MANAGEMENT OF DRYLAND AND DESERT AREAS

E.F. De Pauw
Agroecologist, International Center for Agricultural Research in the Dry Areas (ICARDA), Aleppo, Syria

Keywords: Drylands, Land management, Land degradation, Desertification, Ecology, Agro-ecosystems, Agricultural systems

Contents

Summary

The drylands of the world are becoming increasingly important for food production and are under increasing threat of desertification. Within the overall setting of dryness or ‘aridity’, they exhibit a tremendous diversity in climates, landscapes, soils, geological substrata, surface water and groundwater resources. Although drylands are commonly perceived as fragile ecosystems, highly susceptible to degradation and desertification, it is not always easy to distinguish natural processes related to dryness from human-induced degradation trends. This uncertainty about the human-induced nature of dryland degradation applies in particular to salinization, wind and water erosion, and vegetation dynamics as related to climatic perturbations, fire and animal pressure.

The main principles for successful dryland crop management are well known. Essentially they boil down to retaining precipitation on the land, to reducing evaporation, and to use crops with drought tolerance and that fit the rainfall pattern. An exception is water harvesting, which is a form of irrigation whereby runoff is encouraged from a catchment area, in order to provide more water to a target area.

The rangelands probably constitute the most neglected agricultural sector of the drylands. Although generally of low productivity per unit area, they are the biggest land

resource of the drylands. The key principle of all sound range management is to adapt, through spatial and temporal stock management, grazing intensity to levels that allow the maintenance of palatable species and a sustainable cover. In view of the diversity of vegetation, climate and seasonal conditions within the drylands, this principle is difficult to apply on a sustainable basis. Particularly the pastoral systems, dependent on communal grazing, are under threat, due to their inability to avoid overgrazing.
The key to successful dryland management is to convert the broad principles into site-specific management packages that take full consideration of local agro-ecological conditions, land user goals, and policy frameworks. Given the enormous complexity of possible interactions, a systems approach is necessary.

1. Introduction

The dryland areas of the world have an unexpected diversity in terms of agro-ecology and agricultural systems. They also constitute fragile environments that require very careful management. The diversity, local problems and potentialities of the various dryland farming systems necessitate a holistic approach, on the basis of proven dryland management principles and location-specific management recommendations and packages. An integrated natural resource management approach, which applies participatory research and technology development to locally defined problems and management goals, is vital for the sustainable management of dryland systems.

2. Drylands of the World

1. Hyper-arid zone (P[1]/PET[2] ratio < .03)
This is the zone of the true deserts: very low and irregular rain may fall in any season, with an inter-annual variability of 100% or more. There is almost no perennial vegetation, except some bushes in river beds, although annual plants can grow in good years. In general agriculture and grazing are not possible.
2. Arid zone (.03 < P/PET < 0.2)
This zone has an annual rainfall of 80-150 mm in winter rainfall regimes and 200-350 mm in summer rainfall regimes, with an inter-annual variability of 50-100%. It has scattered vegetation including bushes, small woody, succulent, thorny or leafless shrubs. Only light pastoral use is possible, but not rainfed agriculture.
3. Semi-arid zone (0.2 < P/PET < 0.5)
This zone has a mean annual rainfall from 300-400 mm to 700-800 mm in summer rainfall regimes, and from 200-250 mm to 450-500 mm in winter rainfall regimes, with inter-annual variability of 25-50%. It is a steppe zone with some savannas and tropical scrub, which may contain good grazing areas. Rainfed agriculture is possible, although with great yield fluctuations due to great rainfall variability.
4. Sub-humid zone (0.5 < P/PET < 0.75)

[1] P: annual rainfall
[2] PET: annual potential evapotranspiration

This zone, with higher rainfall than the previous one, has inter-annual rainfall variability of less than 25%. It includes various vegetation types such as tropical savanna, maquis and chaparral, steppes etc. Agriculture is the normal use.

Table 1. UNESCO classification of the arid zones of the world: moisture regimes and summary characteristics.

