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Global Assessment of Land Quality

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ABSTRACT

Land quality is the ability of land to perform specific functions. We were interested in assessing the world's land resources with respect to sustaining grain production without becoming degraded. Two databases were critical for this purpose. First, the digital 1:5,000,000 FAO-UNESCO Soil Map of the World, converted to Soil Taxonomy. And, second, a global climatic database comprised of records for about 25,000 stations, which allowed computation of soil moisture and temperature regimes. Based on this information, the soil map units were placed in one of nine land quality classes, with Class I having the most favorable and Class IX the least desirable attributes. A GIS based spatial analysis revealed the following global extent of soil quality classes, as percentages of the 130,576,900 km^2 of ice-free land of the world: Class I, 3.2%; Class II, 5.0%; Class III, 4.5%; Class IV, 3.9%; Class V, 16.3%; Class VI, 13.2%; Class VII, 8.9%; Class VIII, 28.3%; and Class IX, 16.7%. Class I , II and III land occupies only a small fraction of the global land surface (16.5 million km^2, 12.7%). These lands are generally free of constraints for most agricultural uses. Class IV, V, and VI land occupies a significant part of the earth's land surface (43.8 million km^2, 33.4%). The soils of these areas require considerable management inputs and conservation practices. The large area of land in Class VII, VIII and IX (70.4 million km^2, 53.9%), which includes the desert and the tundra regions, is either too dry, too wet, too cold, or too steep and thus unsuited for sustainable grain production.

INTRODUCTION

The decline, in both quality and quantity, of the world's land resources has long been recognized and promulgated by individuals and organizations such as the World Watch Institute. It was the United Nations Conference on Environment and Development (UNCED), held in Rio de Janeiro in June 1992, which brought the issue into sharper focus and moved it into the political arena. The delegates of the conference adopted Agenda 21 as their program of action for the next century. In paragraph 5.23 of this lengthy document, the delegates recommended "assessment....of sustainable development, and special attention should be given to critical resources, such as water and land, and environmental factors, such as ecosystem health and biodiversity" (UNCED, 1993). Yet, meaningful efforts to implement this recommendation have, so far, failed to materialize and the prospects for concerted action are not encouraging. This likely was one of the underlying reasons for a recent international conference that posed the question, "Land Resources: On the edge of the Malthusian precipice?" The conclusions of this conference and related developments make it obvious that sustainable land management is no longer an option but an imperative.

We believe that a useful point of departure for confronting the problem is to establish the current state of the world's land resources. In this paper, we present a global assessment of the geography and quality of the world's land that is based on the best available soil and climate data. Our intent is to create further awareness of the precarious situation of this nonrenewable resource and to provide information that should facilitate the development of global strategies for land conservation and rehabilitation.

LAND QUALITY

Land quality may be defined as the ability of the land to perform specific functions without becoming degraded. It should be noted that this definition contains an element of time as it implies the sustainability of performance functions. This is a marked departure from previous definitions, which consider land quality as a static attribute. For more information on this subject, the reader is referred to the comprehensive and well-documented article on the parallel concept of soil quality by Karlen et al. (1997).

Among the numerous functions that land must perform are to produce food and fiber, maintain or enhance water quality, support human habitation, partition water flow, and sequester carbon. For the purpose of the present study, we selected the function of the land to sustain grain production, which presumes that the land responds positively to cultural practices conducive to sustainable land management. We chose grain production because it is a decisive factor that controls food security, which is emerging as a major geopolitical issue.

Table 1. Matrix defining land quality classes.

SOIL PERFORMANCE	SOIL RESILIENCE		
	LOW	MEDIUM	HIGH
LOW	IX	VIII	VI
MEDIUM	VII	V	III
HIGH	IV	II	I

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Table 2. Major land resource stresses or conditions, listed in order of severity.

