ZEF Bonn
Zentrum für Entwicklungsforschung
Center for Development Research
Universität Bonn

Jagdish C. Katyal and Paul L.G. Vlek

Number
33

Desertification - Concept, Causes and Amelioration

ZEF – Discussion Papers on Development Policy
Bonn, October 2000

Jagdish C. Katyal and Paul L.G. Vlek: Desertification - Concept, Causes and Amelioration, ZEF – Discussion Papers On Development Policy No. 33, Center for Development Research, Bonn, October 2000, pp. 65.

ISSN: 1436-9931

Published by:
Zentrum für Entwicklungsforschung (ZEF)
Center for Development Research
Walter-Flex-Strasse 3
D – 53113 Bonn
Germany
Phone: +49-228-73-1861
Fax: +49-228-73-1869
E-Mail: zef@uni-bonn.de
http://www.zef.de

The authors:
Jagdish C. Katyal, director at the National Academy of Agricultural Research Management (NAARM), Hyderabad, India, Center for Development Research, Bonn, Germany
Paul L.G. Vlek, director at the Center for Development Research, Bonn, Germany
(contact: p.vlek@uni-bonn.de)

Contents

List of Tables

List of Figures

Abstract

Desertification is a condition of human-induced land degradation that occurs in arid, semiarid and dry sub-humid regions (precipitation/potential evapotranspiration or P/ETP 0.05 to 0.65) and leads to a persistent decline in economic productivity (> 15% of the potential) of useful biota related to a land use or a production system. Climatic variations intensify the decline in productivity, restorative management mitigates it. Drylands or territories susceptible to desertification occupy 39.7% (~ 5.2 billion ha) of the global terrestrial area (~ 13 billion ha). The highest concentration of drylands occurs in Africa, Asia and Australia. Two out of every three hectares of drylands suffer from land degradation of one kind or another. Barring 78 M ha which are irreversibly degraded, the remainder area - affected by desertification - is reclaimable at a price.

Desertification is caused primarily by over-exploitation of natural resources beyond their carrying capacity. Solutions to combat desertification lie in the management of the causes of desertification. However, there are no easy options to combat it. While managing demographic pressure should receive priority, the solutions to combat desertification involve local action, guided by land use and climatic conditions and in harmony with local needs and people's expectations. Drylands are used as rangelands or as croplands, with the latter either irrigated or rainfed. Integrated data on land and soil degradation and on the socio-economic environment within which it occurs are the basis to formulate strategies for reclamation and proper use of drylands.

Rangelands constitute the dominant land use (est. 88%) in the territories susceptible to desertification. Of the 3333 M ha rangeland area affected by land degradation 757 M ha are severely affected., 72 M ha irreversibly. Within rangelands, vegetation degradation is the primary cause of desertification – it represents 72% of the total area desertified worldwide (2576 M ha out of 3592 M ha). Overgrazing by excessive numbers of low productivity livestock and fuel wood extraction by man are the principal causes of vegetation degradation. Centralized management of common rangeland resources and insecure tenancy laws stand in the way of communities and herders adopting a long-term view to conserve and invest in range improvement measures. Inadequate dissemination of knowledge on vegetation improvement methods is another cause of rangeland degradation. Five suggestions are made to assure sustainability and effectiveness of rangeland management programs: (1) shifting to community management of rangelands that have been nationalized, (2) granting formal rights to individual transhumance herders that have been settled, (3) providing education and training on range management and improvement, (4) introducing elite breeds of livestock for high productivity,

and (5) implementing programs for harnessing alternative sources of energy for cooking (solar and biogas).

Rainfed croplands occupy an area of 457 M ha, 216 M ha of which have degraded soils. Some 4 M ha suffer from irreversible degradation. Of the remainder, 29 M ha and 183 M ha are, respectively, affected by severe (reclaimable with engineering works) and moderate degradation. Soil constraints in rainfed croplands arise primarily from their vulnerability to erosion, which leads to loss of organic matter, fertility and rooting depth. Eroded soils are structurally unstable and are prone to crusting and compaction. Risk arising from drought susceptibility and poverty limit the adoption of restorative management. Rainwater conservation to minimize risk is not adopted due to insecure tenancy and centralized management of government supported programs. A lack of adequate knowledge and skills of efficient use and storage of rainwater allow degradation processes to proceed unchecked. The imperatives to succeed are: (1) land tenure policies towards freehold ownership; (2) community participation in the management of rainwater, (3) efficient use of harvested water supported by high value land use options built on indigenous knowledge and (4) government support to facilitate the development of rainfed agriculture.

Irrigated croplands occupy an area of 145 M ha. Of this, 2 M ha are affected by irreversible degradation and 41 M ha suffer from reversible degradation, mainly from salinity and waterlogging. The mechanisms of salinity development differ and so do the solutions when canal or underground water is used for irrigation. With canal water irrigation, three key development options are suggested to remove excess salts and water and to minimize conveyance and application losses of water: (1) effective drainage, (2) properly lined or closed water conveyance systems and efficient irrigation techniques, and (3) participatory management of irrigation systems. The costs of installing drainage and leak-proof conveyance systems are high, but so are the economic and ecological gains. With underground water use, salinity develops as the water reserves are depleted due to over-extraction. While efficient methods of irrigation can help in postponing the occurrence of salinity, sustainable solutions lie in balancing the water withdrawals with recharge. Efforts should therefore be made to promote groundwater replenishment through runoff harvesting. Although it is not always possible to recharge the deep aquifers with the limited quantities of runoff produced by the low annual precipitation, still, the use of harvested runoff for irrigation can save groundwater. Once water-efficient systems are operational, cropping systems that maximize productivity per unit of water can be introduced.

The entire strategy of reclaiming desertified land revolves around water, the reestablishment of the vegetation of rangelands, the rejuvenation of the productivity of rainfed croplands, and the halting of loss of irrigated farmlands. Humans play a central role in that strategy; desertification begins and ends with human action. Unless it ends, the estimated 900 million people affected today will grow to billions tomorrow.

Kurzfassung

Als Desertifikation bezeichnet man die menschlich bedingte Landdegradation, die in ariden, semiariden und trockenen subhumiden Regionen vorkommt (Niederschlag/potentielle Verdunstung oder P/ETP 0,05 bis 0,65) und der zu einer kontinuierlichen Abnahme wirtschaftlicher Produktivität (> 15% des Potentials) der nützlichen Biota im Zusammenhang mit Landnutzungs- oder Produktionssystemen führt. Klimatische Veränderungen verstärken den Produktivitätsrückgang, restaurative Maßnahmen können ihn abmildern. Trockengebiete oder für Desertifikation anfällige Gebiete machen 39.7%(~ 5,2 Milliarden ha) der globalen Fläche (~ 13 Milliarden ha) aus. Trockengebiete haben den größten relativen Flächenanteil in Afrika, Asien und Australien. Zwei von drei Hektar Trockengebieten weisen irgendeine Art von Landdegradation auf. Unter bestimmten Umständen sind die Flächen, mit Ausnahme der irreversibel degradierten 78 Mio. ha, wiederherstellbar.

Desertifikation wird hauptsächlich durch die Übernutzung natürlicher Ressourcen über ihre Tragfähigkeit hinaus verursacht. Lösungen zur Bekämpfung von Desertifikation liegen im Umgang mit den Ursachen für Desertifikation. Es gibt jedoch keine einfachen Patentrezepte für deren Bekämpfung. Während die Bewältigung des demographischen Drucks Priorität haben sollte, erfordern die Ansätze zur Bekämpfung von Desertifikation lokale Aktionen, ausgehend von der Landnutzung und den klimatischen Bedingungen, und in Einklang mit den lokalen Bedürfnissen und Erwartungen der Menschen. Trockengebiete werden als Weide- oder Ackerland genutzt, letzteres entweder künstlich bewässert oder durch Regenwasser gespeist. Integrierte Daten zu Land- und Bodendegradation sowie zu den sozio-ökonomischen Rahmenbedingungen sind die Grundlage für die Formulierung von Strategien zur Rückgewinnung des Landes sowie für eine angepasste Nutzung von Trockengebieten.

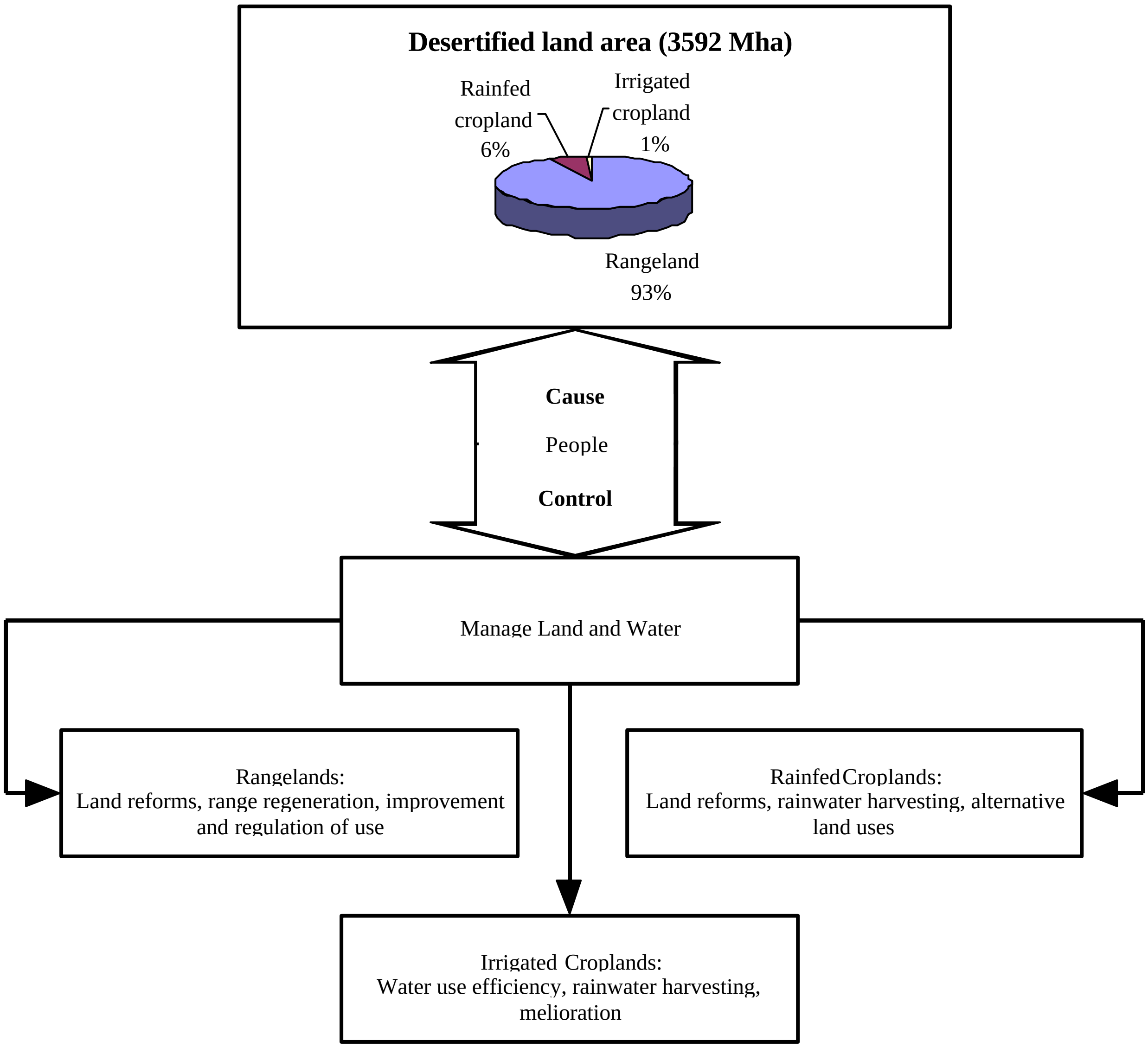
Weideland ist die häufigste Nutzungsform (geschätzt 88%) auf den für Desertifikation anfälligen Flächen. Von den 3333 Mio. ha Weideland, die von Landdegradation betroffen sind, sind 757 Mio. ha stark und 72 Mio. ha irreversibel degradiert. Bei Weideland ist die Vegetationsdegradation die Hauptursache für Desertifikation – sie stellt 72% der insgesamt weltweit von Desertifikation betroffenen Flächen dar (2576 Mio. ha von 3592 Mio. ha). Überweidung durch übermäßigen Viehbesatz und die Gewinnung von Brennholz sind die Hauptursachen für Vegetationsdegradation. Eine zentralistische Organisation der gemeinschaftlichen Weideland-Ressourcen und unsichere Besitzverhältnisse stehen den Gemeinden und Hirten dabei im Weg, langfristig in Konservierungsmaßnahmen und in eine Verbesserung des Weidelandes zu investieren. Unzureichende Kenntnisse der Methoden zur Vegetationsverbesserung ist eine weitere Ursache für Weidelanddegradation. Hier sollen fünf Vorschläge unterbreitet werden, um die Nachhaltigkeit und Wirksamkeit von Weideland-Managementprogrammen sicherzustellen: (1) der Übergang zu gemeinschaftlichem Management

von verstaatlichtem Weideland, (2) die Garantie formaler Rechte für ehemals Wandertierhaltung betreibende Hirten, die seßhaft geworden sind, (3) Ausbildung und Training in Methoden der Weideland-Bewirtschaftung und seiner Verbesserung, (4) die Einführung hochwertiger Viehrassen, um eine hohe Produktivität zu erzielen, und (5) die Einführung von Programmen zur Bereitstellung alternativer Energiequellen (Solarenergie und Biogas) zum Kochen.

Regenfeldbau-Ackerflächen machen eine Fläche von 457 Mio. ha aus, davon weisen 216 Mio. ha degradierte Böden auf. Etwa 4 Mio. ha sind irreversibel degradiert. Von der verbleibenden Fläche sind 29 Mio. ha stark (rückgewinnbar durch technische Maßnahmen) und 183 Mio. ha mäßig degradiert. Auf Regenfeldbauflächen ergeben sich Nachteile hauptsächlich aus der Anfälligkeit für Erosion, die zu Verlusten an organischen Stoffen und Bodenfruchtbarkeit und einer Reduzierung der Durchwurzelungstiefe führt. Erodierte Böden sind strukturell instabil und anfällig für Verkrustung und Verdichtung. Risiken aus der zunehmenden Anfälligkeit für Dürre und Armut beschränken die Durchführbarkeit restaurativer Maßnahmen. Regenwasserkonservierung zur Risikominderung ist aufgrund unsicherer Besitzverhältnisse und wegen dem zentralistischem Management staatlicher Förderprogramme nicht üblich. Der Mangel an angemessenen Kenntnissen und Fähigkeiten hinsichtlich einer effizienten Nutzung und Speicherung von Regenwasser führt zu einer unkontrollierten Ausbreitung der Degradation. Folgende Voraussetzungen müssen gegeben sein, um diesem Einhalt zu gebieten: (1) eine Landbesitzpolitik, die auf private Besitzverhältnisse abzielt; (2) eine Beteiligung von Gemeinden am Regenwasser-Management; (3) eine effiziente Nutzung aufgefangenen Wassers in Verbindung mit hochwertigen Landnutzungskonzepten, die auf einheimischem Wissen basieren sowie (4) staatliche Unterstützung, um die Entwicklung des Regenfeldbaus zu begünstigen.

Bewässertes Ackerland macht eine Fläche von 145 Mio. ha aus. Davon sind 2 Mio. ha von irreversibler Degradierung und 41 Mio. ha von reversibler Degradierung hauptsächlich durch Versalzung und Vernässung betroffen. Die Mechanismen, die zu Versalzung führen, sind unterschiedlich, und somit auch die Konzepte für die Nutzung von Kanal- oder Regenwasser zu Bewässerungszwecken. Für die Bewässerung mit Kanalwasser werden drei hauptsächliche Entwicklungskonzepte vorgeschlagen, um überschüssiges Salz und Wasser abzutransportieren und um Durchleitungs- und Anwendungsverluste zu minimieren: (1) effektive Drainage; (2) sorgfältig abgedichtete oder geschlossene Wasserleitungssysteme und wirtschaftliche Bewässerungstechniken; und (3) ein partizipatorisches Management des Bewässerungssystems. Die Kosten für die Installation von Drainage und undurchlässigen Leitungssystemen sind hoch, aber der ökonomische und ökologische Gewinn ist ebenfalls beträchtlich. Bei der Nutzung von Grundwasser entsteht Versalzung, wenn die Wasserreserven aufgrund von Übernutzung erschöpft sind. Während wirksame Bewässerungsmethoden dazu beitragen können, Versalzung zu verzögern, sehen nachhaltige Konzepte vor, die Wasserentnahme wieder aufzufüllen. Es sollten daher Anstrengungen unternommen werden, Grundwasser durch das Auffangen von Abflußwasser wieder aufzufüllen. Auch wenn es nicht immer möglich ist, die tiefen Grundwassersysteme aus dem Abfluß der niedrigen jährlichen Niederschlagsmenge aufzufüllen, kann die Nutzung aufgefangenen Abflußwassers zu Bewässerungszwecken das Grundwasser schonen. Wenn effiziente Bewässerungssysteme erst einmal betriebsbereit sind, können Anbausysteme eingeführt werden, welche die Produktivität per Wassereinheit maximieren.

Die gesamte Strategie zur Rückgewinnung von Land, das von Wüstenbildung betroffen ist, dreht sich um Wasser; um die Erneuerung der Vegetation auf Weideland, die Wiederherstellung der Produktivität von Regenfeldbauflächen und die Eindämmung von Verlusten an Bewässerungsfeldbauflächen. Der Mensch spielt eine zentrale Rolle bei dieser Strategie; Desertifikation beginnt und endet mit menschlichem Handeln. Wenn die Entwicklung nicht gestoppt wird, wird die heute geschätzte Zahl von 900 Millionen Betroffenen in Zukunft auf Milliarden anwachsen.


Desertified land area (3592 Mha)
Rainfed cropland 6%
Irrigated cropland 1%
Rangeland 93%
Cause
People
Control
Manage Land and Water
Rangelands:
Land reforms, range regeneration, improvement and regulation of use
Rainfed Croplands:
Land reforms, rainwater harvesting, alternative land uses
Irrigated Croplands:
Water use efficiency, rainwater harvesting, melioration

1 Desertification – Definition and Concept

1.1 Background

Merriam Webster's Collegiate Dictionary defines the term desertification as "the process of becoming a desert". The use of the term desertification by natural as well as social scientists is only about 50 years old. Early experts on the subject promoted the idea of the 'encroaching desert', 'moving desert' or 'advancing desert' to illustrate desertification (Adu, 1982 and Mainguet, 1994) with the latter citing several earlier studies related to this aspect of desertification. This "expansion of the desert" theory culminated in the assertion by Lamprey (1975) that the Sahara was marching at a rate of 5.5 km/year. Subsequent studies proved conclusively that no threat from expanding deserts existed (Warren and Agnew, 1988; Dregne and Tucker, 1988; Nelson, 1988 and Forse, 1989). Although the scientific community has largely rejected the thesis of desert encroachment, many national and international policy making and administrative authorities continue to rely upon it to win attention and funding. To illustrate, we cite an article entitled "Encroaching deserts: A silent disaster plaguing the planet", written by Doug Rekenthaler, Managing Editor of the Disaster Relief Organization (Rekenthaler, 1998, on-line). It depicted desertification in the following way: "Like an aggressive cancer, deserts are consuming more and more earth".