The drylands of the world are receiving increasing attention by researchers and development planners for two main reasons. Firstly, future increases in agricultural production will increasingly depend on the contribution from rain-fed agriculture in marginal lands, notably in drylands. A second reason is that the drylands under agricultural use, with 70% of them affected by some degree of degradation, are at the frontline of desertification.

As Noin and Clarke (1998) pointedly observe, “the term ‘drylands’ and its derivatives such as ‘desert, drought, desertification, semi-desert, sahel, steppe, arid, semi-arid, dry sub-humid’, have been variously and loosely used, understood, and defined by different people”. To resolve the terminology issue and to characterize better the dry areas of the globe, UNESCO (1979) has proposed a simple but clear-cut worldwide classification system, based in first instance on the ratio of annual precipitation to annual potential evapo-transpiration, calculated by the standard Penman method (Table 1).

Further subdivisions were based on the temperature regime during winter and summer, resulting in a system of 44 classes. A simplified world map, derived from the UNESCO map, is given in Figure 1. The patterned areas indicate where cold conditions accompany aridity. Based on the UNESCO classification system the drylands are defined by UNEP (1991) as those lands with a precipitation over potential evapo-transpiration ratio of less than 0.65. Drylands thus defined cover approximately 41% of the world’s land area, with two-thirds of these in Africa and Asia (Table 2).

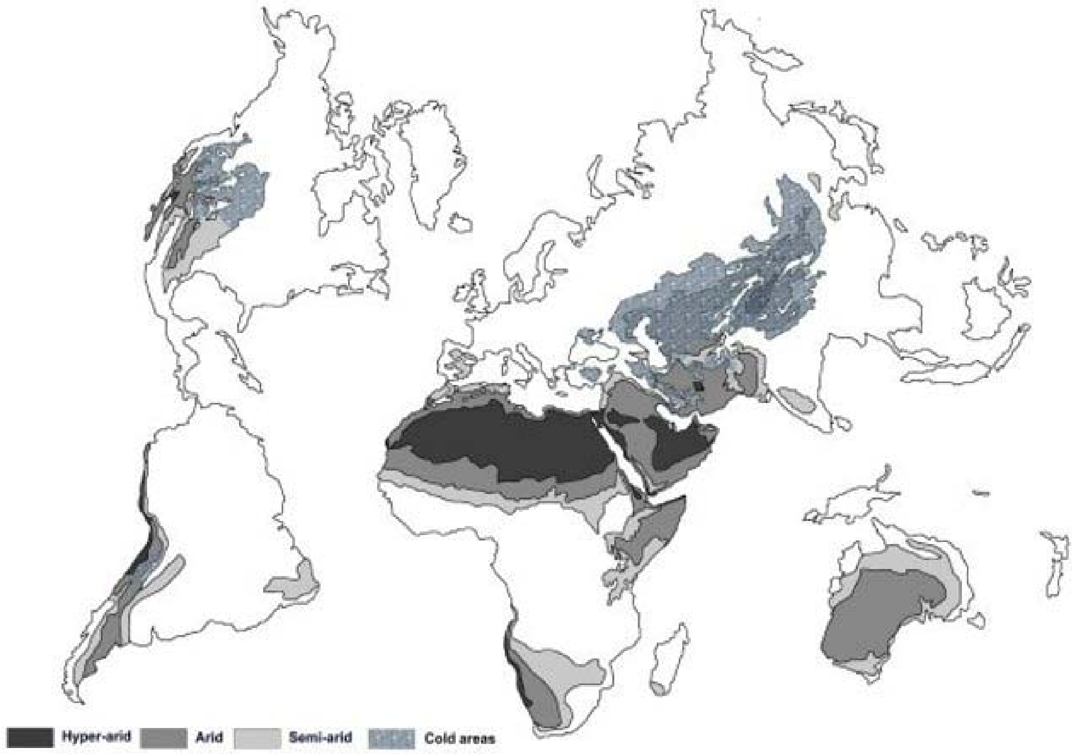

Figure 1. Distribution of the drylands of the world (based on UNESCO, 1979; sub-humid areas not included; Oceania displaced)