STRESS CLASS	LAND QUALITY CLASS	MAJOR LAND STRESS FACTOR	CRITERIA FOR ASSIGNING STRESS
25	IX	Extended periods of moisture stress	Aridic SMR, rocky land, dunes
24	**VIII**	Extended periods of low temperatures	Gelisols
23	VIII	Steeplands	Slopes greater than 32%
22	VII	Shallow soils	Lithic subgroups, root restricting layers < 25 cm
21	VII	Salinity/alkalinity	"Salic, halic, natric" categories;
20	**VII**	High organic matter	Histosols
19	VI	Low water holding capacity	Sandy, gravelly, and skeletal families
18	VI	Low moisture and nutrient status	Spodosols, ferritic, sesquic & oxidic families, aridic subgroups
17	VI	Acid sulfate conditions	"Sulf" great groups and subgroups
16	VI	High P, N, organic compounds retention	Anionic subgroups, acric great groups, oxidic, families
15	VI	Low nutrient holding capacity	Loamy families of Ultisols, Oxisols.
14	V	Excessive nutrient leaching	Soils with udic, perudic SMR, but lacking mollic, umbric, or argillic epipedon (HARI – CORRECT?)
13	V	Calcareous, gypseous conditions	With calcic, petrocalcic, gypsic, petrogypsic horizons; carbonatic and gypsic families; exclude Mollisols and Alfisols
12	V	High aluminum	pH <4.5 within 25 cm and Al saturation > 60%
11	V	Seasonal moisture stress	Ustic or Xeric suborders but lacking mollic or umbric epipedon, argillic or kandic horizon; exclude Vertisols
10	IV	Impeded drainage	Aquic suborders, 'gloss' great groups
9	IV	High anion exchange capacity	Andisols
8	IV	Low structural stability and/or crusting	Loamy soils and Entisols except Fluvents
7	III	Short growing season due to low temperatures	Cryic or frigid STR
6	III	Minor root restricting layers	Soils with plinthite, fragipan, duripan, densipan, petroferric contact, placic, < 100 cm
5	III	Seasonally excess water	Recent terraces, aquic subgroups
4	II	High temperatures	Isohyperthermic and isomegathermic STR excluding Mollisols and Alfisols
3	II	Low organic matter	With ochric epipedon
2	II	High shrink/swell potential	Vertisols, vertic subgroups
1	I	Few constraints	Other soils

LAND QUALITY CLASSES

The principal determinants of land quality for grain production are soil performance and soil resilience. If three levels (high, medium, low) of the two parameters are considered, a conceptual matrix resulting in nine classes can be established that reflect the possible combinations of soil resilience and soil performance (Table 1). Class I has the most favorable and Class IX the least desirable attributes for grain production. To attain some degree of objectivity in placing land in a certain quality class, we developed a list of 24 stress conditions (Table 2). These stress factors, which are based mainly on Soil Taxonomy criteria (Soil Survey Staff, 1998) and can thus be inferred from soil maps, are arranged in priority order (Table 3).

The remediation of the each of the 24 stresses requires a different level of financial investment, and the possibility to correct a stress with minimal cost has been an over-riding consideration in prioritizing the classes (Table 2). For sustainable land management, it is essential that the kind of stresses and the inputs required for their correction and maintenance are understood.

Although we consider land degradation to be a major cause of declining land quality, we felt obliged to ignore this factor in our assessment as there is no reliable information available regarding the pace, scale, and geography of global land degradation, other than the rather qualitative study by the International Soil Reference and Information Center (Oldeman et al., 1991). Our appraisal of land quality thus represents the inherent quality of land before human interference or natural processes affected it.

Table 3. Properties of the inherent land quality classes, obtained by a combination of the performance and resilience attributes of soils in the context of their inherent stresses.