It was Aubreville (1949) who first explained that desertification was not an extension of the existing desert. He described desertification as the transformation of productive land anywhere, into an ecological desert due to the ruinous act of erosion, often impelled by man-made deforestation. His description also implicated climatic variations as a factor of desertification. Almost 30 years after Aubreville published his treatise on desertification, the United Nations Conference on Desertification (UNCOD) was held at Nairobi, in 1977. This conference was the reaction to a severe drought that befell the Sahel and other parts of Africa beginning in the late 1960s and continuing through much of the 1970s. The UNCOD (UNEP-UNCOD, 1978) described desertification as "the diminution or destruction of the biological potential of land that can lead ultimately to desert-like conditions" and called it "an aspect of the widespread deterioration of ecosystems under the combined pressure of adverse and fluctuating climate and excessive exploitation" (Grainger, 1990). The UNCOD description did not clearly identify the target area of applicability of the term desertification. The early 1990 UNEP definition of desertification – "land degradation in arid, semiarid and dry sub-humid areas resulting mainly from adverse human impact" - specified the environments in which land degradation was to be termed desertification (Dregne et al 1991). Subsequently, the following definition, enunciated originally in Chapter 12 of the Report of the United Nations Conference on Environment and Development (UNCED, 1992), held at Rio de Janeiro, was adopted: "Land degradation in arid, semiarid and dry sub-humid areas, resulting from various factors including climatic variations and human activities" (UNCED, 1992). The 1992 UNCED definition not only identifies the types of environments in which land degradation is called desertification, it also attaches equal importance to humans and climate as causes of desertification.

The subject of desertification has since continued to be highly controversial. According to Glantz and Orlovsky (1983), around 100 definitions on desertification were in existence by the early 1980s. Several more definitions have appeared since then (Mainguet, 1994, and Thomas and Middleton, 1996). We have collated some of the criteria included by various authors in their definition of the term regarding the "area of coverage", "causative factors", and "anticipated impacts" of desertification. (Table 1).

Table 1: Synthesis of desertification definitions

Area of Applicability	Causative factors	Anticipated Impact of Desertification	Reference
Arid and semiarid	Human action or climate change	Spread of desert-like conditions, encroaching desert	Rapp, 1974
Dryland areas	Human and natural processes	Development of desert like conditions and sustained decline in yield of major crops	Warren and Maizels, 1977
Arid, semiarid and sub-humid	Human action	Change in the character of land to more desertic conditions, impoverished ecosystem (reduced productivity), and accelerated deterioration of soils and associated livelihood systems	Mabbutt, 1978
All terrestrial ecosystems	Human action	Reduced productivity of desirable plants, undesirable alterations in biomass and biodiversity, accelerated soil erosion and increased hazards to human occupancy	Dregne, 1978
Arid, semiarid and sub-humid	Human action and natural processes	Irreversible change in soil and vegetation with diminution of biological productivity, which in extreme cases may lead to transformation of land into desert	Rozanov, 1982
Arid, semiarid and sub-humid	Human action and climatic variations	Development of non-productive land and reduced productivity	Ahmad and Kassas, 1987
Arid, semiarid and sub-humid	Human action	Sustained land degradation leading to decline in production potential that is not readily reversible	Nelson, 1988
Arid, semiarid and dry sub-humid	Human action	Land degradation	Dregne et al., 1991
Arid, semiarid and dry sub-humid	Human action and variations in climate	Land degradation	UNCED, 1992
Drought-prone areas	Human action and natural processes	Irreversible decrease or destruction of the biological potential of land and its ability to support population	Mainguet, 1994

The definitions given in Table 1 present a mix of agreements and disagreements. Generally, all the definitions agree that desertification is primarily caused by human intervention. Desertification sets in when humans disturb natural equilibria by over-exploiting natural resources. Human actions are largely intentional and, though often based on ignorance, are mostly driven by rising need and/or greed. Overexploitation of natural resources is seen to spur degradation of land that relates to degeneration of soil and biota. Although development of 'desert-like' conditions is mentioned in some definitions (Rapp, 1974; Warren and Maizels, 1977 and UNEP-UNCOD, 1978), none picture desertification as 'encroaching' desert. The measurable consequences of desertification include both decline in economic productivity of land and declining hospitability of the environment for humans and their animal support system.

Disagreements among the definitions are largely seen in the regional coverage and nature of degradation. The applicability ranges from strictly the arid, semi-arid and dry sub-humid regions (UNCED, 1992) to all terrestrial ecosystems (Dregne, 1978). With some exceptions (Bruins and Berliner,1998), the definitions exclude the hyper-arid zones, representing the inner core of the desert where processes leading to desertification as such are less likely to make it more desert-like. Dregne and Cho (1992) rationalized the exclusion of the hyper-arid zone on the basis that "such lands, unless irrigated, are incapable of supporting human occupancy dependent upon plants, directly or indirectly, for food". Whether to include reversible (affordable) land degradation to describe desertification or not, is a major point of contention. Rozanov (1982) believed desertification to represent an irreversible degradation of soil and vegetation. Mainguet (1994) portrayed desertification as "the ultimate step of land degradation to irreversible sterile land". However, Dregne and Chou (1993) intended to include the entire range of degradation – reversible or irreversible - to arrive at an estimate of the global extent and costs of desertification.

1.2 Desertification redefined

In order to clear the pervasive semantic confusion, it will be necessary to adopt quantitative and qualitative indices for each of the key elements constituting a definition. Among all the definitions on desertification, the one given by the UNCED (1992) is clearest and most straightforward in intent and substance. However, it does not distinguish whether the desertification is a 'process' (a natural phenomenon marked by regular changes that lead toward a particular result), or a 'condition' (a state of being) created by land degradation. The answer to this key issue will shift the focus of combating strategies from ameliorating the effect to containing the cause. The UNCED definition does not quantify the degree of land degradation that signifies desertification or distinguish between degradation that is reversible or not. If reversible degradation is included in the term desertification, then what is the threshold value of change (say, productivity loss) that signals its occurrence? Finally, the UNCED definition includes both, man and climate as contributors to desertification.

1.2.1 Desertification as a process or a condition

Rozanov (1982) perceived desertification to be a process of "irreversible change of soil and vegetation of dryland in the direction of aridization" culminating in the "conversion of land into desert". In their lucid account of the term desertification, Thomas and Middleton (1996) observed: "If desertification is treated as a process, this can result in a glossing over of what actually takes place, for, used in this sense, it is simply a blanket term for a whole range of specific biological, chemical and physical changes in the environment. As such desertification is a shorthand term, rather than a specific process with a specific cure". The prevailing view of desertification is that of a condition arising from the process of mostly man-induced land degradation. Many definitions (Rapp, 1974, Warren and Maizels, 1977, and Ahmad and Kassas, 1987) see desertification as the manifestation of desert-like conditions, nay desert! Warren and Agnew (1988) described desertification as "no more than degraded land in an extreme form". Treating desertification as a state or condition gets further support from Mainguet (1994) who even expressed reservations toward using the term desertification to describe destruction of the biological potential of land. Wrote Mainguet: "I prefer the term land degradation...". Since the issue has global dimensions and the word desertification has been accepted by the world community, its usage is not open for recall. Rather, its application seems imperative; as a state of affairs the term conveys a sense of urgency and demands responsive action.

1.2.2 Land degradation – reversible or irreversible

Land is a natural component of an ecosystem. It is composed of several elements describable in terms of biophysical characteristics, including soil, water, flora and fauna, microclimate and physiography. Land serves many purposes of man, i.e., agriculture, forests and pastures, and infrastructure development. Besides these so-called economic uses, land performs environmental regulatory (ecological) functions also. These are related to controlling global warming and acting as a sink for many harmful chemicals. Since soil, in turn, is a component of land, its use and functions form part of those attributed to land. Land degradation is a manifestation of loss in certain intrinsic qualities or a decline in the land's capability to perform vital functions (both economic and ecological).

From an agricultural standpoint, land degradation is reflected in declining productivity and utility. More precisely, it is said to have occurred when the productivity of a land use or production system dips persistently in the face of normal weather and non-changing inputs and management (both in quantity and kind). Blaikie and Brookfield (1987) described it as a sort of weakening in the capability of land to produce benefits when put to a particular land-use under a specific set of management options. Johnston and Lewis (1995) implied that land might be degraded for one purpose and not necessarily for another. Apparently, land degradation is use-specific, management-sensitive, and thus not necessarily permanent. Further, an implicit reference to 'a land use' signifies that land can be put to several alternative uses. The key, according to FAO (1976) is “matching” of land use with land attributes. Degradation is most likely to take place where land use and land attributes are mismatched.

Land degradation leading to loss in total productivity is not a sudden phenomenon. Rather, it tends to occur along a retrogressive pathway. In the initial stages, the reduction in potential productivity is low. A persistent productivity loss of 10% (Dregne and Chou, 1992) to 15% (Sehgal and Abrol, 1994) is considered ‘slight degradation’, which can be overcome by adopting appropriate management practices. If ignored and land degradation is allowed to proceed, productivity declines further, a stage is reached when conventional agronomic practices are found inadequate to regain this lost capacity. Ameliorative management then becomes necessary. This stage of degradation is called ‘moderate degradation’ and corresponds to a potential productivity loss of 10 to 25% (Dregne and Chou, 1992) or 33% (Sehgal and Abrol, 1994). Although major improvements to restore productivity are required, these can still be managed at the farm level (Oldeman, 1988). Land degradation is considered severe (Dregne and Chou, 1992), strong (Oldeman, 1988) or high (Sehgal and Abrol, 1994) when the productivity loss reaches 50% to 66%. Up to this point, land degradation is called reversible because restoration of land is still possible, although at high costs and with major engineering works. Further degradation makes a land unreclaimable economically. This stage of land degradation is effectively irreversible.

It is the insidious progress of land degradation that leads to irreversible desertification. Had the reversible degradation been noticed and serviced in time, the spread of irreversible degradation would have been far less than it is today. In our opinion, enduring reversible degradation should be constant monitored constantly and serviced timely. There is no wisdom in losing a kingdom for want of a nail. Hence it seems sensible to treat reversible land degradation as an integral aspect of desertification as is currently practiced. All assessments of areas affected by desertification (UNEP, 1991; Dregne and Chou, 1992) include those with reversible degradation, except for the slightest forms of degradation. A fall in potential productivity of > 15% of a land use/production system, but persistent in time and space, delineates areas suffering from desertification. The area affected by very severe and thus irreversible land degradation constitutes merely 2.2% (78 M ha out of 3592 M ha) of the total area affected by desertification (Dregne and Chou, 1992).

1.2.3 Land degradation – role of man and climatic variations

Conceptually, land degradation sets in (1) when the potential productivity associated with a land use system becomes non-sustainable or (2) when the land is not able to perform its environmental regulatory function. This implies that land - normally a renewable natural resource - has lost resilience (i.e., its ability to recover from a disturbance) and in the process has partially or totally lost its renewable potential. Except for some chaotic natural phenomena, degradation is mainly due to interaction of the land with its users or community of user organisms. Of all the organisms dependent on land for their survival, humans and their support system assert an overwhelming influence on it. In the first instance, land has a finite capacity to support diverse organisms called "carrying capacity". If the carrying capacity is exceeded persistently, land gets progressively degraded and loses the ability to renew itself (see box on next page and Figure 1). Secondly, mismatches of land use and land attributes lead to degradation. Since humans determine land use, Blaikie and Brookfield (1987) suggested that by definition land degradation should be considered a social problem. Thirdly, restorative management, including appropriate inputs and technologies, can reverse the negative effects of exploitation by human numbers and/or land misuse. Lacking the capability to invest in restoring inputs, small and marginal farmers the world over are doomed to exploit their limited resources often leading to land degradation. Additionally, land use policies (typically ownership rights and rules governing tenancy) that do not recognize and protect the formal rights of land users encourage overexploitation and discourage adoption of relatively permanent land conserving technologies (Syers et al., 1996).

Along with anthropogenic factors, a range of natural factors endemic to territories susceptible to desertification are believed to influence the progress of land degradation (Blaikie and Brookfield, 1987; Barrow, 1991 and Lal, 1997a). Year-round aridity limits bio-productivity and slows down the processes of soil development, resulting in poor quality soils (Stewart et al., 1991). These environmental disadvantages make dryland ecosystems more fragile (readily susceptible to damage). It is, however, the fluctuating rainfall patterns, which has attracted maximum attention in dryland regions. In regions susceptible to desertification, coefficients of variation of annual precipitation frequently exceeds 30%. Fifty percent of the rainfall often falls in less than 10% of the rainy days associated with intensive storm events. It is this high variability that makes dryland regions climatically unstable and particularly prone to drought. In fact, drought and desertification have been related so intimately that the former is often associated with the incidence of desertification (UNEP-UNCOD, 1978; Ahmad and Kassas, 1987).

THOU SHALT NOT TRANSGRESS THE CARRYING CAPACITY

"Thou shalt not transgress the carrying capacity" (Hardin, 1999) – a fundamental ecological principle – highlights the limits that nature imposes on man when it comes to the use of a natural resource such as land. Forgetting this basic fact, that physical boundaries of land can not be stretched with ever-growing population, sets in motion a vicious cycle of events leading to land degradation and desertification with dire consequences. The world's population doubled between 1960 and 1999. In 1998, 80% of the world's population lived in developing countries with only 58% of the total land area and 54% of the cropland area (WRI, 1998). Thus, these regions had to meet the needs for more food, extra fuel to cook it and additional housing and non-agricultural purposes from relatively less land area. The pressure to grow more food forces the raising of crops in quick succession, thus shortening the fallow period. This robs the land of time and opportunity to rejuvenate, as it did as long as lands were vast and population was limited. As organic matter depletes, soil structure deteriorates. Structure-poor soils fall pray to erosion, the principal soil-degrading factor (Oldeman et al., 1991). The denudation of fertile topsoil by erosion imperils the sustainability of agriculture. As productivity falls, the land's carrying capacity shrinks. This makes a soil fragile and further exposes it to forces of degradation.

In addition, small-scale and marginal farmers, who dominate agriculture in the developing countries, have few options to raise crops other than food, irrespective of the suitability of their land holding. According to FAO (1976), mismatches of land use and land attributes induce land degradation. Then the temptation to intensify land use beyond its carrying capacity is a common compulsion of small-scale and marginal farmers the world over. With limited ability to invest in restorative inputs, productivity falls and land degradation exacerbates.

In order to fulfil their timber and energy needs, humans resort to deforestation. Destruction of forests for fuel wood is far greater in the developing countries with high population and lower availability of commercial sources of energy. Forests are also eliminated to gain more area for agriculture. In the process, the vegetative shield against the forces of degradation is stripped off. Lands having thinner vegetative cover are known to degenerate faster. Likewise, farmers encroach upon cropland to serve the requirements of a growing non-agricultural sector. Per capita cropland declines as the population increases. Generally, it is the better quality cropland which is the main victim. In marginal lands, populations also strive to supply their needs by maintaining large herds of domestic animals. Exceeding the number of animals limited by the land'scarrying capacity degrades pastures, leaving behind plant life of no or low significant economic or fodder value. No wonder then that three out of every four hectares of degraded land worldwide (whether cropland or rangeland) are located in developing countries.

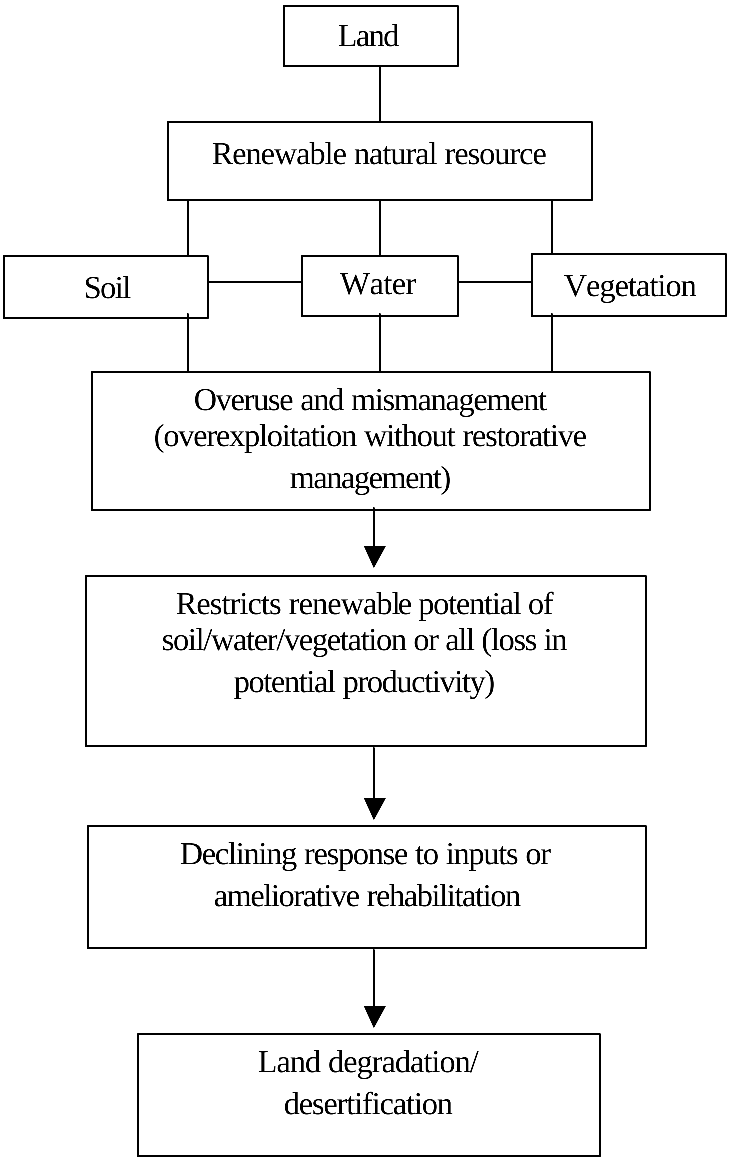
Although evidence is not adequate to link drought to the onset of land degradation, the consequences of land degradation are most pronounced under drought conditions (Dregne, 1978, Hare, 1985, and Mainguet, 1994). During the last 30 years or so, decreasing rainfall with increasing abnormality trends have been observed in Africa (Hulme, 1992 and Zeng et al., 1999). Because of the consistency, these trends suggest a change in climate. Elsewhere, consistent shifts in precipitation (increasing abnormality and decrease in mean annual precipitation) have not been observed in near the same degree (Srivastava et al., 1992). Furthermore, Agnew et al. (1995) could not prove a relationship between climate change, drought and desertification. It is this lack of consistency that leaves the role of drought in initiating land degradation uncertain. In fact, UNEP's 1990 definition (see Mendoza, 1990) attributed land degradation/desertification mainly to adverse human impact. However, neither the role of prevailing climatic variations in intensifying land degradation, nor the influence of global warming on land degradation, should be ignored when designing strategies for combating it.

Thus, the evidence links land degradation directly to human actions and indirectly to climatic variations (drought). While decline in productivity is the primary measure of land degradation, its effects on land are witnessed through the loss in quality of soil, water and vegetation - the three ecologically and economically important attributes of land. How land becomes degraded through loss of sustainable use of soil, water and vegetation is presented in Fig. 1.

Based on the above, we propose that the definition of desertification should include reference to:

- Human action as the causative element
- Land degradation as the driving process
- Decline in economic productivity of biota beneficial to man and his animal support system as the indicator. The decline in productivity must be persistent in time and applicable to a land use or a production system. A 15% fall in potential productivity is suggested as the threshold limit to mark the beginning of significant effects of land degradation
- Climatic variability (including short-term and long-term incidence of drought) and restorative management as the modifiers of the loss in potential productivity
- arid, semiarid and sub-humid environments as areas of prime concern for global initiatives. As per UNEP (1992), territories with P/ETP (the ratio of precipitation to potential evapotranspiration) ranging between 0.05 to 0.65 should be designated as those susceptible to desertification.

Figure 1: Land degradation and loss of renewable capacity of land.



Thus, "desertification is a condition of human-induced land degradation that occurs in arid, semiarid and dry sub-humid regions (P/ETP ranging from 0.05 to 0.65) and leads to a persistent decline in economic productivity (>15% of the potential) of useful biota related to a land use or a production system. Climatic variations intensify the decline in productivity, restorative management moderates it".

2 Desertification: Extent and Causes

2.1 Area affected by desertification

Territories susceptible to desertification are seasonally dry areas in which the ratio of annual precipitation to potential evapotranspiration (P/ETP) falls within the range of 0.05 to 0.65 (UNEP, 1992). Polar and sub-polar regions are kept outside the scope of this definition. Accordingly, drylands occupy 39.7% (~ 5.2 billion hectares) of the global land area (~ 13 billion hectares). Within the drylands, 12.1%, 17.1% and 9.9% of the world area are, respectively in the arid, semiarid and dry sub-humid climates. Drylands are spread over the northern half of Africa, southwest Africa, the Middle East, northwest India extending towards Pakistan, Mexico, North America, the western coast and southern tip of South America, and a large part of Australia (Grainger, 1990). They also occur in central Asia and North of China. The majority of the drylands occur in Africa, Asia and Australia. These continents, contain 37%, 33%, and 14% of the global dryland area, respectively (Dregne, 1983).