Dryland category	Areas (in million hectare)					
	Africa	Asia	Australia	Europe	N.America	S.America
Hyper-arid	672	277	0	0	3	26
Arid	504	626	303	11	82	45
Semi-arid	514	693	309	105	419	265
Dry sub-humid	269	353	51	184	232	207
Total dryland	1,959	1,949	663	300	736	543
Total land area	3,022	4,461	768	1,040	2,423	1,781

Table 2. Distribution of the drylands by continent

3. Geographical Distribution of Drylands

Drylands occur under a wide range of temperature and precipitation regimes. At the most generic level arid conditions are created by the interaction between global atmospheric circulation patterns, the distribution of land and sea and local topography. The air that is heated at the equator rises and cools, loses its moisture in the tropical belt, subsides towards subtropical latitudes 30°N and 30°S and heats up, creating two subtropical high pressure belts from which trade winds blow hot and dry air back towards the equator.

Where the trade winds blow overland, they are responsible for the major desert belts and arid fringes of the world. To this category belong: the Sahara, the Arabian and Iranian deserts in the Middle East, the Turkestan desert in Central Asia, the Namib and Kalahari deserts in southern Africa, the Australian desert and the Atacama-Peruvian desert in South America. On the other hand, where the trade winds blow onshore, such as on the east coasts of Africa, South America and Australia, they bring moisture and preclude the existence of arid conditions. Other arid zones, such as the Gobi and Takla Makan in Central Asia, are created simply by their central position within a huge landmass, which isolates them from oceanic sources of moisture.

Outside the subtropical belt extensive arid belts may occur within the high latitudes as a result of rain-shadow effects. They are typically located on the leeward side of major topographical barriers. This is the case for the North American and Patagonian deserts which are in the rain shadows respectively of the Sierra Nevada and the Andes.

The drylands are unevenly distributed across countries. Given the physical principles that govern the occurrence of aridity, countries in subtropical belts are more prone to arid conditions. However, there is no simple way to classify countries into either humid or arid groups. As Table 3 indicates, ‘dryland’ countries are usually composed of areas with different degrees of aridity. This has important implications for economic development. In countries where a complementary mix of different climatic zones exists, a higher diversity of agricultural production systems is possible, which could compensate for the physical constraints related to aridity elsewhere. However, in countries where arid zones dominate, the contribution of agriculture to the national economy is by necessity limited.

Continent	**Country**	**Degree of aridity**				
		HA	**A**	**SA**	**SH**	**H**
N. America	Mexico		in	as	do	as
	USA	in	in	as	as	do
S. America	Argentina		as	as	as	as
	Bolivia		in	in	in	do
	Chile	as	as	in	in	as
	Colombia				in	in
	Ecuador			in	in	do
	Paraguay			in	as	do
	Peru	in	in	in	as	do
Africa	Algeria	do	as	as		in
	Angola		in	in	as	do
	Botswana			do		
	Chad	as	as	as	as	in
	Egypt	do	in			
	Eritrea	as	do	as		
	Ethiopia		as	as	as	as
	Kenya		as	as	as	as
	Libya	do	as	in		in
	Mali	as	as	as	as	in
	Mauritania	as	as	in		
	Morocco		as	as	in	in

	Namibia	as	as	do		
	Niger	as	as	as		
	S. Africa		as	as	as	as
	Somalia	in	do	as		
	Sudan	as	as	as	as	as
	Tunisia		do	as		in
Asia	Afghanistan		as	as	as	in
	Azerbaijan		do	as		
	Bahrain		do			
	China	as	as	as	as	as
	India		in	as	as	as
	Iran	in	do	as	as	in
	Iraq		do	as	as	
	Israel	as	as	as		
	Jordan	in	do	in		
	Kazakhstan		as	as	in	
	Kyrgyzstan			as	as	as
	Kuwait		do			
	Lebanon			do		
	Momgolia	as	as	do	as	
	Oman	as	do	in		
	Pakistan		as	do	in	in
	Qatar	as	do			
	S. Arabia	as	as	in		
	Syria		as	as	in	
	Tadjikistan		as	as	do	as
	UAE	do	as			
	Uzbekhistan		do	in	in	
	Yemen	in	do	as		
Oceania	Australia		do	as	as	as