Land Quality Class	PROPERTIES
I	This is prime land. Soils are highly productive, with few management-related constraints. Soil temperature and moisture conditions are ideal for annual crops. Soil management consists largely of sensible conservation practices to minimize erosion, appropriate fertilization, and use of best available plant materials. Risk for sustainable grain crop production is generally <20%.
II & III	The soils are good and have few problems for sustainable production. However and particularly for Class II soils, care must be taken to reduce degradation. The lower resilience characteristics of Class II soils make them more risky, particularly for low-input grain crop production. However, their productivity is generally very high and consequently, response to management is high. Conservation tillage is essential, buffer strips are generally required and fertilizer use must be carefully managed. Due to the relatively good terrain conditions, the land is suitable for national parks and biodiversity zones. Risk for sustainable grain crop production is generally 20–40% but risks can be reduced with good conservation practices.
IV, V, & VI	If there is a choice, these soils must not be used for grain crop production, particularly soils belonging to Class IV. All three classes require important inputs of conservation management. In fact, no grain crop production must be contemplated in the absence of a good conservation plan. Lack of plant nutrients is a major constraint and so a good fertilizer use plan must be adopted. Soil degradation must be continuously monitored. Productivity is not high and so low-input farmers must receive considerable support to manage these soils or be discouraged from using them. Land can be set aside for national parks or as biodiversity zones. In the semi-arid areas, they can be managed for range. Risk for sustainable grain crop production is 40–60%.
VII	These soils may only be used for grain crop production if there is a real pressure on land. They are definitely not suitable for low-input grain crop production; their low resilience makes them easily prone to degradation. They should be retained under natural forests or rangeland and some localized areas can be used for recreational purposes. As in Classes V & VI, biodiversity management is crucial in these areas. Risk for sustainable grain crop production is 60–80%.
VIII & IX	These are soils belonging to very fragile ecosystems or are very uneconomical to use for grain crop production. They should be retained under their natural state. Some areas may be used for recreational purposes but under very controlled conditions. In Class VIII, which is largely confined to the Tundra and Boreal areas, timber harvesting must be done very carefully with considerable attention to ecosystem damage. Class IX is mainly the deserts where biomass production is very low. Risk for sustainable grain crop production is >80%.

METHODOLOGY

Two databases provided the biophysical basis for our assessment: first, the Soil Map of the World at a scale of 1:5,000,000 produced by the United Nations Food and Agriculture Organization in cooperation with the United Nations Educational, Scientific and Cultural Organization, which is available in digital form (FAO, 1991); and, second, the climatic data recorded at about 25,000 weather stations from around the world. Employing a water-balance model (Newhall, 1972), the climatic data were used to compute the soil moisture and temperature regimes and construct a pedoclimatic map of the world. This map was superimposed on the FAO/UNESCO soil map. Together with information contained, by definition, in the classification of the FAO map units, the pedoclimatic data were used to convert the FAO map to suborders of Soil Taxonomy (Soil Survey Staff, 1998), resulting in the map presented in Figure 1.

Each soil map unit was evaluated relative to the 24 stress conditions (Table 2) in the fashion of a taxonomic key. If a unit failed to meet any of the 24 stress criteria, it was presumed to have no or few constraints and placed in land quality Class I. Multiple stresses were not considered, although it is recognized that these may be the rule rather than the exception. A country boundary overlay enabled a GIS computation of the area of the determined land quality classes for each country. The error for such a computation is estimated to be about 50 km^2. Population data for 1995 were taken from FAO statistics.

RESULTS

Determined from the GIS-based analysis, the land with the least constraints and therefore the highest potential for sustainable grain production (Class I, II and III) occupies only 16.5 million km^2 or 2.7% of the 130,576,900 km^2 of the world's ice-free land (Table 4, Fig.2). This prime agricultural land must be preserved for food production and the use of other land optimized in support of food security.

About one third (43.8 million km^2, 33.4%) of the global land resources are in Class IV, V, and VI. These lands are susceptible to degradation, and grain production requires substantial management inputs. More than half of the world land (70.4 million km^2, 53.9%) was placed in Class VII, VIII, and IX. These lands are either too cold, too wet, too shallow, too steep, or otherwise unsuited for sustainable grain production. Exploitation of the quarter of the world's land in fragile ecosystems will inevitably cause irreversible land degradation and permanent loss of biodiversity.