Since the holding of UNCOD in 1977, estimates of the extent of areas already desertified were constructed at least on three occasions (Table 2).

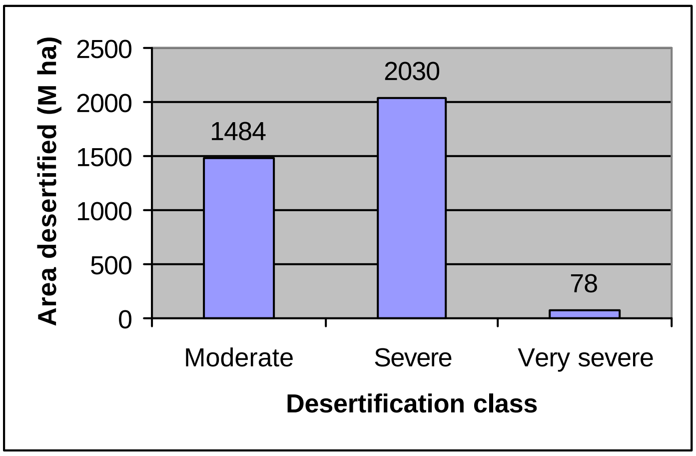
Table 2: Estimates on the status of desertification by FAO/UNESCO/WMO (1977), FAO/UNEP (1984) and UNEP (1991)

Assessment Parameter	FAO/UNESCO/WMO (1977)	FAO/UNEP (1984)	UNEP (1991)
Climatic zone limits to describe desertification	Arid, semiarid and sub-humid	Arid, semiarid and sub-humid	Arid, semi-arid and dry sub-humid
Dryland area (million hectares)	5281	4409	5158
Desertification affected area* (million hectares)	3970	3475	3592
Percentage of dryland area affected by desertification	75	79	70

* Moderately, severely and very severely affected areas

The inconsistencies in these estimates were due primarily to variable criteria applied to delineate drylands (Bruins and Berliner, 1998). Restricting the definition of desertification to the bounds of dry sub-humid areas instead of all humid territories was a key difference between the 1991 assessment and the earlier estimates of 1977 or 1984. The 1991 calculations yielded 3592 million hectares (M ha) out of a total dryland area of 5158 M ha (~ 70%). Of the area considered to be desertified, as much as 93% (3333 M ha) was found in rangelands (Dregne and Chou, 1992). Irrigated and rainfed croplands made up the remainder 7% (~ 1% or 43 M ha and 6% or 216 M ha, respectively). Within the total area affected (Figure 2), 1484 M ha, 2030 M ha and 78 M ha have been classified as suffering from moderate, severe and very severe forms of degradation, respectively (Dregne and Chou, 1992).

Figure 2: Global estimates of drylands suffering from reversible (moderate + severe desertification) and irreversible (very severe desertification) land degradation.



Data source: Dregne and Chou (1992).

2.2 Causes of land degradation

Land degradation occurs when the land’s use by man is incongruent with the land's attributes (FAO, 1976). Man uses land (13 billion hectares - B ha) in four different ways (FAO Statistics Database cited in WRI, 1998):

(1) Cropland, including lands under temporary and permanent crops, temporary meadows, market and kitchen gardens, and temporary fallow (1.46 B ha);

(2) permanent pasture, land used for five or more years for forage, including natural vegetation and cultivated crops (3.41 B ha);

(3) forest and woodland, including land under natural or planted stands of trees, as well as logged-over areas to be reforested in the near future (4.18 B ha); and

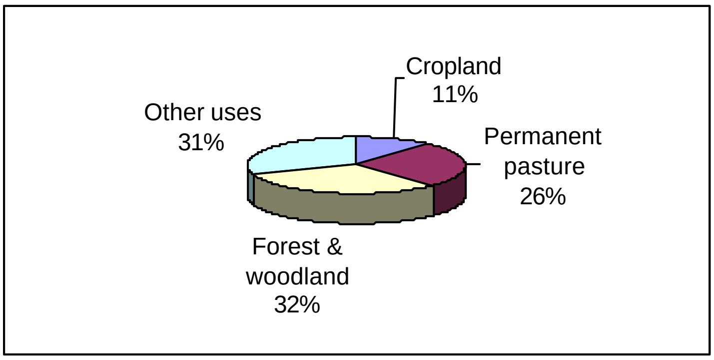
(4) other land or other uses, which includes uncultivated land, grassland not used for pasture, built-on areas, wetlands, wastelands, barren lands and roads.

Of the 1.46 B ha of cropland (including permanent cropland), barely 255 million hectares (18%) are irrigated. More than half of it (145 million hectares or 57%) is located in the drylands (UNEP, 1991).

The distribution of the earth's land resources among various uses (Figure 3) is indicative of current (1992-1994) use status and is by no means fixed. According to Richards (1990), the world's arable land area increased from 265 M ha in 1700 to about 1500 M ha by 1980; a rise of 466%! During the same period, the world lost 1.2 B ha of forest and woodland – a loss equivalent to one out of every five hectares. In fact, these shifts of area from one land use to another continue even today.

Generally, population rise, industrial growth, and societal affluence influence these area shifts. As long as the change from one use to another does not produce direct adverse effects on land quality and/or the new land use is sustainable, shifts should be guided by need and availability. But both are often blatantly ignored when decisions on land-use shifts are made. For instance, over the last 50 years, the world's loss of 33% of its forest cover was accompanied by a loss of 25% of its topsoil (Gates, 1999).

Figure 3: Distribution of earth's land resources (13.04 billion ha) among various uses



Data source: WRI (1998)

As a consequence, the role of land as a sink for carbon dioxide is also lost. The likely results are accelerated global warming, shifts in biodiversity, and a possible increase in rainfall anomalies. All contribute, directly or indirectly, to greater land degradation and desertification.

The cropland area since 1950 has increased by about 25%. Maximum growth in cropland area is happening in the developing countries, driven by the need to feed their burgeoning populations. This is shown by trends in growth of cropland area during a recent decade (1982-84 to 1992-94) (WRI, 1998). While the cropland area in the world as a whole rose by 2.0%, its 4.8%

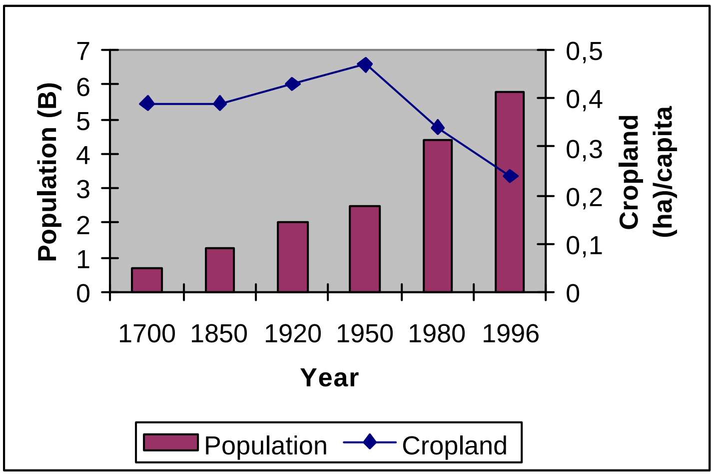
growth in the developing countries contrasted with a fall of 1.1% in the developed world. The corresponding population grew by about 1.7%, 2.0% and 0.5%, respectively. New arable areas in the developing countries were evidently obtained by clearing natural vegetation and by diverting land from "other uses". In all likelihood, the diverted area was less suitable for arable farming and thus more vulnerable to degradation. In the future also, developing countries with relatively less land area (58%) and greater population (80%) (WRI, 1998) are expected to put more pressure on the land and will be compelled to make further adjustments among different land uses. How population growth and land-use policies influence the shifts in land use and affect land degradation leading to desertification are discussed below.

2.2.1 Population growth, land use and land degradation

Over the past few centuries, the rate of increase in arable area has slowed down, although population growth has not. For instance, the relative increase in arable land was 103% from 1700 to 1850, and only 28% from 1950 to 1980 (Richards, 1990). However, population growth continued unabated. Against the nine-fold surge in population from 1700 (0.7 billion) to 1999 (6 billion) the arable area has spread only about five fold (Richards, 1990 and UNDP, 1998 on-line). Accordingly, per capita cropland availability has fallen from 0.39 ha to 0.22 ha, (Figure 4). Opportunities for adding cropland area are shrinking fast, so the rate of cropland expansion is expected to fall further in the future. The present growth rate of arable land (0.2%) is only one seventh the growth rate in population (Lal, 1997b). The decline in per capita cropland availability will be particularly sharp in the developing countries, where 94% of the future population growth (74 out of 78 million each year) will occur (UNDP, 1998 on-line). In Sub-Saharan Africa, for instance, land holding per capita of 1.6 ha in 1990 will drop to 0.63 ha in 2025 (Norse et al., 1992 cited in Scherr 1999).

With humanity's need for food increasing, declining per capita cropland availability will lead to intensified use of already stressed resources in the developing countries, which include more than 80% of the countries suffering from desertification (Dregne and Chou, 1992). Out of the total degraded soils within the drylands of the world, about 70% (691 M ha out of 1035 M ha, according to Thomas and Middleton, 1996) are concentrated in the heavily populated Asian and African countries.

Figure 4: Growth in population and its influence on per capita cropland availability.

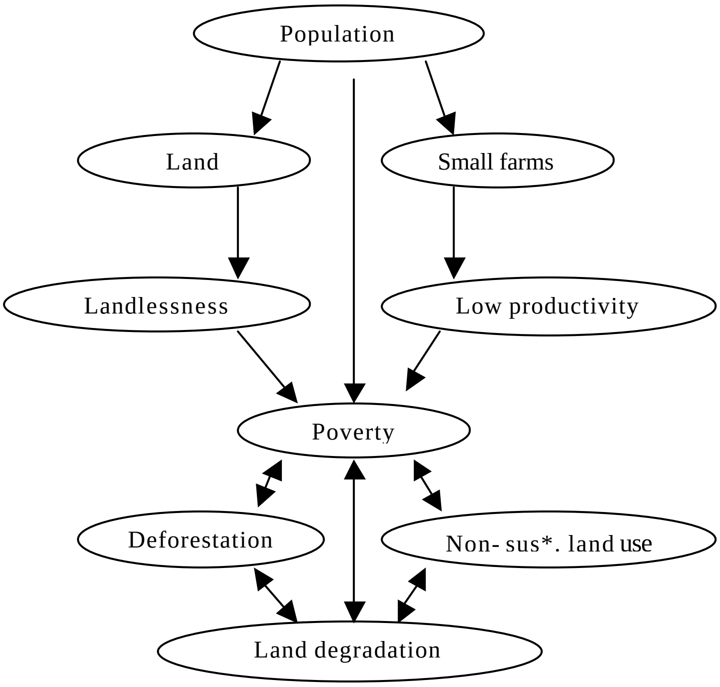


Source: Richards (1990), UNDP (1998 on-line) and WRI (1998).

2.2.1a Population-poverty-land degradation nexus

Mounting population pressure on more or less fixed land resources leads to division and sub-division of land holdings. Reduced holding size further marginalizes the small-scale farmers. According to FAO, as the farms become smaller, production per person declines and landlessness increases, which aggravates poverty (FAO undated document available on-line).

Figure 5: Population-poverty-land degradation nexus



In turn, poverty fosters non-sustainable land management and causes land degradation directly. Poor farmers encroach upon forests, use cleared lands for farming without land conservation measures, overgraze rangelands and use unbalanced fertilizer practices – all indirectly leading to land degradation. Productivity falls, land shortages become increasingly severe and poverty multiplies. The sequential nature of the population-poverty-land degradation nexus is illustrated in Figure 5.

2.2.1b Mismatches of land attributes and land use

Progressive additions to cropland area are derived from deforested areas (Richards, 1990, and LeHouerou, 1992) and land under "other uses" (WRI, 1998). Typically, such land cover conversions are fraught with dangers of increasing land degradation on two counts. Firstly, the land that is diverted is not well suited for agriculture because opportunities for transferring good cropland have already mostly been exhausted. Secondly, their inherent low productivity contributes little, if at all, to improving the general conditions of the holders. "Poverty limits the opportunity for protecting and enhancing the environment because poor people have few options but to exploit the natural resource base in order to attain food security" (CGIAR, 1994). For small-scale and marginal farmers, who are the majority of farmers in the developing world, exploiting the land for food production becomes a justifiable strategy to ensure family survival in the present. With the overwhelming prevalence of this near-sighted land management, processes of degradation set in and sustainability is imperiled. The lack of means for investment in basic restorative management and lack of knowledge prevents farmers from halting land degradation.

2.2.1c Out-migration

Another effect of increasing population is the out-migration of displaced farmers to cities, since local opportunities for alternative economic activities are low or poorly developed (UNSO, 1994 on-line). However, the benefits of migration in terms of lessening pressure on land are difficult to realize when migration does not keep up with population growth. Further, migration preferentially drains village communities of the most able-bodied workers. Consequently, human-energy resources for land-improving activities are severely depleted, thus leading to further impoverishment of land resources. Myers et al. (1995) showed that today in parts of Sudan many families have more land than labor to cultivate it.

2.2.1d Expanding cities

As they absorb migration from rural areas, and with increased industrialization, cities of the developing world are growing at unprecedented rates. Expanding cities need more and more land, which is generally obtained at the expense of prime agricultural land in the urban peripheries. Shifts of this kind are already occurring in China (Bongaarts, 1998) and India (Katyal, 1997a) – two agricultural giants and the most populous nations on earth. Consequently, the areas affected by land degradation increase since it is poor quality lands taken from "other uses" that must compensate for the loss of high quality land in the vicinity of cities.

2.2.2 The lack of holistic approaches

In former times, when land was more abundant, and the people were fewer, tracts of cultivated land were left fallow after a few years in order to rejuvenate (shifting cultivation). With population growth, this has dramatically changed towards ever-shorter fallow periods. The indigenous farming systems were based on extensive-area practices. Their inherently low-yielding ability was in harmony with the environment, since they seldom overstepped the limits of the carrying capacity set by nature. In time, however, low-productivity systems have lost relevance in view of the ever-increasing demand for food and fiber. While the present-day high-intensity farming practices are designed to support high productivity, they appear to be non-sustainable in the absence of holistic land management. A holistic land management approach satisfies the needs of the stakeholders in an economically favorable way while simultaneously including curative measures to preserve the quality of the land and prevent its degradation. In essence, it balances the economic benefits of a technology against its environmental consequences. More commonly, the former is pursued while the latter is ignored. This happens because the vast majority of the poor small and marginal farmers cannot afford the replacement costs of lost cultivated soil, used water or extracted vegetation. Typical examples are: irrigation-mediated waterlogging and salination; over-development of underground water (extraction exceeding replenishment) leading to intrusion of saline waters and drying of wells; unbalanced fertilizer use and development of micro- and secondary-nutrient deficiencies; inefficient use of fertilizers whose residues cause environmental pollution; abandoning organic manures in favor of chemical fertilizers leading to nutrient deficiencies, soil fragility, and excessive tillage accelerating organic matter loss and global warming. Mainguet and Letolle (1998) vividly described the damaging effects of the indiscriminate use of agro-chemicals on soils and waters in the Aral Sea basin.

2.2.3 Land use policies and land degradation

Land ownership and security of tenure are necessary for small and marginal farmers to adopt a long term view to conserve and invest in land and water conservation measures or to adopt tree cultivation (Syers et al., 1996 and Whiteside, 1998). Diverse systems of land ownership and tenure systems exist across continents. In Africa, land access is mostly through traditional/communal entitlements. According to Syers et al. (1996), farmland distribution works differently under two contrasting situations. When the population is low, the headman distributes the land among farmers who have access to land and natural resources but no entitlement rights. Inheritance by the first descendents (i.e., sons and nephews) is permissible, sale of land is not allowed. Consequently, farmers do not take long-term measures, as they have no guarantee that they will profit from them in the future. In the second system, where land is scarce, a piece of land is assigned to one farmer (a kind of incipient title deed). A kind of loose ownership supported by direct inheritance stimulates longer-term investments in land and perennial plantations. However, in this system there is a need to introduce mechanisms to protect the rights of less powerful farmers, particularly women (Whitehead, 1998). Women farmers, who are most of the food producers, are not allowed to buy inputs or own the land (Syers et al., 1996). In Asia, the land tenancy system is more complex. It varies between freehold and tenancy of land. Land improvement through permanent soil and water conservation structures is generally ignored where tenancy is insecure (Syers et al., 1996).

Land tenure system and land use policies have a major influence on land degradation arising from animal husbandry, which forms an integral part of the total agricultural production system in the drylands. Of the three livestock-based production systems identified by Gefu (1997) in Africa, transhumance pastoralism, the seasonal movement of livestock across fodder-yielding ecologies (the other two are mixed farming and ranching), has been affected most by the land use policies and land use shifts. Consequently, it has been both a victim and a cause of instability of rangelands leading to their degradation. Firstly, on community lands, cattle-herders' rights are limited to the use of forage resources (Syers et al., 1996). As the cultivated area spreads, the rangelands shrink. LeHouerou (1992) cited a number of case studies from Asia and Africa that pointed to an increase in arable area at the rate of 0.5 to 0.7% per annum across several countries. The gain in arable area took place at the cost of areas under natural vegetation. This conversion put more pressure on the reduced rangelands as the number of animals continued to increase (Kassas, 1992). Secondly, instead of strengthening the community-led rangelands management – a step necessary for the sustenance of common property resources – several African governments nationalized the rangelands (Swift, 1982). Nationalization proved a retrogressive step (Warren and Agnew, 1988), since it encouraged individual exploitation against community needs. The lack of an effective system of group management (Livingstone, 1977) was the primary cause of degradation and collapse of communally-held rangelands used by individual pastoralists (Hardin, 1968).

The subsistence of transhumance pastoralism has suffered due to the disappearance of grazing grounds (LeHouerou, 1992 and Gefu, 1997). Shrinking grazing lands led to the establishment of grazing reserves by expanding the borewell water resources. Sedentarization and concentration of herds around their new homes created problems, previously unknown. Intensified year-round grazing by animals left hardly any room for regeneration (LeHouerou, 1992). It caused the virtual elimination of the herbaceous cover, thus severely affecting the carrying capacity of the rangelands. The bio-diverse rangeland environment had been naturally tuned to support multi-species large herds having plant-specific feeding habits (Swift, 1982). The advantage of endemic plant diversity was lost with the switch to single-species cattle husbandry (Thomas and Middleton, 1996). Ultimately, the rangeland became inadequate to carry the original stocking ratios. It became, de facto, a case of overstocking contributed by inefficient use of the natural rangelands resources.

In addition to causing vegetation destruction, sedentarization also led to degradation of rangeland soils. Repeated trampling of the areas in the vicinities of the waterholes worsened the situation, since it enhanced loosening of the soil surface with the consequent occurrence of sheet erosion, windblown loss of topsoil, and reactivation of ancient sand dunes (Ayoub, 1998). One out of every five hectares of rangeland affected by desertification suffers from soil degradation (Table 3) mostly of the irreversible category (Dregne and Chou, 1992). Denial of formal rights to land has dissuaded herders from adopting long-term agricultural practices and have provided little incentive to implement soil conservation practices (Syers et al., 1996).

Herders are continuously pushed out of their age-old grazing territories (Sghaier and Seiwert, 1993) due to shrinking grazing lands, declining rangelands quality and declining carrying capacity (Thomas and Middleton, 1996). Yet, the number of livestock has seldom been adjusted to this changing scenario. According to Ayoub (1998), the livestock density of drylands in arid and semi-arid Africa, home to the largest number of pastoralists, exceeds the carrying capacity by a factor of three to four. Violation of the carrying capacity beyond natural limits remains the principal cause of the deteriorating status of rangelands leading to desertification, not only in Africa but elsewhere also (Jodha, 1990). Worldwide, 93% of the desertified area (3333 M ha out of 3592 M ha) has its origins in rangeland degradation (UNEP, 1991).