Table 3. Countries with drylands

Explanatory notes:
(a) Degree of aridity: HA: hyper-arid; A: arid; SA: semi-arid; SH: semi-humid; H: humid
(b) The symbols used refer to relative importance within the country: in : inclusion (< 5% of country); as: associated (at least 5-10% of country); do: dominant (> 50% of country)

In terms of population characteristics the dryland countries are a very heterogeneous group. Noin and Clarke (1998) reckon that in the twenty most arid countries of the world total population has multiplied more than six times since the beginning of the twentieth century. They also estimate that the contribution of these countries to the world population is expected to increase from a base of 4.3% in 1900 to 11.5% in 2025.

4. Agro-ecological Diversity and Vulnerability

Climate is the first determinant of agro-ecological diversity in drylands. Already through the simple combination of aridity and temperature regimes, 44 different agro-climatic zones were differentiated world-wide (see above). Rainfall distribution is also a major determinant. Winter precipitation is more effective in building up a reliable moisture supply for plants than summer rainfall. For this reason, the same crop that grows well under a winter rainfall regime of 300 mm may easily require the double amount under summer rainfall.

Within this heterogeneous climatic setting, the drylands exhibit a tremendous diversity in landscapes, soil, geological substrata, surface water and groundwater resources. Topography plays a major role in modifying the moisture supply, not only by trapping rainfall or attracting occult precipitation, but also by lowering the rate of evaporation at higher altitude. The ‘soilscape’ (landform-soil complex) is an important determinant of land use potential by its control over runoff and infiltration. Different landforms, lithologies, sparsity of vegetation, and regional tectonics combined with the differential resistance of the parent rock to stress and shear, create wide differences in the properties of land to generate runoff and to accept and store groundwater.

Agro-ecological niches constitute another source of dryland diversity. These are areas where natural conditions and production systems are quite different from outside. Examples of extensive natural agro-ecological niches with more humid conditions from those around include the large river floodplains of North and West Africa (Nile, Niger) and the semi-arid mountain ranges of the Sahara and the Arabian Peninsula (Hoggar, Tibesti, Yemen and Asir Highlands). At meso-and micro-scale oases are typical examples of highly productive areas owing to a reliable but highly site-specific water supply from springs. Irrigation development is the single most important factor in creating artificial agro-ecological niches in the drylands.

Drylands are commonly perceived as fragile ecosystems that are highly susceptible to degradation and desertification. The rapid population increases in the arid zone countries have certainly intensified existing environmental pressures on marginal soils, steep lands and other fragile environments, with growing threats to the natural resource base and biological diversity. Nevertheless, it has to be recognized that there is a lot of confusion about the true vulnerability of the dryland ecosystems and the irreversibility of any degradation trends.

One reason for the confusion is that within the drylands natural processes occur that, in the absence of benchmarks and monitoring systems, can be easily confused with land degradation. The first process is primary salinization. Salinity often occurs in natural soil types due to their lithological inheritance (e.g. marine deposits), or a topographical position that favours seepage of laterally moving groundwater, subsequent evaporation and salt deposition. In many arid regions lower foot-slopes are favoured landscape positions for saline seepages.

Wind erosion is another natural process in arid regions. The detachment, removal, and subsequent deposition elsewhere of soil particles is a function of wind force, lack of vegetation cover, shelter-exposure effect of different landscape positions, and susceptibility of soils to detachment. The latter is inversely related to the silt and clay content. For this reason dust storms and sand drift have always been characteristic of the sandier parts of the arid zones.

