technologies was related to shelterbelt protection.

Dr. Wang: Provided a general overview of the state of desertification in China. He indicated that human causes of desertification included over cultivation, over grazing, over collection of shrubs for fuel, and misuse of water resources. In China, the population has doubled from 1949 to 1997 whereas available agricultural land has reduced by half.

Dr. Tahir: Provided a general overview of global desertification problems and ICARDA's activities in arid regions. He mentioned that approximately 34% of the world's land surface is considered to be hyper-arid and arid area, resulting in a loss of 9 million km2 to desert each year. His presentation focused on activities sponsored by ICARDA in this region.

Dr. Golubev: Presented the Russian perspective on land degradation. He used the example of Kaomikia, an area northwest of the Caspian Sea. This area is affected by severe droughts every 3 – 5 years and by very severe drought every 10 – 15 years. He also highlighted the problems encountered in the Aral Sea disaster.

Thursday, 15 October, 1998

Morning: Symposium Technical Session and Closing Ceremony

Mr. Rezaei: Presented a detailed description of the desertification problems faced by Iran. Out of a total area of 165 million ha., approximately 34 million ha. is affected directly by desertification. He described the Iranian action plan for combating desertification, which included the following points:

- Emphasis on family planning
- Sustainable agriculture
- Providing fuel to farmers
- Legalization of people's societies in rural areas
- Rangeland improvement
- Forest management
- Rehabilitation of desertified lands
- Water resource management
- Decentralization of decision-making
- Emphasis on public awareness

Mr. Beltran: Presented a model used by FAO for evaluation of the suitability of a soil for agricultural activity. It is an empirical model that accounts for chemical composition of soils, climate, soil characteristics, drainage, irrigation method, and land use.

Dr. Pazira: Described in general terms the problems with soil salinization in Iran, with emphasis on Khuzestan province. He indicated that approximately 50% of the agricultural lands in Iran, Iraq, Turkey, and Pakistan are affected by salinity.

Mr. Asphia: Presented case studies of plants for combating salinization problems in soils.

Dr. Kowsar: Emphasized that sufficient water resources are available through rivers. He described a project where the natural aquifer was restored through an infiltration basin using flood water from a river. The reducing infiltration capacity with time was reduced by sowbags.

Dr. Rognon: Provided a description of strategies for sand dune fixation. The new technologies developed by him included erection of brush-wood barriers, drawing up squares, and simultaneous tree planting (BOFIX system). The second part of his talk focused on fixation of barchan sand dunes. He emphasized the importance of modeling to simulate sand dune movement.

Dr. Dregne: Described the methodology for quantifying damage due to desertification. He indicated the need for risk assessment, evaluation of the cost of damages, and continual monitoring on national basis. In this respect, it is important to identify clear unambiguous indicators of desertification. He suggested that the cost of combating desertification ranged from $50 to $750/ha, whereas the highest return was from irrigated lands (98%) versus low return from rangeland (30%). Therefore, he concluded that no beneficial options exist for areas with annual rainfall less than 250 mm.

Dr. Panah: Described a project in Ardaban area in which LANDSAT satellite imagery was utilized to define the extent of salinized soils. This imagery could also be used for location qanats.