Overexploitation, continuing imbalance and mismanagement of inputs, and neglect of land improvement due to policies of insecure tenure all lay the foundations for unsustainable use of the earth's resources. In the process, soil loses quality (SSSA, 1996) and becomes infertile, more erodible and compacted. Within the world's drylands, of the area affected by land degradation/desertification almost 35% (1016 M ha out of 3592 M ha as per UNEP, 1991) suffers from soil degradation (Table 3).

Table 3: Extent of soil degradation within the area affected by land degradation.

Land Use Category	Total Area Within Drylands (M ha)	Area Affected by Land Degradation (M ha)	Area Affected by Soil Degradation (M ha)
Irrigated cropland	145	43	43
Rainfed cropland	457	216	216
Rangeland	4556	3333	757
Total	5158	3592	1016

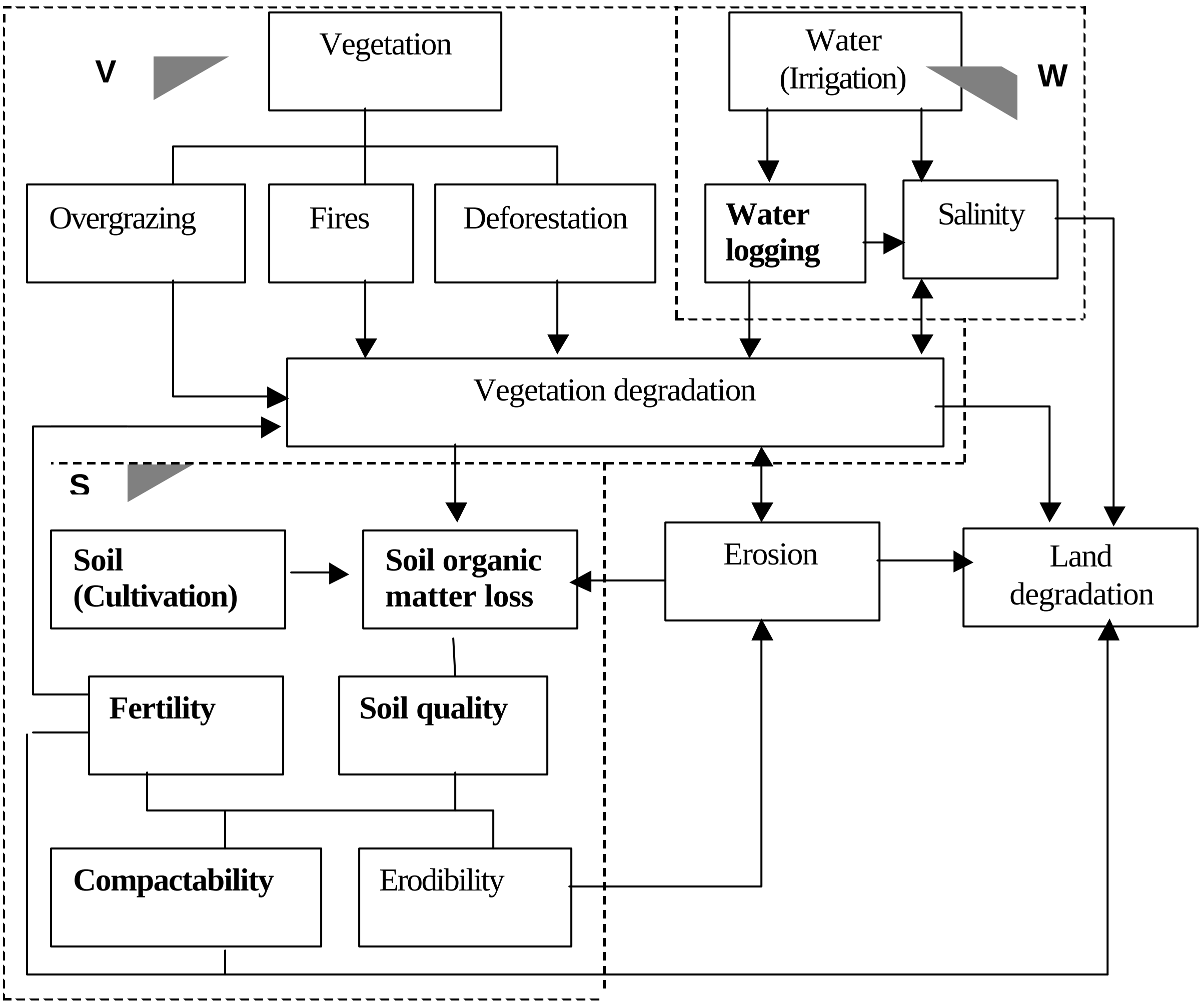
Data source: UNEP (1991)

The preponderance of evidence presented thus far confirms that land degradation is a man-made problem. It is not a new phenomenon and has been in existence since the dawn of agriculture (Barrow, 1991 and Hillel, 1991). What is new is the intensity of degradation in recent times. For example, Rozanov et al. (1990) showed that the soils of the world on average lost 25.3 million tons (M tons) of humus per year since agriculture began some 10,000 years ago. However, these losses were an average of 300 M tons per year in the last 300 years and 760 M tons in the past 50 years, thus appearing to be well correlated with the growth of population, expansion of croplands, destruction of vegetation, global warming and emergence of yield-enhancing technologies. In essence, the last 50 years have been a saga of economic growth and ecological losses, both inequitably distributed. The inherently disadvantaged dryland environments have suffered relatively more ecological damage and less economic gain. Despite all knowledge regarding the causes of land degradation, it continues to spread at a rate of 6 M ha per annum (FAO/UNEP, 1984).

3 Process of Land Degradation

On an overall basis, sustainable land use implies harmony between man's use of land and the land's ability to maintain or renew its quality. Degradation sets in once this balance is upset, and soil, water and vegetation – the basic elements of land – are damaged, as manifested in several different ways: (1) Soil loses life-sustaining topsoil (by erosion) and some essential nutrients (thus developing nutrient imbalances), accumulates harmful chemicals (by salinization, alkalinization or acidification), or develops physical deformities such as compaction or textural discontinuity in the profile (including hard-setting and pan formation). (2) Water accumulates close to or above the soil surface (waterlogging) or becomes scanty or salty. (3) Vegetation loses productivity of useful plants due to systematic devegetation (deforestation), overgrazing by livestock, and invasion by less useful species (resulting in loss of biodiversity).

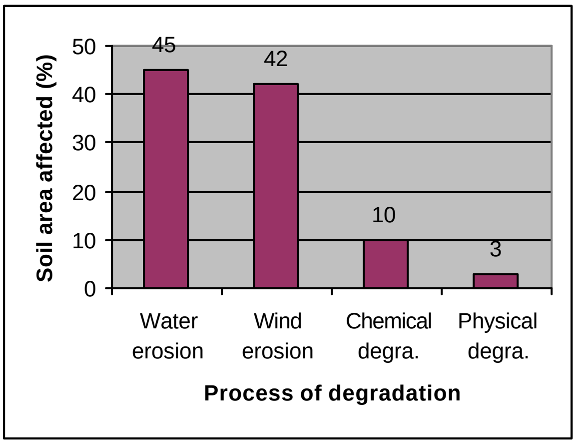
Figure 6: Man induced processes of land degradation- interconnectivity and simultaneousness in occurrence



Note: (V = vegetation, W = water, and S =soil)

Depending upon the nature of damage to the land, processes of degradation are classified as physical (erosion, soil organic carbon loss, compaction, waterlogging), chemical (salinization, acidification, nutrient imbalances), and biological (rangeland degradation, deforestation, loss in biodiversity) (Lal, 1997a). Their combined results are ruinous. A poor state of vegetation and a concomitant loss of organic matter are both a cause and an effect of accelerated erosion. Waterlogging, salinization, vegetation degradation cycle is another example. In this vicious cycle of land degradation, a process can reinforce another at one point in time and be reinforced at another. This spiral feedback between processes, with erosion as the central process of land degradation, is presented in Figure 6. The prominence given to erosion reflects the fact that 87% of the world's degraded soils are ascribable to this single process (Figure 7).

Figure 7: Proportions of dryland soil area affected by various processes of soil degradation



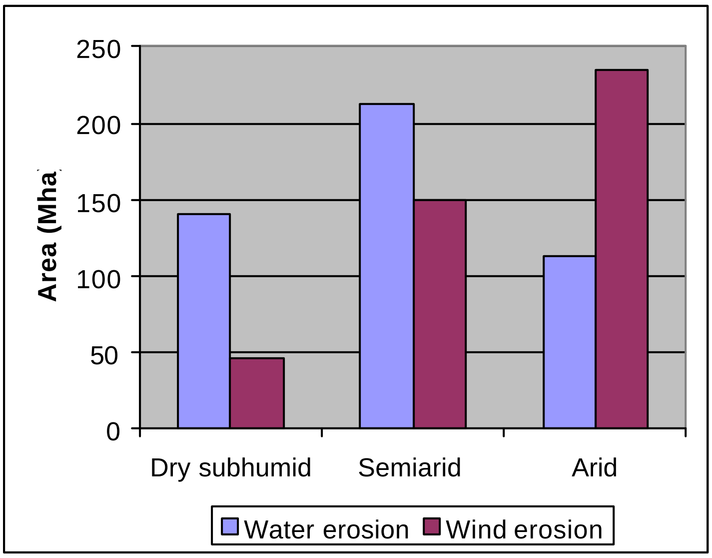
Source: (UNEP, 1992)

3.1 Erosion

The translocation of topsoil from one place to another by erosion is a process engineered by the forces of moving water (water erosion) or wind (wind erosion). Erosion is a natural soil-forming process.. However, when accelerated by human actions, erosion increases in intensity and soil displacement greatly exceeds soil formation, bringing soil degradation in its wake. Decreasing infiltration and increasing runoff provide the basic conditions for water erosion. This condition occurs universally, as reflected in the regional distribution of water erosion (Figure 8). Tropical rains often descend as violent storms (Huda et al., 1985), which invariably produce runoff. In comparison, all that is required for wind erosion to occur is a minimum wind shear stress that can detach and force the movement of naturally held soil particles from their place. Evidently, soils with smooth dry and loose surfaces offer the least resistance to blowing wind and are particularly vulnerable to wind erosion. Hence wind erosion is most pervasive in arid regions (Figure 8)

In the natural state, soils are generally protected from accelerated erosion by the aboveground and below ground parts of plants. Aboveground plant cover, provided by stems and leaves, diminishes the potential of wind and water to erode soils by acting as barriers to their destructive forces. Roots, on the other hand, reduce erosion by binding and anchoring soil particles. Crown density – an index of ground cover provided by the vegetation - significantly influences the intensity of erosion as measured by the annual soil loss per unit area. A reduced crown density (whether due to overgrazing of rangelands, deforestation, or destruction of vegetation by intentional or accidental fires) results in a greater intensity of erosion (Singh et al., 1992).

Figure 8: Influence of climate on the distribution of area affected by wind and water erosion



Source: Middleton and Thomas (1997).

In addition to acting as a barrier against the forces of erosion, vegetation also provides some indirect erosion-mitigating effects. Polysaccharides – among the decomposition products of organic matter - bind soil particles together in discreet structural units. Soils with stable aggregates resist erosion, since they allow more water to infiltrate and thus reduce runoff. With vegetation removed, soils tend to lose organic matter and the mineral soil particles tend to disperse. In the denuded state, soils tend to compact, harden, lack efficient water-intake characteristics, and become extremely exposed to water erosion. Dispersed soil particles also are scoured more readily by wind.

The hydro-transmission characteristics of a soil profile or cloddiness of the soil and the slope of the surface determine the onset and subsequent intensity of erosion. Soils resisting the infiltration and percolation of water are more susceptible to water erosion, while soils with a non-cloddy, pulverized surface are vulnerable to wind erosion. The most abundant soils in the semiarid tropics are Alfisols (Stewart et al., 1991). These are unusually exposed to erosion due to their structural instability (which encourages crusting and hard setting, and obstructs water infiltration), limited rooting depth and the tendency to occur on slopes rather than in valley bottoms. Aridisols and Entisols - the two other soil Orders dominating arid and semiarid tropics (Dregne, 1976) - though porous, are prone to wind erosion due to the mostly dry surface and lack of stable structure. Their tendency to self crusting makes them vulnerable to water erosion as well. The more productive but less extensive Vertisols (black clay soils) (Stewart et al., 1991) are prone to severe water erosion because, once saturated, they become virtually impervious to water. Whatever the soil type, it is the factor of slope that determines the erosive power of running water. The longer and steeper the slope, the greater the erosive power.

Among various processes of degradation, erosion is the number one process causing the most extensive degradation of soils around the world (Oldeman et al., 1991). In drylands, the contribution of erosion to overall soil degradation amounts to 87%. Of the total area (1642 M ha) eroded worldwide (Oldeman et al., 1991), about 55% (900 M ha) are found in drylands (UNEP, 1992). Whereas the degradation arising from water erosion is ubiquitous, wind erosion is most common in semiarid and arid environments (Figure 8) (Middleton and Thomas, 1997). Africa harbors the largest area affected by wind erosion (Table 4). In the world's drylands, wind and water erosion constitute 42% and 45% respectively, of the total soil degradation. These data suggest that in developing strategies to fight desertification, high priority should be accorded to the control of erosion.

Table 4: Distribution of areas affected by various processes of soil degradation (in millions of hectares)

Continent	Erosion		Physical	Chemical	Total
	Water	Wind			
	---------------------------------- Million ha ----------------------------------				
Africa	119	160	26.5	13.9	319
Asia	158	153	50.2	9.6	370
Australia	70	16	0.6	1.2	87.2
Europe	48	39	4.1	8.6	99.7
N. America	38	38	2.2	1.0	79.2
S. America	35	27	17.0	0.4	79.4
World	467	432	100.6	34.7	1035.1

Source: (UNEP, 1992) (Totals may not add up exactly due to rounding of figures).

3.2 Salinization

In drylands, irrigation has been the key to overcome the adverse effects of recurrent droughts. Irrigation has been vital to ensure food for a growing population. Despite the short-term benefits measured as increases in crop yields, irrigation-based agriculture has been fraught with instability. Kassas (1987) labeled irrigation of drylands “one of the seven paths to desertification”. According to Hillel (1982), mismanagement and misuse of irrigation schemes all too often make them self-destructive.

The roots of the irrigation related problems lie in the wasteful and inefficient use of irrigation water, both before it reaches the farm and after it is applied to fields. The conveyance of irrigation water through improperly lined canals leads to seepage and results in a rise of the water table. This happened, for example, in the canal-irrigated areas of both Pakistan (El-Hinnawi and Hashmi, 1982) and India (Singh, 1992). Transmission losses can be as high as 30% before water from canals reaches the fields (Murthy and Takeuchi, 1998). In flood irrigation, which continues to be the most prevalent method of irrigation, water application rates invariably exceed plant requirements. Efficiency of water use by flood irrigation seldom reaches 50%, although application methods are available to raise it to 85% (by sprinkler) or 95% (by drip). The inefficient use of water spurs problems of waterlogging and salinization (as well as alkalinization). In India (Table 5), a massive expansion in the canal irrigated area was followed by an equally huge increase in the areas affected by waterlogging and salinity (Singh, 1992).

Table 5: Development of saline and water logged area associated with some Indian canal commands

Project	Waterlogged Area (1000 ha)	% of Command Area	Saline Area (1000 ha)	% of Command Area
Ramganga	195	10	352	18
Gandak	562	53	400	38
Nagarjuna	114	24	69	14
Sharda	260	7	253	7
Chambal	99	20	40	8
Mahi	89	39	61	29

Source: Singh (1992).

The development of waterlogging and salinity/alkalinity is an outstanding example of man’s role in inducing land degradation in areas that did not pose any problem earlier. In most arid soils, salts reside at some depth below the soil surface (primary salinity) and as such pose a minimal threat to plant growth. In some areas these salts may concentrate at depth, with the location of accumulation depending upon the depth of rainwater leaching (Singh, 1992). These salts remain in situ because in dry areas the topsoil dries out faster than the dissolved salts can move toward it by capillary rise. However, following the introduction of irrigation, water may penetrate the soils to depth where it reaches the native salts allowing them to rise to the surface (a phenomenon known as secondary salinity) where it becomes harmful. The installation of drainage systems is a viable solution to combat the development of secondary salinity is often lacking due to cost cutting in irrigation projects so as to promote administrative acceptability. In the early years of an irrigation project, drainage continues to be ignored because problems from salt development are still limited and the benefits of a drainage system appear insignificant. However, with the passage of time, as the salts accumulate to toxic levels, the introduction of drainage may become cost prohibitive and its ameliorative effects low and slow.

If preventive steps are not taken, the irrigation-induced rise of salinity will remain a serious problem, making agriculture increasingly difficult to sustain. According to Ayoub (1998), the world is losing between 1.0 and 1.3 M ha of irrigated lands annually due to salinization - mainly of drylands. UNEP (1991) has reported the degradation of some 43 M ha of irrigated lands, representing 30% of the irrigated area in the world's drylands (145 M ha), which are prone to salinity related problems (Table3).

In the water-scarce areas of the drylands, salinity can also develop due to irrigation with underground waters. Two pathways contribute to the development of salinity. Firstly, regular application of naturally occurring saline waters is location-specific and limited. The second pathway involves the use of genuinely safe waters, at least to begin with. Ihowever, the over-exploitation of groundwater increases the salt concentration in the depleted aquifers. Irrigation with saline water then causes the surfacing of harmful salts and spread of salinity. Over-exploitation occurs when groundwater is withdrawn regularly without providing for its replenishment via rainwater conservation. The problem increases with the growing number of wells (tube-wells) in an area (Singh, 1992). In India, where irrigation from groundwater went from 12 M ha in 1971 to 24 M ha in 1991, extensive usage of groundwater in excess of the annual replenishment has caused a depletion of groundwater reserves in many areas of the country (CMIE, 1997). Brown and Halweil (1999) cited examples of falling water tables from every continent of the world.

In coastal areas, overdraft of groundwater triggers the land-ward movement of seawater. The result is contamination of fresh water aquifers with salt-loaded marine water. Intrusion of seawater has affected coastal drylands in the Middle East (Speece and Wilkinson, 1982). In India (Singh, 1992, and CMIE, 1997), it has salinized a 120 km-long western coastal strip (0.3 M ha), forcing people to abandon wells and even land.

3.3 Vegetation degradation

Vegetation degradation as described by LeHouerou (1992) is essentially a "long term decrease in biomass and ground cover of perennial native vegetation, with respect to a pristine or primeval condition under little or no anthropozoic impact". In other definitions, along with productivity shifts, changes in structure and botanical composition of the plant communities are also considered to constitute vegetation degradation. Invasion of grasslands by unpalatable thorny bushes like mesquite (*Prosopis glandulosa*) in dryland areas of Texas and New Mexico of USA (Schlesinger et al., 1990) is one such example of rangeland degradation. A rangeland may, however, be degraded for cattle and sheep, but not for goats and camels, which have distinctly different feeding habits.

Natural vegetation change is generally progressive in nature in well-endowed drylands (e.g., such areas that are fed regularly by water-borne sediments). In contrast, retrogressive vegetation changes occur once a degeneration of land resources takes place in response either to certain persistent natural phenomena or man-made processes. Natural land degradation develops because the sparse native vegetation and its inherently low productivity are not able to contribute the necessary organic matter that gives life to soil and binds soil particles. With this degeneration in soil quality, productivity falls, leading to reduction of vegetation. However, natural degradation of vegetation is typically gradual and often reversible (Suliman, 1988). In contrast, man-induced destruction is mostly rapid with diminished time or chance to compensate for the loss.