Even water erosion, as expressed by rills and gullies, can be surprisingly severe in the drylands. The limited vegetation cover and associated low biological activity cannot protect the soils from rainfall impact; they can produce relatively large runoff volumes in relation to the absolute rainfall amounts. Soils rich in silt, such as loess or derived from volcanic ash, marls, and fine-grained intrusive or metamorphic rocks, are particularly vulnerable to water erosion.

A contentious issue, particularly in the context of desertification research, is the distinction between ephemeral and permanent changes. Dryland ecosystems have their own dynamics and respond strongly to variability in the moisture supply, as affected by either drought or decadal-scale rainfall cycles. Climatic perturbations, fire and animal pressure can all be viewed as natural features of dryland ecosystems. Therefore, knowing that even in undamaged dryland areas considerable fluctuations may occur in biomass and the size and composition of plant and animal populations, Lewin (1986) has considered that dryland ecosystems can be seen with some justification as robust and resilient rather than fragile.

The natural processes described above have been dramatically accelerated by human intervention. The most widespread expression of degradation is in the degeneration of the vegetation cover. Major parts of the dryland range vegetation, particularly in North Africa and the Near East, have been significantly degraded in quantity and quality. Vegetation destruction takes place by overgrazing and fuel-wood collection, both activities being driven by the needs of growing populations. A less visible form of vegetation degradation is in the change of the plant species composition of rangeland ecosystems. The balance between perennials and annuals is often disturbed, which could be detrimental for the ability of dryland ranges to hold soil and water, or the ecosystem becomes dominated by a few unpalatable species.

Continuous cultivation of steppe areas rapidly exhausts the limited stock of organic matter, which glues the topsoil. Under conditions of low moisture, low organic matter and rapid oxidation of humus, soil structure deteriorates more rapidly, particularly under continuous annual cropping using disc and moldboard ploughs. Under these conditions the topsoil becomes denser, less aerated and less pervious to rain and plant roots. At the same time, splash erosion causes crust formation and the capping of the topsoil, sealing the surface and resulting in higher runoff and erosion. The Dust Bowl of the American Mid-West, which caused damage by wind erosion to 2.8 million hectare of farmland, has been blamed by Thomas and Middleton (1994) on a combination of drought and inappropriate dryland cropping practices. Similarly, Hinman and Hinman (1992) have described soil erosion in the early 1980s as a major cause for the abandonment of 0.5 to 1.5 million hectares of cropland in the former Soviet Union.

The availability of cheap pumps and lack of regulation of groundwater abstraction, have allowed many farmers in the drylands to expand irrigation. In most cases this has led to rapid aquifer depletion, often accompanied by deterioration of water quality following seawater intrusion, the pumping of deeper saline water to the surface and the contamination of shallow aquifers with more saline water. Overuse of irrigation water and the associated problems of waterlogging and salinization have been particularly acute in the Middle East and Central Asia. Hinman and Hinman (1992) have shown that the irrigated drylands of the Americas had to cope with the same challenges.

-
-
-

Bibliography

De Pauw, E. (1982). The concept of dependable growing period and its modelling as a tool for land evaluation and agricultural planning in the wet and dry tropics. Pédologie,1982(3): 329-348 [This paper highlights how the available growing period on which farmers can rely is degraded by rainfall variability and influenced by the soil moisture storage capacity].

De Pauw, E., W. Goebel, and H. Adam (2000). Agrometeorological aspects of agriculture and forestry in the arid zones. Agricultural and Forest Meteorology 2793 (2000) 1-16. [This paper highlights the natural diversity and vulnerability of agro-ecosystems in the arid zones, the rapid changes in their production systems, and the needs for agro-meteorological research].

Dixon, J., A. Gulliver and D. Gibbon. (2001). Farming Systems and Poverty. FAO and World Bank, Rome and Washington D.C., 412 pp. ISBN 92-5-104627-1. [This book describes more than 70 major farming systems of the developing world with particular emphasis on the strategies, challenges and likely opportunities in each system to escape from poverty and hunger].