Anthropogenic processes of vegetative degradation are causes both directly by humans and indirectly by their animals. Humans introduce arable farming into rangelands to satisfy the increasing needs for food and other products (LeHouerou, 1992). Vegetation is often set on fire for the purpose of clearing vegetated land rapidly or to eliminate economically useless plants (Parry, 1996). As long as burning was light and the interval between fires ranged from six to seven years, vegetation could regenerate (Pratt, 1967). However, increased frequency of fires has become a major cause of widespread destruction of native vegetation and accompanying land degradation. Moreover, a several-fold increase in erosion and runoff followed when bulldozers were used to remove vegetation instead of manual clearing (Lewis and Berry, 1988). Damage due to fuel-wood extraction is also substantial. However, Dregne and Chou (1992) maintain that overgrazing by livestock stands as the principal factor of vegetation destruction in rangelands. In view of the pivotal place of livestock in the economy of territories susceptible to desertification, wide-scale degradation of rangelands is a matter of serious concern.

3.4 Organic matter loss

Organic matter in soils arises primarily from the residues of plants and animals. It plays a key role in sustaining soil quality through its regulatory influence on soil fertility, structure, compactability and erodibility (SSSA, 1996). Organic matter affects soil fertility, in as much as it determines the availability of several essential plant nutrients (Vlek and Vielhauer, 1994). Compaction destroys soil structure, organic matter protects it (Lal, 1999). Hence, unless organic matter conservation is practiced, soil degradation will ensue. Worldwide, 35 M ha of drylands have been ravaged by physical degradation (Figure 6), generally due to loss of organic carbon, compaction and hard setting.

In soils, native or added organic matter is decomposed by the soil (micro)-fauna to derivatives, which are responsible for its beneficial effects. Part of the break-down products of organic matter accumulate as humus or disappear as carbon dioxide. Practices and conditions that favor higher and faster evolution of carbon dioxide contribute to the loss of organic matter from soils. As tillage folds more air into the soil, the loss of organic matter is hastened when soils are tilled repeatedly (Lal, 1999). Deep and intensive tillage with the help of tractors accelerates the loss. Removal of soil-buried stubble due to tractor tillage (Thomas and Middleton, 1996) further adds to organic matter destruction. And tractors for tillage are no longer the exception in countries like the Sudan (Lee and Brooks, 1977), Iran (Ganji and Farzaneh, 1990) and India (Venkateswarlu, 1994). Three to four times greater wind erosion occurred when the traditional country plough was replaced by tractorized tillage, (Venkateswarlu, 1994), with concomitant loss of organic matter. In contrast, conservation tillage favors organic carbon enrichment of soils (Lal, 1999).

The speed of microbial decomposition of organic matter depends further on conditions such as moisture and temperature. In the humid tropics, organic matter decomposition rates are high particularly during the rainy season (Syers et al., 1996), but so are natural additions from the vegetation. Alternating wet and dry cycles have been found to accelerate the pace of decomposition further (Birch, 1955). Tropical soils, particularly those of arid and semiarid regions, rarely build up organic carbon reserves exceeding 0.6% (Virmani et al., 1982). Their counterparts in temperate environments have organic carbon levels ranging between 1.2% and 2.5% (Dudal, 1965). A study involving 57 bench mark soils from tropical India showed a significant influence of pedoclimate on organic carbon levels of soils (Katyal and Sharma, 1991). As the soils became drier (a change from an aquic to an aridic moisture regime), the organic carbon levels dropped sharply.

Depletion of soil organic carbon has been documented as a result of (1) arable farming on former rangelands, forest, and woodlands; (2) erosion; (3) repeated burning of organic residues and vegetation; (4) disuse of organic manure, including removal of crop residues; (5) monoculture without cover crops; and (6) persistently low productivity (LeHouerou, 1992, Cole et al., 1993 and Lal, 1995). Since the dawn of agriculture, around 60 billion tons of soil organic carbon has been released from the soil to the atmosphere as carbon dioxide, which contributes to global warming (Kevin et al., 1993). It is estimated that this disappearance is equivalent to a single decade of global fossil fuel combustion at the rates that prevailed in the early 1990s.

4 Solution to Combat Desertification

Dregne and Chou (1992) estimated that nearly 1860 M ha, or little more than half of the desertified area worldwide, requires rehabilitation. The cost of rehabilitation over a 20-year period was calculated to about US$ 213 billions. If not rehabilitated, Dregne and Chou figure that the income foregone (over a 20-year period) could equal a staggering US $ 564billions. Further, it is estimated (FAO/UNEP, 1984) that the world tends to lose about six million hectares of land to degradation/desertification each year. Razanov et al. (1990) believe that this loss to degradation is practically irreversible. The reliability of these statistics has been a subject of debate (Mainguet, 1994, and Thomas and Middleton, 1996). Although the accuracy of the numbers may be argued, the massiveness of the problem and its potentially negative impact on sustainable development is beyond question. In fact, if present trends are any indication, it is anticipated that the severity of desertification is will increase as the pressure of population on land mounts, with most of it in developing countries.

Solutions to combat desertification lie in controlling the causes of desertification. A cause-treatment approach is the way to counter the degradation processes and to ensure sustainability. However, the intricate web of human actions and natural constraints that causes desertification suggests that there are no easy ways to combat desertification. The solutions will likely be site and situation specific. The task to stabilize and sustain agricultural production in the environmentally disadvantaged drylands is a real challenge. Depending on the causes of land degradation, detailed earlier in this report, the possible solutions for combating land degradation should consider the following:

- Climatic variability
- Irrigation water, quality of soil and vegetation management
- Structural and organizational needs

4.1 Climatic variability

Against the background of general aridity and irregularly recurring droughts, sustainable food security will require agricultural management strategies adjusted to short-term and long-term variations in water availability. A proper mix of adaptation and mitigation strategies will be necessary.

4.1.1 Crops/varieties and length of growing season

Adaptation involves fitting an organism (from its existing germplasm or by creation of a new bio-type by genetic engineering) to an environment, as well as making alterations in land use to fit the land. For rainfed agriculture in arid environments, the length of the growing season sets limits on the duration of cropping (Virmani, 1994). Aligning the crop/variety duration to the length of the growing season is a first step in drought management. An alternative route is to develop plants with resistance or tolerance to drought. Selective breeding for short duration is an effective tool to fit a shortened season due to drought. A typical example is short-duration pigeon pea developed by ICRISAT that has given new impetus to its cultivation in areas with a limited growing season. Biotechnology offers wide prospects for infusing shortness or stress tolerance in cultivated plants.

4.1.2 Land management techniques

Adopting certain drought-specific land-management options can also mitigate the effect of low rainfall. Solutions must be adapted to the quality of the land and to the availability of resources to the farmer. A successful application of these fundamental principles of land management can be found in Burkina Faso, Africa. Farmers there have evolved what is known as the *Zaï* system of planting pearl millet. The methodology involves digging a planting hole, followed by placed manuring, seeding and earthing up after plant-stand establishment. Seeding in discrete planting holes moderates population pressure and concentrates water at the planting site. Selective manuring of micro-sites rather than over the entire field concentrates the treatment effect and yields high efficiency. Finally, earthing up creates a mosaic of micro-catchments for maximum rainfall harvesting and minimum evaporative loss thanks to the creation of dust mulch. Though labor intensive, *Zaï* is an excellent management system that acts to concentrate scarce water and nutrients at the base of each seedling for maximum benefit. Such technologies deserve further evaluation and development by integrating it with high-yielding stress-tolerant plant types.

Mixed seeding of two or more crops (one of which is usually a legume), thus combining variable architecture, duration, and drought tolerance, has been a time-tested strategy by farmers to cover the risks of a fluctuating precipitation regime. These systems are called intercropping or alley cropping when line-sowing of companion crops is arranged in predetermined ratios and geometry. In normal rainfall years all crops succeed, whilst in dry years the success of at least the most drought tolerant crop is assured. Mixed cropping acts as a kind of safety net against total crop failure. It also aims for higher productivity and soil fertility build up thanks to the legume component. Scientists'-recommended techniques of intercropping are experiencing poor adoption rates. This may change once machines are developed that can sow crops in predetermined row ratios and can be used for harvesting.

4.1.3 Agroforestry

The economic productivity of *Zaï* and mixed cropping is generally not high enough to alleviate poverty or to raise the quality of farm life. Alternative land uses that provide continuing economic productivity, ecological sustainability, resource optimization, and overall quality of life should form the core of any strategy to combat desertification. Agroforestry - a system of land use with simultaneous cultivation of trees or bushes and of arable crops or pasture plants fulfils many of the economic, social and environmental requisites (Katyal et al., 1994). Integration of arable crops with trees provides an opportunity to harness the potential of the crop when the trees are young and do not yet yield an economic benefit. When the trees mature they compensate for the reduction in crop yield through products that fulfil the varied needs of the farmers. The presence of trees imparts stability to the system and spreads the risk among the annual and perennial components. Even under severe circumstance, a tree often survives and provides fodder and fuel (Katyal et al., 1994). It makes the environment more hospitable. Additionally, trees make use of off-season rains, recycle nutrients from deeper soil layers, and suppress weeds because of their large canopy.

Agroforestry systems are suitable for areas with mean annual rainfall of about 350 mm or more and with land capability class IV or better. Areas with lower rainfall land capability ranking may support either intercropping of trees and forage species (agro-pastoral systems) or their monoculture (Katyal et al., 1994). In an agroforestry system, crops and trees compete for light, nutrients, and water. Optimum performance depends upon their relationship in sharing these resources. Ideally, the presence of trees should cause a minimum reduction in crop productivity. Under no circumstances should the tree produce allelopathic effects on crop growth. Drought-tolerant *Faidherbia albida* (LeHouerou, 1992) and *Prosopis cineraria* (Mann and Shankarnarayanan 1980) are typical examples of trees that benefit the crop underneath. Arable crops produced two and one half times more yield with an optimized population of these trees than without them (Katyal et al., 1994).

Alternatively, perennial bushes of economic value may be used as they are easier to manage in the system. Henna (*Lawsonia inermis*) is a typical example of a highly drought-tolerant bush (Katyal, 1999). Its leaves yield reddish brown dye used especially for hair coloring. Within a year, it starts yielding the a high-value commercial product. In normal rainfall years, the reduced productivity of the intercropped annual is less than 10% (with 1000 bushes/ha). In drought years, when the yielding ability of cultivated annuals suffers severely, the productivity of henna is hardly affected. Henna can stabilize and raise economic productivity with environmental sustainability.

Agroforestry may gain greater acceptance with economically attractive, multipurpose tree species, provide farmers have access to markets for these products. Trees yielding fruits, oil, pesticides, pharmaceuticals, flavoring agents, timber, fuel and fodder should be considered. A list of multipurpose trees popular in the drylands of India is presented in Table 6. Similar surveys are necessary to draw from the accumulated wisdom of farmers elsewhere so as to identify site-specific trees for multiple conjunctive agroforestry. Farmers' knowledge of local bushes, which abound in the drylands, should also guide the selection of appropriate candidates for agroforestry purposes. If necessary, efforts should be made to develop improved genotypes of indigenous species of trees and bushes with stress tolerance and higher economic productivity.

Table 6: A list of multipurpose tree/shrub species of agroforestry systems from India.

Tree species	Utility
Multipurpose tree species	
Sapindus trifoliatus	Soaps, shampoo, saponin, medicines
Azadirachta indica	Timber, fuel wood, bio-pesticides
Ficus religiosa	Fodder, fuel wood
Ricinus communis	Oil, industrial uses – resins, pharmaceuticals, greases, etc.
Jatropha carcus	Diesel oil, pharmaceuticals, pesticides
Prosopis cineraria	Timber, fodder, fuel wood
Lawsonia inermis	Dye, pharmaceuticals
Fruit/vegetable/ flavoring-agent yielding species	
Annona squamosa	Fruits, bio-pesticides
Zizyphus mauritiana	Fruits, fodder, fuel wood
Tamarindus indica	Fruit, vegetable, jelly, preservative, fuel wood, timber
Psidium guayava	Fruits
Emblica officinalis	Medicinal, pharmaceuticals, pickles
Moringa oleifera	Vegetable, seeds used as water purifier
Muryya koenigii	Flavoring for curries, pharmaceuticals, vegetable

Source: Katyal et al. (1997)

4.1.4 Rainwater management

Water plays a central role in drought management and in the sustainable development of all agriculture. Additionally, the availability of water is a fundamental requirement for farmers to invest in, other inputs necessary to support the sustainable development of drylands and secure the necessary credit. There are various routes to secure water supply: in situ rainwater management, run-off harvesting and irrigation.

Rainwater conservation is a means of drought mitigation that begins with pre-drought management that involves maximization of in-profile storage of rainwater. Rainwater intake by the soil profile is promoted by increasing the infiltration rate and prolonging infiltration opportunity time. The water stored in the soil serves the growing crops during the frequent dry spells. Pre-rainy-season tillage is often recommended to make the top layer of the soil more permeable to infiltrating water. However, tillage promotes organic matter loss (Lal, 1999) and its effects vary across soils (Abrol and Katyal, 1995). Tillage of Alfisols is generally found to be necessary to enhance in-situ rainwater conservation and crop yields (ICRISAT, 1985). The practice of tillage along the contour (or across the slope) and of flat seeding followed by ridging after crop establishment, appears to improve the effectiveness of tillage for rainwater conservation. Ridging and furrowing create a mosaic of mini-catchments to trap rainwater. The *Zaï* system of cultivation also combines the benefits of tillage and micro-catchments resulting from planting-site development. Broad bed and furrow (El Swaify et al., 1985) is especially suitable for vertisols, which require the provision to prevent waterlogging. The effectiveness of soil-stored water can be enhanced by reducing post-storage evapotranspiraton losses. This is achieved by covering the soil with organic or plastic mulch weed control.

In-situ rainwater conservation techniques, outlined above, are often not adequate to absorb the entire amount of tropical precipitation, which tends to occur in a few heavy storms (Huda et al.,1988). Typically, between 30% and 40% of the total precipitation is converted into runoff. Bunds of different kinds (contour or graded) have been important means, not for in-situ rainwater conservation, but also for runoff harvesting and erosion control. Despite their merit and the availability of government financial support, farmers did not sustain the bunding program in India, where it has been promoted over the last 50 years (Katyal, 1997b). The program failed because it did not address farmers' concerns over the disturbance of property lines as well as over the loss of land due to the large size of the bunds (Kerr and Sanghi, 1993). More significantly, tenant farmers remain generally opposed to making investments in permanent land improvement techniques (Syers et al., 1996). Strengthening the property bunds to as a means of rainwater harvesting may offer a viable solution (Kerr and Sanghi, 1993).

Runoff harvesting has been pursued since time immemorial (see Mainguet, 1994; Shah, 1996; and Wastelands, 1998). In a large catchment, runoff is directed to concentrate at the drainage point of a watershed by the construction of terraces or dams, or it is held in the natural watercourses by means of a series of dams for subsequent irrigation, for drinking water or for aquaculture. These community-based techniques have proved their value in sustaining the livelihoods of all the stakeholders - farmers as well as herders. In the recent past, many of the traditional systems have, however, fallen into disuse due to a breakdown of community institutions and government interventions or takeovers. From India, an article in Wastelands (1998) reported that legal changes in 1975 "took away the jurisdiction of individuals and village communities over all water sources and placed it with the government. In Jammu and Kashmir many traditional *Kuhals* were taken over by the government, but as it failed to manage them, these traditional systems were totally obliterated causing difficulties in rural communities". The government-supported watershed program –a technically sound national program– did not yield sustainable results because farmers did not feel responsible for maintaining the soil- and water-conservation structures erected during the project period (Katyal and Das, 1993 and Kerr et al. 1996). During more successful programs that followed, it became clear that financial support alone was not an adequate incentive for sustained acceptance. The close involvement of those who have to live with the consequences of the program was found to be the basic element of success (Sodhi, 1997). There is a need to revive the traditional, participatory systems of water harvesting (Shah, 1996), which harmonized natural opportunities with community wisdom and strengths.

Holistic rainwater management will thus necessitate: (1) institution of water saving techniques; (2) farmers' participated and supported development and sharing of harvested rainwater; (3) strengthening information dissemination through skill and knowledge development of farmers on alternative land uses; and (4) appropriate government support to facilitate operation on each of the interventions listed at 1 to 3.

4.2 Irrigation water, soil and vegetation management

Management aspects of water, soil, and vegetation are interdependent and complementary. Treating the management of these resources as an integrated composite rather than as disparate elements is the foundation for holistic land management.

4.2.1a Irrigation water – underground

The major difficulty with underground water is that it dwindles if withdrawals exceed replenishments. In most of the lands susceptible to desertification, the possibilities for replenishment of pumped water from greater depth are limited, and overexploitation results. It leads to depletion of water reserves and drying of wells. The adoption of water-efficient application systems the augmentation of supplies can lessen the burden on native groundwater. Runoff collection in percolation ponds is generally sufficient to refill shallow wells. Water thus harvested for irrigation can be saved in deeper strata. This directly contributes to the longevity of underground water reserves and slows the surfacing of salinity. Unfortunately, once irrigation systems are created, rainwater harvesting sometimes slackens or is neglected.

4.2.1b Irrigation water – canal

The spread of canal irrigation has been a key feature in the development of agriculture in arid regions. Large-scale irrigation projects involving a network of canals and their distributries carrying water miles away from large reservoirs formed the foundation on which the so called "green revolution" was built. While the spread of prosperity in response to irrigation has been common across countries, sustaining this benefit has been difficult. Countries conducting water through pipelines or leak-proof canals and with highly efficient irrigation techniques have been relatively successful in sustaining the benefits from irrigation (Warren and Agnew, 1988). Israel is an example of such a success. On the other hand, in countries where water was distributed through unlined open canals and its application followed inexpensive methods (flooding), the benefits from irrigation were low and non-sustainable (Hillel, 1982). By this low-cost approach one-third of the water was lost before irrigation and another one-third after application. So striking has been the adverse effect of mismanagement and inefficient irrigation, that in the Sahel "for every new hectare brought under irrigation another irrigated hectare went out of cultivation because of bad design [or] bad management" (ICIHI, 1986, quoted in Warren and Agnew, 1988). In India, where canal irrigation was developed rapidly for over the last 30 years, an analysis of 17 canal commands with the potential to irrigate 10.7 M ha showed a loss of 15% to waterlogging and another 12% to salinity (Singh, 1992).

Despite today's understanding and the availability of preventive and remedial technologies, the problems of waterlogging and salinity continue to spread. Currently, the performance of irrigation projects in India is so poor that even the maintenance and operation costs hardly match the recoveries in the way of water duty (World Bank, 1999). Indeed, the business-as-usual approach must give way to new approaches that can improve the performance of irrigation projects and raise the productivity of applied water. According to Shanan (1998), "delivery networks must be easy to operate and difficult to corrupt". Provision of drainage and strengthening of the distribution lines with brick and mortar is of prime importance. But a cooperative management scheme, enlisting the expertise of irrigation specialists and responsive to the water users (farmers), is needed to insure the proper maintenance and overall performance of irrigation systems (World Bank, 1999). Joint management of operations would be more transparent and it is likely to be better and more sustainable. The problems caused by the inefficient use of water by the top-end farmers will diminish and the functioning of the system as a whole will be more efficient. In order to enhance water use efficiency, a shift is needed from cheap methods of application (flood irrigation) to more costly but efficient techniques of application (by sprinkler or drip). While government support will be necessary in this shift, its success will depend on the development of a motivated and highly skilled human resource.

4.2.2 Soil quality management

Soil quality is antonymous to soil degradation. The key soil quality attributes that are to be stabilized or improved in order to combat desertification are soil fertility, erodibility, and compactability. Erosion affects all three attributes of soil quality (Figure 6) as it robs the soil of its most valuable asset, its soil organic matter.

4.2.2a Erosion management

Most of the strategies to combat erosion focus on obstructing the path of wind and water so as to decelerate their velocities. Generally, earthen or rubble bunds/levees are constructed to control water erosion. Vegetative barriers control wind erosion. These barricades must be applied repeatedly, at a frequency governed primarily by soil physiography (relief and vegetative cover) and features of water and wind force and direction. It is essential that the erosion-control measures cover an extensive landscape (say a watershed), since the occurrence of erosion is not restricted to individual fields. Hence, erosion control, like rainwater management, necessitates community action, involving all the stakeholders owning a landscape/watershed.