Draz, Omar (1978). Revival of the hema system of range reserves as a basis for the Syrian range development program. Pages 100–103. In: Hyder, D.N. (ed.), Proceedings of the first International Rangeland Congress. Society for Range Management, Denver, Colorado. [This paper summarizes earlier and less accessible technical reports prepared for the Food and Agriculture Organization of the United Nations].

FAO (1997). Irrigation in the Near East region in figures. Water report 9, 281 pp, FAO, Rome. [This report presents comprehensive profiles for the countries of the Near East region in respect of water resources and use and irrigation trends].

FAOSTAT (1999). Statistical Databases of the Food and Agriculture Organization of the United Nations. URL: http://apps.fao.org [On-line database of FAO with statistics related to agricultural production in all countries of the world going back to 1961].

Hall, M. and Dixon J. (1988). Transfer and application of today's knowledge to dryland farming. In: P.W. Unger, W.R. Jordan, T.V. Sneed, and R.W. Jensen (eds.) Proceedings of the International Conference on Dryland Farming, August 15-19, 1988, Amarillo/Bushland, Texas, USA, pp.18-24. [This key paper presented in a major conference on dryland agriculture points out the risks involved in applying standard dryland technologies and practices in development projects that focus on physical environments and technologies rather than on people's welfare. The paper advocates a systems approach, that offers technological solutions matching household and community aspirations and local knowledge].

Hinman, C.W. and Hinman J.W. (1992). The plight and promise of arid land agriculture. Columbia University Press, 253 pp., ISBN 0-231-06612-0. [This book describes the various causes of problems in the arid lands of the world, their current status, as well as guidance for improved land and water use, and excellent descriptions of alternative new crops for arid regions].

Lewin, R. (1986). In ecology, change brings stability. Science 234: 1071-1073. [This paper shows evidence from ecological studies which indicates that dryland ecosystems commonly experience dramatic changes in character and biomass in response to natural climatic fluctuations, fire and animal pressure, and that such changes are often reversible and evidence of robustness rather than vulnerability].

Loomis, R.S. and Connor D.J. (1992). Crop ecology: productivity and management in agricultural systems. Cambridge University Press. 552 pp. ISBN 0-521-38776-0. [This book focuses on the processes that produce crops and pastures, photosynthesis and use of water and nutrients in fields. It is unique in its combination of production processes at the level of single plants and systems].

Meigs, P. (1953). World distribution of arid and semi-arid homoclimates. In: Reviews of research on arid zone hydrology, Paris, United Nations Educational, Scientific, and Cultural Organization, Arid Zone Programme-1, p. 203-209. [This paper is the basis for the first version of the UNESCO classification of drylands].

Noin, D. and Clarke J.I. (1998). Population and environment in arid regions of the world. In: J. Clarke and D. Noin. Population and Environment in arid regions. Man and the Biosphere Series, Volume 119, pp.1-18. [This paper presents a uniquely deep perspective on the inter-relationship between desert peoples and their environment. It covers issues such as human causes of desertification, environmental problems of living in arid regions, population dynamics, arid zone management and policies].

Nordblom, T. and Shomo, F. (1995). Food and feed prospects to 2020 in the West Asia/North Africa Region. ICARDA, Social Science Papers 2, 56 pp. [This paper shows in hard figures how livestock systems in the Middle East have an increasing need for imported feed to supplement a decreasing range feeding capability].

Papendick R.I, and Campbell G.S. (1988). Concepts and management strategies for water conservation in dryland farming. In: P.W. Unger, W.R. Jordan, T.V. Sneed, and R.W. Jensen (Eds.) (1988). Proceedings of the International Conference on Dryland Farming, August 15-19, 1988, Amarillo/Bushland, Texas, USA, pp. 119-127. [This key paper presented in a major conference on dryland agriculture summarizes major technologies for reducing water loss, such as methods to reduce within-field runoff, to suppress evaporation and control weeds, as well as water conservation systems, such as improved fallow and water harvesting].