4.2.2b Organic matter management

Serious efforts to replenish the loss and to maintain soil organic matter at some acceptable levels are generally lacking. The apathy towards soil organic-matter (SOM) management is not necessarily due to farmers' ignorance, since their knowledge about the value of its use is as old as agriculture itself. Insufficient availability, largely due to competing uses and lack of a well organized system of returning byproduct wastes to fields, is the key constraint to amending the organic matter in the soil. The dung produced by cattle is used as fuel rather than as a plant-nutrient source. Conversion of dung into biogas by anaerobic fermentation may be a win-win solution with multiple benefits. Firstly, biogas fills the energy needs for cooking with an energy value higher than dung. Secondly, it generates slurry, which is valuable as manure and contains a higher concentration of nutrients than dung. Thirdly, use of biogas is environmentally friendly, since it is a clean energy source. Indirectly, it helps in reducing carbon dioxide emissions from fossil fuel burning. Likewise, it cuts down the use of fuel wood and slows down deforestation.

Biogas technology has not become as popular as its potential would suggest. Slurry is more difficult to handle than solid dung, requiring special lifting and transporting devices. In view of the high costs, a community approach or a custom-hired service may be the only feasible way to manage slurry. Moreover, small and marginal farmers lack the number of cattle necessary to provide adequate quantities of manure for efficient gas generation. Combining animal dung and human excrements would help to assure adequate supply of the raw material for gas generation. Communal biogas plants may thus be the only option. This requires strong government support, but not with administrative preconditions like the insistence on biogas plants construction by government approved firms, as is common in India.

Green manuring is a well-known approach to SOM amelioration and nutrient supply. Here again, its acceptance lags despite the proven benefits. The competition for land between a green manure and the main subsistence or cash crop is the principle cause of farmers' reluctance. In rainfed areas, the limited length of the cropping season further restricts the traditional method of raising a green manure crop (or a cover crop). To overcome these constraints, a green manure must essentially be raised either during the dry (uncropped) season (Katyal et al., 1999), or be grown in parcels of land unsuitable for crop cultivation. Alternatively, unused areas such as property bunds can be utilized. Such areas can be grown with perennial, drought-tolerant forage legumes, which will save cost on repeat cultivation and create a permanent supply of green vegetative matter. While in good rainfall years the hay or prunings are applied as green manure, during drought years they can feed the cattle. Woody parts may be used as fuel.

Green manure crop can also be started on residual moisture in the post-rainy season, thereby avoiding competition with regular crops during the rainy season. Success of this crop will subsequently depend upon the distribution and probability of occurrence of post-rainy season rainfall. A long-term probability analysis of rain distribution will enable the demarcation of areas where this technology can be advanced. Due to the brief nature of the post-growing season, only fast growing, drought-tolerant legumes will be suitable. Horse gram (Dolichos biflorus) is one such legume.

The limited quantities of organic manures make it imperative to use them with highest efficiency. Over time, farmers have found ways to save on organic manure by targeting applications to cropped areas only. *Zaï* farmers in Burkina Faso concentrate organic manure application in planting holes. Groundnut farmers in India apply organic manure to pre-fixed planting rows. Since the gains from these native techniques are limited to the immediate crop, there is a need to develop SOM conservation systems for long-term benefits. Conservation tillage may be a one approach towards that goal.

4.2.2c Soil fertility management

Soil organic matter improves soil physical conditions and fertility due to an enhancement of the biological community that functions efficiently. Soil biota is diverse and impacts ecosystem functioning in many ways. Diverse species teamed together can break up recalcitrant fractions present in an organic residue (Rupela, 1997). Individual organisms may play more specific roles. For instance, mycorrhizal fungi benefit the plant by mobilizing otherwise immobilized nutrients, and help in controlling pests and diseases. Earthworms do soil composting and modify soil structure. Selection and introduction of appropriate soil biological techniques such as worm-culture can help build soil quality attributes. Small-scale farmers with limited means are likely benefit the most from this approach.

The problem of soil fertility decline is so serious (Vlek and Vielhauer, 1994 and Smaling et al., 1997) that it may not be possible to cover all of it with organic approaches alone. In extent and intensity, said Warren and Agnew (1988), “we believe that of all the threats to sustainability, the threat to soil fertility is most serious”. Thus, fertilizers have a definite place in soil fertility management, although dryland farmers often consider them risky investments. However, research findings over the last several years have confirmed that fertilizer application across diverse dryland environments imparts greater yield stability with favorable economics (Katyal et al., 1987). Further, the response to fertilizers was found to be more sustainable when their application was integrated with organic manures/biofertilizers (Vlek, 1993; Katyal et al., 1999). The integrated use of mineral fertilizers, organic manure, and soil biological support lessens the reliance on fertilizers and better matches the economic limitations faced by the dryland farmers. Simultaneous application of other standard agronomic practices (appropriate high yielding variety, in situ soil and water conservation techniques, and weed control) are necessary to maximize the benefits of integrated soil fertility-management systems.

4.2.3 Vegetation management

Vegetation loss takes place primarily due to overgrazing, deforestation (including fuel wood extraction), and unregulated fires, or combinations thereof (Dregne and Chou, 1992). Thinning of vegetation initiates land degradation, which in turn leads to further deterioration of an area's vegetative cover. The frequent occurrence of drought amplifies the influence of land degradation on the vegetation and vice versa. Combating desertification, therefore, must consist of controlling deforestation, encouraging afforestation, regulating fires so that their effect is minimized, and limiting the intensity of grazing to the carrying capacity of the land.

In developing countries, about 40% of the energy for cooking is derived from non-commercial sources; fuel wood, dung, and crop residues. That percentage increases beyond 80% in small towns and hamlets (Lele et al., 1994). Fuel wood remains the predominant source of energy for cooking. In order to lessen dependence on woody perennials, it is essential to improve the efficiency of cooking with fuel wood and to search for alternative sources of energy. Biogas and solar energy offer attractive alternatives for energy in the tropics. Small glass-paneled solar cooking boxes to prepare that part of the food, that can be cooked in the open (outside the kitchen), can save up to 70% of the energy requirements. Proper fencing of the cooking area will be essential to afford protection from stray animals. Several households can be served by a common fenced cooking area.

Overgrazing is an important cause of rangeland degradation because natural regrowth is not able to keep pace with the grazing pressure (Kassas, 1995). Adjusting the number of livestock to the carrying capacity may seem easy, but pastoralists tend to feel more secure with larger herds. Improving pasture productivity with appropriate technology is a way to extend the limits of the carrying capacity of pastureland. Benefits from this strategy are expected to be significant, but are linked with the granting of the pastoralists formal legal rights to the land

(Young and Solbrig, 1993 cited in Parry, 1996). Transferring the rights of use and management of common-property resources to the village community and its grassroots institutions is necessary likewise. Introduction of quality animals (more efficient converters of feed) will also help to reduce the population pressure and to sustain high economic yield.

The basic principle of afforestation is to encourage the recovery of the lost vegetation. It can be accomplished by promoting and protecting the growth of native vegetation, or replanting with new vegetation. When forest revegetation is allowed to occur through natural recovery (LeHouerou, 1992), it requires total protection from man and animals throughout the regrowth period. Virtual exclusion of people and domestic animals is possible through social fencing of an area. This requires strengthening of the grassroots-level institutions and enforcing a community-led understanding that the designated area is to be temporarily off-limits.

Planted recovery starts with land preparation followed by the introduction of indigenous or exotic vegetation (Mainguet, 1994). Protection of what is planted from man and livestock in this fragile environment is equally necessary. The purpose of land preparation is to create a medium that assures maximum survival and sustainable growth and development after initial establishment. For example, improvement of the planting site by digging a pit and filling it with a reconstituted soil mixture has been found to be highly useful in the early establishment and subsequent survival of planted vegetation (Katyal, 1999). Experience shows that direct seeding, instead of transplanting with nursery-raised seedlings (Eden, 1996 on-line document), and concentrating the runoff with appropriate in-situ conservation techniques, can further enhance establishment and survival. Promotion of multipurpose trees will lead to faster acceptance by the farmers. The presence of trees in agro-pastoral systems moderates temperatures and has been shown to produce four to six times higher pasture biomass than in the absence of trees (LeHouerou, 1980).

Indiscriminate and repeated burning to gain quick access to land has led to widespread destruction of vegetation with very little chance for regeneration. The first solution to reduce such destructive effects is to increase the spacing between successive fires, so that the ability of the vegetation to regenerate from seed or root sprouting is not imperiled (Parry, 1996). Mainguet (1994) considers the timing of the operation more important than the burning itself. Burning in the beginning of the dry season, when the vegetation is patchy, has far less of an effect on vegetation than burning at the end of the dry season when the biomass is plentiful and very dry.

4.3 Structural and organizational needs

Land degradation is induced primarily by human actions. It is initiated by over-exploitation of natural resources beyond their carrying capacity. Appropriate technology can stretch the carrying capacity, but not when: (1) these technologies are in conflict with the local needs and people's expectations and, (2) the pressure of population on land remains. Hence, communities play a key role in the sustainable use of natural resources in the context of broader national policies against desertification (Parry, 1996).

4.3.1 People participation

According to Blackburn and Holland (1998), people participation means the full involvement of local populations in the identification of problems and the seeking of solutions with teams of scientists, planners and development specialists. This approach to the development of drylands links ecological constraints to systems developed by the farming community for the use of fragile land and to the development initiatives by the government. Participation gives local people a chance to have a say in what takes place in their area in the name of development (Rhoades, 1999). It considers people's aspirations and needs as an integral part of the development agenda, which makes solutions 'demand-driven' (Rhoades and Booth, 1982).

Participation of local people with government functionaries makes the former more responsive and the latter more responsible. A typical example is the joint management of irrigation (canal) projects. Working together will make government officials more concerned about the system's functioning and its maintenance and make farmers more devoted to a need-based use of water. In watershed development programs, participation encourages local ownership and management – a fundamental requirement for protection and preservation of permanent soil and water conservation structures (Farrington and Lobo, 1997). Social fencing, so vital to regenerate degraded rangelands and to sustain them after development, is not possible without people themselves agreeing to keep off.

Similarly, it is less likely that afforestation will succeed or deforestation will stop, if local communities are excluded from the management of these programs (Berkes, 1989). People participation creates an enabling environment for the equitable distribution of benefits from developed assets. For instance, if water resources are developed, those farmers who contribute to their development but are not able to use them due to topographical limitations should be able to sell their shares to others. Likewise, non-timber forest products should be shared by people who participate in joint forest management programs. An example of how to organize a participatory watershed program based on several earlier methodologies is outlined in Annexure I.

People participation will be necessary in formulating research programs as well. According to Ryan (1997), researcher-farmer interaction can be expected to yield greater pay off because: (1) it reduces the research lag time, currently, 5 to 15 years before the research findings become a technology. (2) it cuts short the adoption lag of a technology package, which can be as long as 25 years. (3) it increases levels of adoption, which currently fluctuate around 30%, and (4) it ensures that ceiling levels of adoption are maintained or increased over time. Commonly, soil and water conservation-related technologies are embraced by the farmers for as long as they receive financial support. Various steps in designing participatory research with farmers are presented in Annexure II.

4.3.2 Administrative and policy issues

Inclusion of people in the development and research plans right at the entry point offers a unique opportunity to develop location- and situation-specific plans and technologies. It also fosters community actions on a landscape basis. In order to secure the participation of farmers as a community, a transfer of administrative powers to grassroots-level village-based institutions will be necessary. Devolution of all but the most strategic land management decisions is expected to encourage the equitable use of land. It will ensure effective implementation of the people-agreed programs and their timely monitoring and evaluation. It will also facilitate the allocation of public funds and the auditing of their use by statutory bodies.

Participatory activities are not likely to succeed unless farmers have a genuine interest in arresting land degradation. For instance, herders have little incentive to make improvements in rangeland if they do not have similar access to it as farmers (Syers et al., 1996). Of the several causes for not implementing long-term soil and water conservation practices, foremost is the lack of legally defined land use rights (Parry, 1996). The institution of land tenure reforms is fundamental to sustain people's interest in permanent land improvements. The prevalent mode of tenancy must evolve toward freehold tenure, as has been proposed in Uganda (World Bank, 1993).

4.3.3 Human resource and infrastructure development

Population management is a key issue in development. In almost all the developing countries affected by desertification, the livelihood of around 70% of the population depends upon agriculture. Land imposes limitations on the number of individuals it can support. The present number exceeds the carrying capacity, leading to land degradation. Although a large population can be supported by productivity-enhancing technologies and by moderating standards of living, still there is a limit to the number that can be sustained without inducing deterioration of the land. UNSO (1994) suggested pursuing education and training programs, which can diversify livelihoods and thereby decrease the size of the agriculture-dependent population. Education and training are also necessary for efficient use of natural resources – water, soil and vegetation. Additionally, the training of government functionaries is needed in participatory techniques so as to create a mind-set conducive to devolved and decentralized management programs.

In order for farmers to obtain optimum value for their produce, it is necessary to set up the simultaneous development of infrastructure for access to markets, produce handling and for minimizing post-harvest losses. Value adding-processes to increase profit and marketing know-how pricing and consumer preferences will empower farmers. Risk minimization through timely weather advisories will help to prepare both government agencies and farmers for the eventuality of drought and help them to initiate preemptive steps to cope with it (Mainguet, 1994).

5 Indicators of Land Degradation

Land degradation is not a sudden event but a gradual process. The costs of preventing land degradation are not high if action is taken early. Once severe, however, the land must be abandoned once its reclamation becomes economically prohibitive. Currently, a consistent loss in biological productivity (when inputs and management are not changed or climatic fluctuations are within normal bounds) is the general criterion employed to distinguish degraded from non-degraded lands, and the degree of this loss distinguishes among degradation classes. It is more of a confirmatory criterion for degradation that has already occurred, since it cannot predict whether the land has an inherent tendency to degrade. Late diagnosis adds to the cost of reclamation and can make land practically irrecoverable, causing sustained environmental damage.

There is an urgent need to develop indicators that can predict the onset of desertification. Rubio and Bochet (1998) have given a list of selection and evaluation criteria that may be employed to develop an assessment system of land degradation/desertification by means of indicators. According to them, potential indicators should meet the following general requirements: be quantitative, sensitive enough to give early warning of the impending change, widely applicable, able to assess the present status and trend, able to distinguish change due to natural cycles as opposed to anthropogenic interventions, and relevant to ecologically significant phenomena. Although they listed many potential desertification indicators, they did not present critical values to define the inception of desertification. Urgent efforts are, therefore, necessary to develop threshold limits or symptoms of change that can serve as a wake up call (before the effect becomes visible). These should provoke measures to amend the ongoing land use practices so as to arrest the process before it intensifies and wreaks its deleterious effect.

This approach may yield the least expensive way of arresting the further spread of desertification. The stakes are high, with the potential to save of six million hectares of the world's land now lost annually to desertification (FAO/UNEP, 1984).

6 Summary and Conclusion

6.1 Definition and concept

The original UNEP 1990 and UNCED 1992 conferences, defined desertification as a condition arising from man-induced land degradation and discounts it as a natural process per se. We expand this definitions as follows: "Desertification is a condition of human-induced land degradation that occurs in arid, semiarid and dry sub-humid regions (P/ETP 0.05 to 0.65) and leads to a persistent decline in economic productivity (>15% of the potential) of useful biota related to a land use or a production system. Climatic variations intensify the decline in productivity, restorative management moderates it." Desertification is thus not the expansion of existing deserts. It is a condition that arises in areas even far removed from deserts.

Land areas with P/ETP ranging between 0.05 and 0.65 are collectively designated as drylands, or lands susceptible to desertification. Such lands occupy 5168 M ha worldwide (~ 40% of the global land area of about 13 billion hectares). Extensive drylands occurs in Africa (37%), Asia (33%) and Australia (14%).

In principle, desertification sets in when: (1) the inherent potential productivity of land in use becomes persistently non-sustainable, and/or (2) the land is not able to perform its environmental regulatory functions. Desertification implies that land - a renewable natural resource - has lost resilience and in the process is partially or totally unsuited for its intended use. Degradation occurs in several ways due to use of land by man and his animals. Firstly, land degrades because its natural carrying capacity is exceeded constantly by people and animals. Secondly, mismatches between land use and land attributes contribute to degradation. Thirdly, non-adoption of restorative management, including appropriate inputs and technologies, allows land degradation to proceed. Certain natural processes can exacerbate man-induced land degradation. Year-round aridity will limit bio-productivity and slow down the processes of natural soil restoration. Poor-quality soils fail in serving as a buffer between crop and occasional drought, thus accentuating the effects of land degradation. Hence, the consequences of land degradation are most pronounced under drought conditions and lead to poverty. Poverty and insecure land-tenure policies that do not recognize ownership rights of the stakeholders constrain investments in land conservation and improvement.

6.2 Processes and extent of desertification

Erosion, salinization, rangeland degradation and organic matter loss are the principal pathways leading to desertification. The resultant effects are a series of degeneration of soil, water and vegetation – the three basic elements of land. The manifestations of land degradation then are: (1) soil loses its life-sustaining topsoil (erosion), accumulates certain harmful chemicals (salinization/ alkalinization/acidification), loses some of its essential nutrient elements, or develops certain physical deformities such as compaction and textural discontinuity in the profile. (2) water accumulates close to the soil surface or above the soil surface, or becomes scanty or salty. (3) vegetation loses productivity of useful plants due to systematic denudation, overgrazing by livestock, or invasion by certain less useful species leading to a loss of biodiversity. As much as 3592 M ha (70% of the total dryland area) are affected by desertification (Table 2). Of those, 3333 M ha suffers from rangeland degradation. The balance affects rainfed (216 out of 457 M ha) and irrigated (43 out of 145 M ha) arable lands. Of the total area affected by desertification, about 78 M ha suffer from irreversible degradation (Figure 2) and is thus unreclaimable economically.

Within the area affected by desertification, 1035 M ha (UNEP, 1992) suffer from various degrees of land degradation. Of this, 427 M ha suffers from slight degradation, which is manageable at the farm level (Oldeman, 1988). Of the remaining 608 M ha, 7.5 M ha represent extreme forms of land degradation and are thus not reclaimable (irreversible land degradation). About 600 M ha are reclaimable. Of this areas 130 M ha (strongly degraded) will require major engineering works for terrain restoration. Erosion is responsible for most of the degradation – i.e., 87% of the total (Figure 7).

6.3 Solutions to combat desertification

6.3.1 Basic issues

Over the years, a large volume of information has been gathered on the causes and control of land degradation. “Despite the availability of knowledge on the ways in which desertification may be controlled, that knowledge has not been and is not being applied in an effective manner”(Heathcote, undated, available on-line). Heathcote’s concern seems justified since indications are that desertification continues to spread (FAO/UNEP, 1984). According to Syers et al. (1996), climatic risks, concerns of land users (ownership rights), institutional and market failures, limited farm household labor, and cash constraints are among the causes contributing to poor adoption of remedial technologies. Inadequate and inappropriate information and dissemination methods are the other causes (Katyal, 1997 and Scherr, 1999). The integrated approach, emphasizing a close link between farmer, researcher, government development officer and NGOs through partnership, may narrow the existing gap between technology that is available and accepted. However, the core issue of hampered credit flow for agricultural development in regions with climatic risks will need to be addressed first.

Along with agricultural development, initiatives are needed for population control, investment in human capital (through education and training), and development of marketing infrastructure. A positive approach to agricultural development (productive, profitable and stable) will create an enabling environment for greater investment in restorative land management. This is seen to influence economic well being and land-quality sustainability directly. Education and training, according to UNSO (1994), may be expected to encourage more mobility, expand opportunities, and decrease the dependence on agriculture as the sole source of livelihood for people in rural areas. A good marketing infrastructure, including better transportation facilities, will improve the profitability of farming as well.

In order to minimize land degradation arising from the presently uncertain land and grazing rights in Africa and insecure tenancy rights in Asia (Syers et al., 1996), there is a need to institute land tenure policies that discourage exploitative and destructive use and encourage constructive management for sustainable development. According to Young and Solbrig (1993 cited in Parry, 1996) granting formal documentation and registration of land rights to pastoralists is one of the important steps toward rangeland improvement. Free-hold tenure (World Bank, 1993) is seen to attract investments in permanent soil and water reclamation and conservation activities that are essential to restoring degraded lands and to preventing desertification in the future.

6.3.2 Water management

Risk management is central to land management leading to sustainable agricultural development. Since risk to agriculture is often related to water scarcity arising from the innate variability of rainfall patterns, all strategies for combating land degradation/desertification must be based on water conservation. Development and efficient utilization of water resources – whether under rainfed or irrigated conditions - is essential to sustain the quality of land and the performance of agriculture. Typically, in rainfed areas, the use of other production inputs is affected by water scarcity. Hence, rainwater management for maximum conservation and use efficiency is the first intervention that must be instituted as a permanent activity, not merely as a crisis management program in response to drought. Emphasis should be placed on investments in small-scale water harvesting structures for irrigation. To assure that rainwater management becomes the rule rather than the exception, a water literacy program for farmers must be undertaken, emphasizing community water harvesting and sharing as well as efficient use. In this task, water use should be linked to economic and environmental benefits. Farmers should be taught that the efficient use of water (i.e., the value of product per unit of volume of water) maximizes economic productivity and offers the potential to halt or even reverse land degradation.

The emphasis on rainwater management in irrigated areas is as important as it is in rainfed areas. After all, increasing the efficiency of water use in irrigated areas is at the heart of restricting the spread of waterlogging and salinity. No doubt, the investments required for minimizing the conveyance losses and application losses will be high. But the investments to be made for preventing water losses will be justified if the ongoing contribution of wasted water to land degradation is taken into account and negated. Further, the losses contribute to a reduction in the command area due to desertification, which is a dead investment in terms of loss in productivity and overall production. A World Bank (1999) study revealed that India could gain an additional food grain output of 88 M tons annually by merely raising water use efficiency from 35% to 43%.

6.3.3 Rainfed areas

Significant areas susceptible to desertification are found in the rain dependent regions. In order to manage the uncertainty generated by year-to-year variations in rainfall, long- term data are required to determine the base-line normal rainfall and to understand the pattern of its variability (amplitude and periodicity). It is primarily the interaction of rainfall distribution with soil quality characteristics and farmers' management practices that forms the basis for defining location-specific production systems. For instance, animal-based systems dominate where arable agriculture is climatically too risky (Katyal et al 1994). Long-term plans to develop drylands will need to take the natural resource endowment (rainfall and soil quality) as the base and superimpose the socio-economic framework to arrive at new production systems that can narrow the gap between the potential productivity and what is actually being realized.

Agroforestry systems offer many advantages in this regard. They optimize land use and reduce risk by distributing it between annuals and perennials, and thus helping to stabilize productivity and income. Development of superior types of trees and bushes from the indigenous species known to farmers will enhance adoption and add value to the basket of products. Sustaining the productivity of cultivated annuals will necessitate steps to build up soil-quality. Creating a permanent store of soil organic matter must be the critical element in this strategy. The conversion of dung into biogas and raising of perennial green manure plants on wastelands offer such opportunities. Farmers will support such alternative management systems only if its economic potential is distinctly higher than of the existing ones. Knowledge regarding consumer acceptability of the economic yield and infrastructure for marketing will thus be essential. Since most farm units are small and the farmers are many, coordinating their farming and marketing functions as a corporate activity would be advantageous.

In addition to long-term strategies involving the introduction of new production systems for risk management, there is a need to institute short-term measures that are seasonal in nature. Such contingency plans should be in consonance with the prevailing pattern of rainfall.Precautionary measures, which involves making timely arrangements for special input supplies (e.g., seeds of short-season varieties) and the implementation of drought-specific activities (say, nursery raising instead of open field seeding) would be required for success. Frequent news bulletins on the expected pattern of rainfall in the coming season or days will be necessary to decide which of the options to implement . Early advisories on impending drought can help farmers to adapt planting to limited rainfall by selecting appropriate crops/varieties, adjusting plant densities, and adopting techniques for in-situ rainwater conservation. With forecasts of a delay in the onset of the rainy season, farmers can start cultivation by raising nursery plants, to be transplanted when the rains come. Mechanisms and services must be set up for better and more reliable forecasts of rainfall and quick means of communication to the development officials and farmers.

6.3.4 Government role

Governments can play a significant role in mitigating drought. The institution of long-term strategies leading to the sustainable development of dryland regions is required. Assistance in setting up small-scale irrigation schemes based on rainwater management is considered a high priority. So is the institution of strategies for; (1) strengthening information dissemination and communication systems, (2) building people's skills (education and training), (3) creating infrastructure for mobility and trade, and (4) implementing pro-farmer land ownership policies.

The local people who inadvertently induce desertification, should be consciously involved in its reclamation. The principle known as people participation is a unique way to develop demand-driven location-specific plans toward managing natural-resources and responding to the unequal needs of disparate stakeholders (farmers, herders). People participation should be rooted in community action on a landscape basis. Its functioning will require greater democratization and decentralization. Administrative powers should be vested in grass-roots, village-based institutions. With the transfer of administrative and monitoring responsibility to community-based institutions, government functionaries will likely become more responsive in order to lead the program to success. Appropriate education and training programs should be launched for village community leaders and government operatives so as to encourage the evolution of a mindset that supports the new roles and responsibilities.

Annexure

Annexure I: An approach to community participation in joint watershed management program

1. Organize the village community into an informal group e.g., thrift and credit society. An NGO can be involved to initiate this action (**entry point rapport building**).

2. Once the community is brought together, its members will have a common platform to articulate their needs and perceptions on rainwater conservation and erosion control measures. Such a forum will also facilitate open discussions to reconcile the rationale behind government plans with the indigenous knowledge and wisdom (**community-based situation and issue analysis**). The discussions could also lead to a better assessment of the resources, their status and pattern of use, perceived constraints and a prioritized list of solutions (situation analysis).

3. In the next step of micro-planning, farmers' viewpoint will be central to preparing a road map of activities to be implemented. Government agencies, NGOs, and grassroots institutions can all help to develop a practical plan. Pros and cons of possible alternatives can be discussed to arrive at holistic solutions. The group should develop micro-plans, including setting goals and targets, formalizing responsibilities, and sharing resources (**micro-planning and activity road map**).

4. Once the micro-plans have been drawn up, the community should devise the plan of implementation, set goals and targets, and identify the indicators for monitoring progress (**implementation and monitoring**). The contributions of the community and the government funds for development activities can be coordinated and managed by the grassroots level village-based institutions.

5. Following the completion of the project, the community should evaluate the program against the targets and goals set initially (**evaluation**). Feedback from individual members can be the basis for refining or extending the program. The grassroots level village-based institution should be responsible for sustaining the program.

In this overall strategy for strengthening community participation in joint watershed management, the main purpose is to make the village or community responsible for what is to be done and government agents responsive to the communities' requirements in a coordinated effort to make the program a success.

Annexure II: Schematic presentation of various steps on participatory research

Perception of the problem

Created by fusion of farmers' view on land degradation and scientific concepts

Step 1. Nature of the problem and its extent

Actions and approaches

Scientists need to assess and understand the farmers' rationale of his practices in various land use situations. Working hand in hand with them, resource capability should be appraised to prioritize problems and issues

Step 2. Review of the problem to identify researchable issues

Solutions

Work out the possible solutions jointly with the farmers to enhance the opportunity value of existing land use systems in terms of technology development. What criteria farmers consider will need to be known to evaluate merit of the new systems.

Step 3. Objectives of research and data needs

Monitoring and evaluation

Monitoring of progress and evaluation of the results on completion. Farmers should be part of monitoring and evaluation. Depending upon the feed back, results may be disseminated for adoption or new research should be planned.

Step 4. Evaluation of the program and feed back

Support

In order to institute the implementation of those parts of the development strategy which farmers are not capable of implementing, support need to be provided. Also support will be necessary to create infrastructure favoring backward (consumer preferences, processing, grading and storage) and forward (transport, marketing) linkages to create an enabling environment for trade with high returns.

Step 5. Critical support on items which are beyond the reach of farmers and on

References

Abrol IP and Katyal JC (1995) Sealing crusting and hardsetting soils in Indian agriculture. In Sealing Crusting and Hardsetting Soils: Productivity and Conservation (So HB, Smith, GD, Raine SR, Schafer BM and Loch RJ eds.). Australian Society of Soil Science. The University of Queensland, Brisbane, Australia. pp 31-51.

Adu SV (1982) Desertification in West Africa. In Desertification and Soil Policy. Symposia Papers III. Transactions of the 12th International Congress of Soil Science, New Delhi, India, pp 26-43.

Agnew CT Binns T and Binns T (1995) Desertification, drought and development in the Sahel. In People and Environment in Africa (Binns T ed.). John Wiley and Sons, Chichester, UK. pp 137-149.

Ahmed YJ and Kassas M (1987) Desertification: Financial Support for the Biosphere. Hodder and Stoughton, London, UK.

Aubreville A (1949) Climats, Forets et Desertification de l'AfriqueTropicale. Societe d'Editions Geographiques, Martimes et Coloniales, Paris, France.

Ayoub A (1998) Degradation of dryland ecosystem: assessment and suggested actions to combat it. Advances in GeoEcology 31: 457-463.

Barrow CJ (1991) Land Degradation: Development and Breakdown of Terrestrial Environments. Cambridge University Press, Cambridge, UK.

Berkes F (ed) (1989) Common property resources, ecology and community based sustainable development. London.

Birch HF (1955) The effect of soil drying on humus decomposition and nitrogen availability. Plant and Soil 10: 9-31.

Blackburn J and Holland J (1998) Who Changes? Institutionalizing Participation in Development. Intermediate Technology Publications Ltd., London, UK.

Blaikie P and Brookfield H (1987) Land Degradation and Society. Methuen, London, UK.

Bongaarts J (1998) Can the human population feed itself? In The Earthscan Reader in Population and Development (Demeny P and McNicoll G eds.). Earthscan Publications Ltd., London, UK. pp 306-312.

Brown LR and Halweil B (1999) Population Outrunning Water Supply as World Hits 6 Billion. World Watch News Brief 99-9 (www.dbell@worldwatch.org).

Bruins HJ and Berliner PR (1998) Bioclimatic aridity, climatic variability, drought and desertification. In The Arid Frontier: Interactive Management of Environment and Development (Bruins HJ and Lithwick H eds). Kluwer Academic Publishers, Dordrecht, The Netherlands. pp 97-116.

CGIAR (1994) Challenging Hunger: The Role of CGIAR. A brochure about a uniquely valuable venture in international cooperation. CGIAR Secretariat, Washington DC, USA.

CMIE (1997) Directory of Indian Agriculture. Center for Monitoring Indian Economy Pvt. Ltd., Mumbai, Maharashtra, India.

Cole CV Flach K Lee J Sauerbeck D and Stewart B (1993) Agricultural sources and sinks of carbon. Water, Air Soil Pollution 70: 111-122.

Dregne HE (1976) Soils of the Arid Regions. Elsevier, Amsterdam, The Netherlands.

Dregne HE (1978) Desertification: man's abuse of the land. Journal of Soil and Water Conservation 33: 11-14.

Dregne HE (1983) Desertification of Arid Lands, Advances in Deserts and Arid Land. Harwood Academic Publishers, New York, NY, USA.

Dregne HE (1997) Desertification assessment. In Methods for Assessment of Soil Degradation (Lal R Blum WH Valentine C and Stewart BA eds.). CRC Press, Boca Raton, Florida, USA. pp 441-447.

Dregne HE and Chou Nan-Ting (1993) Global desertification dimensions. In Degradation and Restoration of Arid Lands (Dregne HE ed.). International Center for Arid and Semiarid Studies, Texas Tech University, Lubbock, Texas, USA. pp 249-282.

Dregne HE Kassas M and Rozanov (1991) A new assessment of the world status of desertification. Desertification Control Bulletin 19: 6-18.

Dregne HE and Tucker CJ (1988) Desertification encroachment. Desertification Control Bulletin 16: 16-19.

Dudal R (1965) Dark Clay Soils of Tropical and Subtropical Regions. Agricultural Development Paper 83. FAO, Rome, Italy.

Eden (1996, on-line) What is direct seeding, and why do it? (www.eden-foundation.org/project/whyds.html).

El-Hinnawi E and Hashmi M (1982) Global Environmental Issues. UNEP, Dublin, South Africa.

El-Swaify SA Pathak P Rego TJ and Singh S (1985) Soil management for optimized productivity under rainfed conditions in the semiarid tropics. Advances in Soil Science 1: 1-63.

Eswaran H Reich P and Beinroth F (undated, on-line) Global desertification tension zones. Available on-line www.nhq.nrcs.usda.gov/WSR/Landdeg/papersI/tzpaper.html.

FAO (undated on-line) The problem of land degradation. Available on-line www.fao.org/docrep/v9909e/v9909e02.htm.

FAO (1965) Soil Erosion by Water: Some Measures for its control on Cultivated Lands. Agricultural Paper No. 81. FAO, Rome, Italy.

FAO (1976) A Framework for Land Evaluation. FAO Soils Bulletin 32. Rome, Italy.

FAO/UNEP (1984) Map of Desertification Hazards. UNEP, Nairobi, Kenya.

FAO/UNESCO/WMO (1977) World Map of Desertification. UN Conference on Desertification. 29 August to 9 September, Nairobi, Kenya.

Farrington J and Lobo C (1997) Scaling up participatory development in India: lessons from the Indo-German watershed development programme. Natural Resource Perspectives 17: 1-6.

Forse B (1989) The myth of the marching desert. New Scientist February: 31-32.

Ganji MR and Farzaneh A (1990) Desertification and its control in the Islamic Republic of Iran. In Desertification Revisited: Proceedings of an Ad hoc Consultative Meeting on the Assessment of Desertification. UNEP.

DC/PAC, Nairobi, Kenya. pp 319-326.

Gates J (1999) Whose Wealth of Nations? Global Futures Bulletin # 84, 15 May 1999.

Gefu JO (1997) Managing natural resources for sustainable livestock production. In Agriculture Between Environmental Concerns and Growing Food Needs (Reule M and Ritter W eds.). Allianz der International Ausgerichteten Deutschen Agraforschung (ATSAF), Bonn, Germany. pp 163-184.

Glantz MH and Orlovsky N (1983) Desertification: A review of the concept. Desertification Control Bulletin 9: 15-22.

Grainger A (1990) The Threatening Desert: Controlling Desertification. Earthscan Publications Ltd. London, UK.

Hardin G (1968) The tragedy of the commons. Science 162: 1243-1248.

Hardin G (1999) The Ostrich Factor: Our Population Myopia. Oxford University Press, Oxford, UK.

Hare FK (1985) Climatic variability and change. In Climatic Impact Assessment (Kates RW Ausubel JH and Bererian M eds.). John Wiley and Sons Ltd., Chichester, West Sussex, UK. pp 7-68.

Heathcote RL (undated, on-line) Summary and conclusions: The role of perception in the desertification process. (www.unu.edu/unupress/unupbooks/ 80190Eog.htm).

Hillel D (1982) Advances in Irrigation. Academic Press, London, UK.

Hillel DJ (1991) Out of the Earth: Civilization and the Life of the Soil. The Free Press, New York, NY, USA.

Hong CW Katyal JC and Vlek PLG (1992) Losses and utilization of nitrogen by sorghum as affected by the depth of a swelling clay soil. Journal of Agronomy & Crop Science 168: 263-271.

Huda AKS Pathak P Rego TJ and Virmani SM (1988) Agroclimatic considerations for improved soil and water management and efficient fertilizer use in semiarid India. Fertilizer News 33: 51-57.

Hulme M (1992) Rainfall changes in Africa: 1931-60 to 1961-90. International Journal of Climatology 12: 685-699.

ICRISAT (1985) International Crops Research Institute for the Semi-Arid Tropics. Annual Report 1984. ICRISAT Patencheru, Andhra Pradesh, India.

Jodha NS (1990) Rural common property resources: Contribution and crisis. Foundation day Lecture. Society for Promotion of Wastelands Development. New Delhi, India.

Johnson DL and Lewis LA (1995) Land Degradation: Creation and Destruction. Cambridge, Blackwell, UK.

Kassas M (1987) Seven paths to desertification. Desertification Control Bulletin 15: 24-26.

Kassas M (1992) Desertification. In Degradation & Restoration of Arid Lands (Dregne HE ed.). International Center for Arid and Semiarid Land Studies. Texas Tech University, Lubbock, Texas, USA. pp 1-26.

Kassas M (1995) Desertification: a general review. Journal of Arid Environments 30: 115-128.

Katyal JC (1997a) Indian agriculture – profile of land resources, crop performances and prospects. Journal Indian Society of Soil Science 45: 659-674.

Katyal JC (1997b) Research needs in the changing context of rainfed farming in India. In Research for Rainfed Farming (Katyal JC and Farrington J eds.). Central Research Institute for Dryland Agriculture, Hyderabad, Andhra Pradesh, India. pp 86-105.

Katyal JC (1999) Rainfed agriculture in India – problems and prospects. Paper presented during Deutscher Tropantang 1999: A Conference on Tropical and Subtropical Agriculture and Forestry. Humbolt University, Berlin, Germany.

Katyal JC and Das SK (1993) Transfer of agricultural technology in rainfed regions. Fertilizer News 38 (4): 23-30.

Katyal JC Das SK Korwar GR and Osman M. (1994) Technology for mitigating stresses: Alternative land uses. In Stressed Ecosystems and Sustainable Agriculture (Virmani SM Katyal JC Eswaran H and Abrol IP eds.). Oxford and IBH Publishing Co. Pvt. Ltd. New Delhi, India. pp 291-306.

Katyal JC Hong CW and Vlek PLG (1987) Fertilizer management in Vertisols. In Management of Vertisols under Semi-Arid Conditions. IBSRAM Proceedings # 6. International Board for Soil Research and Management Inc. Bangkok, Thailand. pp 247-266.

Katyal JC Karunachand L and Rao DG (1997) Agroforestry in Andhra Pradesh: Opportunities for biotechnological interventions. Presentation in a Workshop on Biotechnological Interventions for the Improvement of Agroforestry, Horticulture and Fodder. Institute of Public Enterprise, Hyderabad, Andhra Pradesh, India.

Katyal JC Rao NH and Reddy MN (1999) Critical aspects of organic matter management in the tropics – the example India. Journal Nutrient Cycling in Agroecosystems (accepted).

Katyal JC and Sharma BD (1991) DTPA extractable and total Zn, Cu, Mn and Fe in Indian soils and their association with some soil properties. Geoderma 49: 165-179.

Kerr JM and Sanghi NK (1991) Indigenous Soil and Water Conservation in India's semiarid Tropics. Gatekeeper Series No. 34, IIED, London, UK.

Kerr JM Sanghi NK and Sriramappa G (1996) Subsidies in Watershed Development Programs in India: Distortions and Opportunities. International Institute for Environment and Development Gatekeeper Series # 61. London, UK.

Kevin G Wallace H Broecker S and Bonani G (1993) The effect of changing land use on soil radiocarbon. Science : 262: 725-726.

Lal R (1995) Global soil erosion by water and C dynamics. In Soils and Global Change (Lal R Kimble JM, Levine E and Stewart BA eds.). CRC/Lewis Publishers, Boca Raton, Florida, USA. pp 131-142.

Lal R (1997a) Soil quality and sustainability. In Methods for Assessment of Soil Degradation (Lal R Blum WH Valentine C and Stewart BA eds.). CRC Press, Boca Raton, Florida, USA. pp 17-30.

Lal R (1997b) Research and development priorities. In Methods for Assessment of Soil Degradation (Lal R Blum WH Valentine C and Stewart WA eds.). CRC Press, Boca Raton, Florida, USA. pp 547-554.

Lal R (1999) Aggregation effects on C sequestration in different ecoregions. Abstracts ASA/CSSA/SSSA Annual Meetings. Utah, Ohio, USA. pp 175-176.

Lamprey HF (1975) Report on the Desert Encroachment Reconnaissance in Northern Sudan, 21 October to 10 November 1975. Report of 1975 published as an article in 1988 in Desertification Control Bulletin 17: 1-7.

Lee FA and Brooks HC (1977) The Economic and Political Development of Sudan. Westview Press, Boulder, Colorado, USA.