Postel, S. (1999). Pillar of Sand: can the irrigation miracle last? New York and London: Worldwatch/W.W. Norton, 313 pp. [This book highlights the high reliance of global agriculture on irrigation and the outlook for sustainable production increases in the context of technological innovations, irrigation management systems, silting of reservoirs, salinization, and the potential impact of climate change].

Ruthenberg, H. (1990). Farming systems in the Tropics. Clarendon Press, Oxford, UK, 424 pp. ISBN 0-19-859482-8. [This book describes, through very lucid summaries and ample case studies, tropical and to some extent subtropical farming systems and is one of the main references on the subject matter].

Stewart, B.A. (1988). Dryland farming: the North American experience. In: P.W. Unger, W.R. Jordan, T.V. Sneed, and R.W. Jensen [eds.]. Proceedings of the International Conference on Dryland Farming, August 15-19, 1988, Amarillo/Bushland, Texas, USA, pp. 54-59. [This key paper presented in a major international conference on dryland agriculture sums up the experience in applying major practices of water conservation in North American dryland areas, with emphasis on summer fallowing, stubble-mulch tillage and conservation tillage].

Thomas, D.S.G. and Middleton N.J. (1994). Desertification: exploding the myth. John Wiley and Sons, Chichester. 194 pp. ISBN 0-471-94815-2. [This book argues that the desertification issue has risen to its current prominence to some extent on the basis of scientific facts, but probably more from political and social pressures, and uses new research findings to demonstrate that this high-profile problem is much smaller than previously accepted].

Tucker, B.B. (1988). Soil fertility assessment and management strategies in dryland systems. In: P.W. Unger, W.R. Jordan, T.V. Sneed, and R.W. Jensen [eds.]. Proceedings of the International Conference on Dryland Farming, August 15-19, 1988, Amarillo/Bushland, Texas, USA, pp. 361-366. [This key paper presented in a major conference on dryland agriculture outlines dryland strategies practices and challenges for the application of nitrogen, phosphorus, potassium and other nutrients].

UNEP (1991). Status of desertification and implementation of the United Nations plan of action to combat desertification. UNEP, Nairobi, Kenya. On-line document: http://www.na.unep.net/des/uncedtoc.php3 [The official UN document declaring desertification an environmental issue of global concern, requiring further research, and calling for action plans at national and regional level for preventive, corrective or rehabilitation measures depending on the state of degradation].

UNESCO (1979). Map of the world distribution of arid regions. Map at scale 1:25,000,000 with explanatory note. UNESCO, Paris, 54 pp. ISBN 92-3-101484-6. [The official printed map, which in some respects, e.g. the good spatial representation of mountains and highlands, is still superior to later updates].

Wood S., Sebastian K. and Scherr S.J. (2000). Pilot analysis of global ecosystems: agro-ecosystems. International Food Policy Research Institute and World Resources Institute. URL: http//www.ifpri.org. [This study assesses the condition of the world's agro-ecosystems through indicators that represent their adequacy to deliver services such as food, feed and fibre; water services, biodiversity, and carbon storage. It also assesses pressures on and the current state of the underlying natural resource base].

Biographical Sketch

Dr. Eddy De Pauw is a citizen of Belgium, where he was born in 1948 in Ghent. He holds M.Sc. degrees in Geology, Soil Science and Development Cooperation from the University of Ghent, as well as a Ph.D. in Soil Science from the same University. Since 1996 he has been Research Project Manager and agroclimatologist at the International Center for Agricultural Research in the Dry Areas (ICARDA), Aleppo, Syria, where he leads the Agroecological Characterization Project and the GIS unit.

In this position and as former staff member of the Food and Agriculture Organization of the United Nations (FAO) and the International Board for Soil Research and Management (IBSRAM), he has lived and worked for 25 years in Africa and Asia. His research interests include land evaluation, drought monitoring, land degradation, and GIS.