LeHouerou HN (1980) Browse in Africa, The Current State of Knowledge. ILCA, Addis Ababa, Ethiopia.

LeHouerou HN (1992) An overview of vegetation and land degradation in world arid lands. In Degradation and Restoration of Arid Lands (Dregne HE ed.). International Center for Arid and Semiarid Land Studies, Texas Tech University, Lubbock, Texas, USA. pp 127-164.

Lele U Mitra K and Kaul ON (1994) Environment, Development and Poverty: A Report of the International Workshop on India's Forest Management and Ecological Revival. CIFOR Occasional Paper no. 3. Center for International Forestry Research, Bogor, Indonesia.

Lewis LA and Berry L (1988) African Environments and Resources. Unwin Hyman Winchester Massachusetts, USA.

Livingstone I (1977) Economic irrationality among pastoral peoples: Myth or reality. Development and Change 8: 209-230.

Mabutt JA (1984) A new global assessment of the status and trends of desertification. Environmental Conservation 11: 100-113.

Mainguet M (1994) Desertification-Natural Background and Human Mismanagement. Springer-Verlag, Berlin, Germany.

Mainguet M and Letolle R (1998) Human-desertification in the Aral sea basin. In The Arid Frontier: Interactive Management of Environment and Development (Bruins HJ and Lithwick H eds.). Kluwer Academic Publishers, Dordrecht, The Netherlands.

Mann HS and Shankarnarayanan KA (1980) The role of Prosopis cineraria in an agro-pastoral system in western Rajasthan. In Browse in Africa, The Current State of Knowledge (LeHouerou HN ed.). ILCA, Addis Ababa, Ethiopia. pp 437-442.

Mendoza M (1990) Global assessment of desertification: world atlas of thematic indicators of desertification. In Desertification Revisited: Proceedings of an Adhoc Consultative Meeting on the Assessment of Desertification. UNEP DC/PAC Nairobi, Kenya. pp 289-294.

Middleton N and Thomas D (1997) World Atlas of Desertification (Second Edition). Arnold, London, UK.

Murthy VVN and Takeuchi K (1998) Land and Water Development for Agriculture in the Asia Pacific Region. Oxford and IBH Publishing Co. Pvt. Ltd.,New Delhi, India.

Myers M David R Akrat S and Hamid AA (1995) The effects of male out-migration on women's management of natural resources in the Sudan. Dryland Issue Paper 60, International Institute for Environment and Development, London, UK.

Nelson R (1988) Dryland Management: The Desertification Problem. Environmental Department Working Paper 8. World Bank, Washington DC, USA.

Oldeman LR (1988) Global Assessment of Soil Degradation (GLASOD). Guidelines for General Assessment of Status of Human-Induced Soil Degradation. International Soil Reference and Information Center, Wageningen, The Netherlands.

Oldemann LR Hakkeling RTA Sombrock WG (1990) World Map of the Status of Human Induced Soil Degradation: An Explanatory Note. International Soil Reference and Information Center, Wageningen, The Netherlands.

Oldemann LR Hakkeling RTA and Sombroek WG (1991) World Map of the Status of Human-Induced land Degradation: An Explanatory Note (2nd revised edition). International Soil Reference and Information Center, Wageningen, The Netherlands.

Parry JT (1996) Land degradation in tropical drylands. In Land Degradation in the Tropics: Environmental and Policy Issues (Eden MJ and Parry JT eds.). Pinter, London, England. pp 91-97.

Pratt DJ (1967) A note on the overgrazing of burned grassland by wildlife. East African Wildlife Journal 5: 178-179.

Rapp A (1974) A Review of Desertification in Africa – Water, Vegetation and Man. Secretariat for International Ecology, Stockholm, Sweden.

Rekenthaler D (1998) Encroaching deserts: A silent disaster plaguing the planet. Available on-line www.disasterrelief.org/disasters/981218Deserts/

Rhoades R (1999) The participatory multipurpose watershed project: Nature's salvation or Schumacher's nightmare? In Integrated Watershed Management in the Global Ecosystem (Lal R ed.). CRC Press, Boca Raton, Florida, USA. pp 327-343.

Rhoades R and Booth R (1982) Farmer-back-to-farmer. A model for generating acceptable agricultural technology. Agricultural Administration 11: 127-137.

Richards JF (1990) Land transformation. In The Earth as Transformed by Human Action (Turner BL Clark WC Kates RW Richards JF Mathews JT and Meyer WB eds.). Cambridge University Press, Cambridge, UK. pp 163-168.

Rozanov BG (1982) Assessing, monitoring and combating desertification. In Desertification and Soils Policy. Transactions of the 12th International Congress of Soil Science, New Delhi, India. pp 56-68.

Rozanov BG Targulian V Orlov DS (1990) Soils. In The Earth as Transformed by Human Action (Turner BL Clark WC Kates RW Richards JF Mahtews JT and Meyer WB eds.). Cambridge University Press, Cambridge, UK.

Rubio JL and Bochet E (1998) Desertification indicators as diagnostic criteria for desertification risk assessment in Europe. Journal of Arid Environments 39: 113-120.

Rupela OP (1997) Composting crop residues and plant litter – a business enterprise. In Plant Microbe Interaction in Sustainable Agriculture (Behl RK Khurana AL and Dogra RC eds.). CCS HAU Hisar and MMB, New Delhi, India. pp 189-197.

Ryan JG (1997) Research and technology design strategies for Indian rainfed agriculture. In Research for Rainfed Farming (Katyal JC and Farrington J eds.). Central Research Institute for Dryland Agriculture, Hyderabad, Andhra Pradesh, India. pp 106-118.

Scherr SJ (1999) Soil Degradation: A Threat to Developing-Country Food Security by 2020? Food, Agriculture, and the Environment. Discussion Paper 27. International Food Policy Research Institute, Washington DC, USA.

Schlesinger WH Reynolds JF Cunningham GL Huenneke LE Jarrell WM Virginia RA and Whitford WG (1990) Biological feedback in global desertification. Science 247: 1043-1048.

Sehgal JL and Abrol IP (1994) Soil Degradation in India: Status and Impact. Oxford and IBH Publishing Co. Pvt. Ltd., New Delhi, India.

Sghaier M and Seiwert WD (1993) Winds of change and the threat of desertification: Case from the Tunisian Sahara. Geo Journal 31: 95-99.

Shah T (1996) Concept paper on Indian Water Sector Initiatives. UNDP India Water Sector Strategies.

Shanan L (1998) Irrigation development: proactive planning and interactive management. In The Arid frontier: Interactive Management of Environment and Development (Bruins HJ and Lithwick H eds.). Kluwer Academic Publishers, Dordrecht, The Netherlands. pp 251-276.

Singh NT (1992) Dryland salinity in the Indo-Pakistan subcontinent. In Degradation & Restoration of Arid Lands (Dregne HE ed.). International Center for Arid and Semiarid Land Studies, Texas Tech University, Lubbock, Texas, USA. pp 179-248.

Singh G Babu R Narain P Bhushan LS and Abrol IP (1992) Soil erosion rates in India. Journal of Soil and Water Conservation 47: 97-99.

Smaling EMA Nandwa SM and Janssen BH (1997) Soil fertility in Africa is at stake. In Replenishing Soil Fertility in Africa. Soil Science Society America Special Publication # 51. American Society of Agronomy and Soil Science Society of America, Madison, Wisconsin, USA.

Smith GD Coughlan KJ Yule DF Laryea KB Srivastava KL and Cogle AL (1992) Soil management options to reduce runoff and erosion on a hard setting Alfisol in the semiarid tropics. Soil and Tillage Research 25: 195-215.

Sodhi PS (1997) KRIBHCO's initiative – participatory renewable natural resources management. In Research for Rainfed Farming (Katyal JC and Farrington J eds.). Central Research Institute for Dryland agriculture, Hyderabad, Andhra Pradesh, India. pp 46-56.

Speece M and Wilkinson MJ (1982) Environmental degradation and development of drylands. Desertification Control Bulletin 7: 2-9.

Srivastava HN Dewan BN Dikshit SK Rao PGS Singh SS and Rao KR (1992) Decadal trends in climate over India. Mousam 43: 7-20.

SSSA (1996) Glossary of Soil Science Terms. Soil Science Society of America, Madison, Wisconsin, USA.

Stevenson FJ (1982) Organic matter and nutrient availability. In Non-symbiotic Nitrogen Fixation and Organic Matter in the Tropics. Transactions of the 12th International Congress of Soil Science, New Delhi, India. pp 137-151.

Stewart BA Lal R and El-Swaify SA (1991) Sustaining the resource base of an expanding world agriculture. In Soil Management for Sustainability (Lal R and Pierce FJ eds.). Soil and Water Conservation Society, Ankey, Iowa, USA. pp 125-145.

Suliman MM (1988) Dynamics of range plants and desertification monitoring in the Sudan. Desertification Control Bulletin 16: 27-31.

Swift J (1982) The future of the African hunter-gatherer and pastoral people. Development and Change 13: 159-181.

Syers JK Lingard J Pieri C Ezcurra E and Faure G (1996) Sustainable land management for the semiarid and sub-humid tropics. Ambio 25: 484-491.

Thomas DSG and Middleton NJ (1996) Desertification: Exploding the Myth. John Wiley & Sons Ltd., West Sussex, England.

UNCED (1992) Earth Summit'92. The UN Conference on Environment and Development. Rio de Janeiro, Brazil.

UNDP (1998) World Population 1998. United Nations Department of Economic and Social Affairs, Population Division. (www.undp.org/popin/wdtrends/p98/p98pwld.txt).

UNEP (1991) Status of Desertification and Implementation of the United Nations Plan of Action to Combat Desertification. Report of the Executive Director to the Governing Council of the third Special Session. UNEP, Nairobi, Kenya.

UNEP (1992) World Atlas of Desertification. Edward Arnold, Sevenoaks, UK.

UNEP-UNCOD (1978) United Nations Conference on Desertification, 29 August – 9 September 1977.

Roundup Plan of Action and Resolutions. UN, New York, NY, USA.

UNSO (1994) Poverty alleviation and land degradation in the drylands: Issues and action areas for the international convention on desertification. Available on-line www.undp.org/seed/unso/public/pov-eng.htm.

Venkateswarlu J (1994) Managing extreme stresses in arid zone of western Rajasthan (India) – CAZRI experience. In Stressed Ecosystems and Sustainable Agriculture (Virmani SM Katyal JC Eswaran H and Abrol IP eds.). Oxford & IBH Publishing Co. Pvt. Ltd., New Delhi, India. pp 161-172.

Virmani SM Sahrawat KL and Burford JR (1982) Chemical properties and fertility management of Vertisols. In Vertisols and Rice Soils of the Tropics. Transactions of the 12th International Congress of Soil Science, New Delhi, India. pp 80-93.

Virmani SM (1994) Climatic resource characterization in stressed tropical environments: Constraints and opportunities for sustainable agriculture. In Stressed Ecosystems and Sustainable Agriculture (Virmani SM Katyal JC Eswaran H and Abrol IP eds.). Oxford and IBH Publishing Co. Ltd., New Delhi, India. pp 149-160.

Vlek PLG and Vielhauer (1994) Nutrient management strategies in stressed environments. In Stressed Ecosystems and Sustainable Agriculture (Virmani SM Katyal JC Eswaran H and Abrol IP eds). Oxford and IBH Publishing Co. Ltd., New Delhi, India. pp 203-230.

Vlek, PLG (1993) Strategies for sustaining agriculture in sub-Saharan Africa: The fertilizer technology issue. In. Technologies for sustainable agriculture in the tropics. pp 265 – 277. ASA Special publication 56. Madison WI. USA.

Warren A and Agnew C (1988) An Assessment of Desertification and Land Degradation in Arid and Semi-arid Areas. International Institute of Environmental Development. Drylands Programme. Ecology and Conservation Unit, University College London, UK.

Warren A and Maizels JK (1977) Ecological change and desertification. UNCOD A /CONF 74-77:1.

Wastelands (1998) Traditional water harvesting structures: statement of shared concern. Wastelands Newsletter XIII (3): 18-24.

Whiteside M (1998) Encouraging sustainable smallholder agriculture in southern Africa in the context of agricultural services reform. Natural Resource Perspectives 36: 1-13.

World Bank (1993) Uganda Agriculture. A World Bank Country Study. The World Bank, Washington DC, USA.

World Bank (1999) India : water resources management sector: Report on irrigation. Paper presented at the NCAER-IEG-World Bank Conference on Reforms in Agricultural Sector for Growth, Efficiency, Equity and Sustainability. New Delhi, India.

WRI (1998) World Resources: A Guide to the Global Environment 1998-99. WRI/UNEP/UNDP/World Bank, New York, USA.

Zeng N Neelin JD Lau KM and Tucker CJ (1999) Enhancement of interdecadal climate variability in the Sahel by vegetation interaction. Science 286: 1537-1540.

The following papers have been published so far:

No. 1	Ulrike Grote, Arnab Basu, Diana Weinhold	Child Labor and the International Policy Debate Zentrum für Entwicklungsforschung (ZEF), Bonn, September 1998, pp. 47.
No. 2	Patrick Webb, Maria Iskandarani	Water Insecurity and the Poor: Issues and Research Needs Zentrum für Entwicklungsforschung (ZEF), Bonn, Oktober 1998, pp. 66.
No. 3	Matin Qaim, Joachim von Braun	Crop Biotechnology in Developing Countries: A Conceptual Framework for Ex Ante Economic Analyses Zentrum für Entwicklungsforschung (ZEF), Bonn, November 1998, pp. 24.
No. 4	Sabine Seibel, Romeo Bertolini, Dietrich Müller-Falcke	Informations- und Kommunikationstechnologien in Entwicklungsländern Zentrum für Entwicklungsforschung (ZEF), Bonn, January 1999, pp. 50.
No. 5	Jean-Jacques Dethier	Governance and Economic Performance: A Survey Zentrum für Entwicklungsforschung (ZEF), Bonn, April 1999, pp. 62.
No. 6	Mingzhi Sheng	Lebensmittelhandel und Kosumtrends in China Zentrum für Entwicklungsforschung (ZEF), Bonn, May 1999, pp. 57.
No. 7	Arjun Bedi	The Role of Information and Communication Technologies in Economic Development – A Partial Survey Zentrum für Entwicklungsforschung (ZEF), Bonn, May 1999, pp. 42.
No. 8	Abdul Bayes, Joachim von Braun, Rasheda Akhter	Village Pay Phones and Poverty Reduction: Insights from a Grameen Bank Initiative in Bangladesh Zentrum für Entwicklungsforschung (ZEF), Bonn, June 1999, pp. 47.
No. 9	Johannes Jütting	Strengthening Social Security Systems in Rural Areas of Developing Countries Zentrum für Entwicklungsforschung (ZEF), Bonn, June 1999, pp. 44.
No. 10	Mamdouh Nasr	Assessing Desertification and Water Harvesting in the Middle East and North Africa: Policy Implications Zentrum für Entwicklungsforschung (ZEF), Bonn, July 1999, pp. 59.
No. 11	Oded Stark, Yong Wang	Externalities, Human Capital Formation and Corrective Migration Policy Zentrum für Entwicklungsforschung (ZEF), Bonn, August 1999, pp. 17.

No. 12	John Msuya	Nutrition Improvement Projects in Tanzania: Appropriate Choice of Institutions Matters Zentrum für Entwicklungsforschung (ZEF), Bonn, August 1999, pp. 36.
No. 13	Liu Junhai	Legal Reforms in China Zentrum für Entwicklungsforschung (ZEF), Bonn, August 1999, pp. 90.
No. 14	Lukas Menkhoff	Bad Banking in Thailand? An Empirical Analysis of Macro Indicators Zentrum für Entwicklungsforschung (ZEF), Bonn, August 1999, pp. 38.
No. 15	Kaushalesh Lal	Information Technology and Exports: A Case Study of Indian Garments Manufacturing Enterprises Zentrum für Entwicklungsforschung (ZEF), Bonn, August 1999, pp. 24.
No. 16	Detlef Virchow	Spending on Conservation of Plant Genetic Resources for Food and Agriculture: How much and how efficient? Zentrum für Entwicklungsforschung (ZEF), Bonn, September 1999, pp. 37.
No. 17	Arnulf Heuermann	Die Bedeutung von Telekommunikationsdiensten für wirtschaftliches Wachstum Zentrum für Entwicklungsforschung (ZEF), Bonn, September 1999, pp. 33.
No. 18	Ulrike Grote, Arnab Basu, Nancy Chau	The International Debate and Economic Consequences of Eco-Labeling Zentrum für Entwicklungsforschung (ZEF), Bonn, September 1999, pp. 37.
No. 19	Manfred Zeller	Towards Enhancing the Role of Microfinance for Safety Nets of the Poor Zentrum für Entwicklungsforschung (ZEF), Bonn, October 1999, pp. 30.
No. 20	Ajay Mahal, Vivek Srivastava, Deepak Sanan	Decentralization and Public Sector Delivery of Health and Education Services: The Indian Experience Zentrum für Entwicklungsforschung (ZEF), Bonn, January 2000, pp. 77.
No. 21	M. Andreini, N. van de Giesen, A. van Edig, M. Fosu, W. Andah	Volta Basin Water Balance Zentrum für Entwicklungsforschung (ZEF), Bonn, March 2000, pp. 29.
No. 22	Susanna Wolf, Dominik Spoden	Allocation of EU Aid towards ACP-Countries Zentrum für Entwicklungsforschung (ZEF), Bonn, March 2000, pp. 59.

No. 23	Uta Schultze	Insights from Physics into Development Processes: Are Fat Tails Interesting for Development Research? Zentrum für Entwicklungsforschung (ZEF), Bonn, March 2000, pp. 21.
No. 24	Joachim von Braun, Ulrike Grote, Johannes Jütting	Zukunft der Entwicklungszusammenarbeit Zentrum für Entwicklungsforschung (ZEF), Bonn, March 2000, pp. 25.
No. 25	Oded Stark, You Qiang Wang	A Theory of Migration as a Response to Relative Deprivation Zentrum für Entwicklungsforschung (ZEF), Bonn, March 2000, pp. 16.
No. 26	Doris Wiesmann, Joachim von Braun, Torsten Feldbrügge	An International Nutrition Index – Successes and Failures in Addressing Hunger and Malnutrition Zentrum für Entwicklungsforschung (ZEF), Bonn, April 2000, pp. 56.
No. 27	Maximo Torero	The Access and Welfare Impacts of Telecommunications Technology in Peru Zentrum für Entwicklungsforschung (ZEF), Bonn, June 2000, pp. 30.
No. 28	Thomas Hartmann-Wendels Lukas Menkhoff	Could Tighter Prudential Regulation Have Saved Thailand's Banks? Zentrum für Entwicklungsforschung (ZEF), Bonn, July 2000, pp. 40.
No. 29	Mahendra Dev	Economic Liberalisation and Employment in South Asia Zentrum für Entwicklungsforschung (ZEF), Bonn, August 2000, pp. 82.
No. 30	Noha El-Mikawy, Amr Hashem, Maye Kassem, Ali El-Sawi, Abdel Hafez El-Sawy, Mohamed Showman	Institutional Reform of Economic Legislation in Egypt Zentrum für Entwicklungsforschung (ZEF), Bonn, August 2000, pp. 72.
No. 31	Kakoli Roy, Susanne Ziemek	On the Economics of Volunteering Zentrum für Entwicklungsforschung (ZEF), Bonn, August 2000, pp. 47.
No. 32	Assefa Admassie	The Incidence of Child Labour in Africa with Empirical Evidence from Rural Ethiopia Zentrum für Entwicklungsforschung (ZEF), Bonn, October 2000, pp. 61.
No. 33	Jagdish C. Katyal, Paul L.G. Vlek	Desertification - Concept, Causes and Amelioration Zentrum für Entwicklungsforschung (ZEF), Bonn, October 2000, pp. 65.

ISSN: 1436-9931

The papers can be ordered free of charge from:

Zentrum für Entwicklungsforschung (ZEF)
Center for Development Research
Walter-Flex-Str. 3
D – 53113 Bonn, Germany

Phone: +49-228-73-1861
Fax: +49-228-73-1869
E-Mail: zef@uni-bonn.de
http://www.zef.de