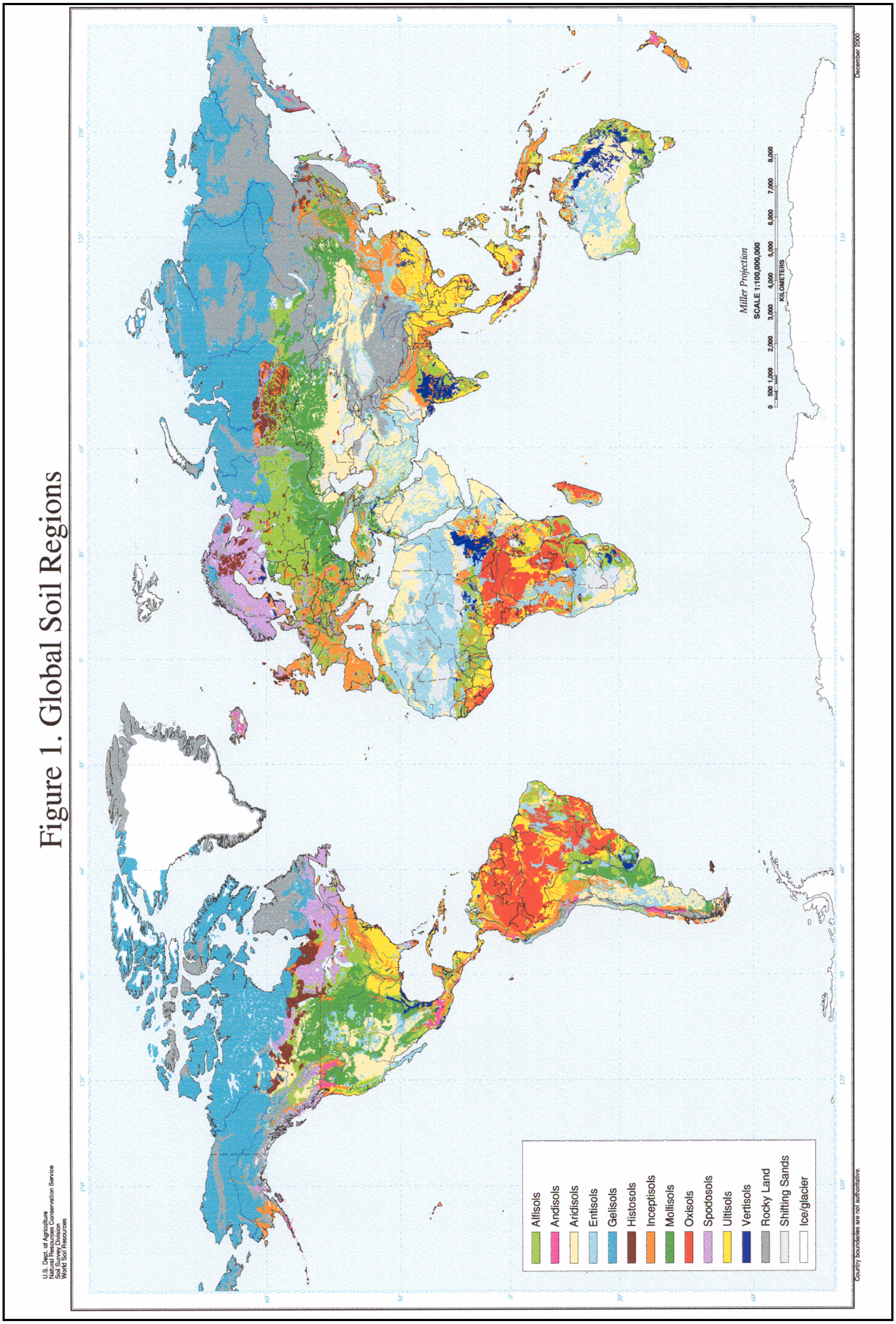

Figure 1. Global soil regions.

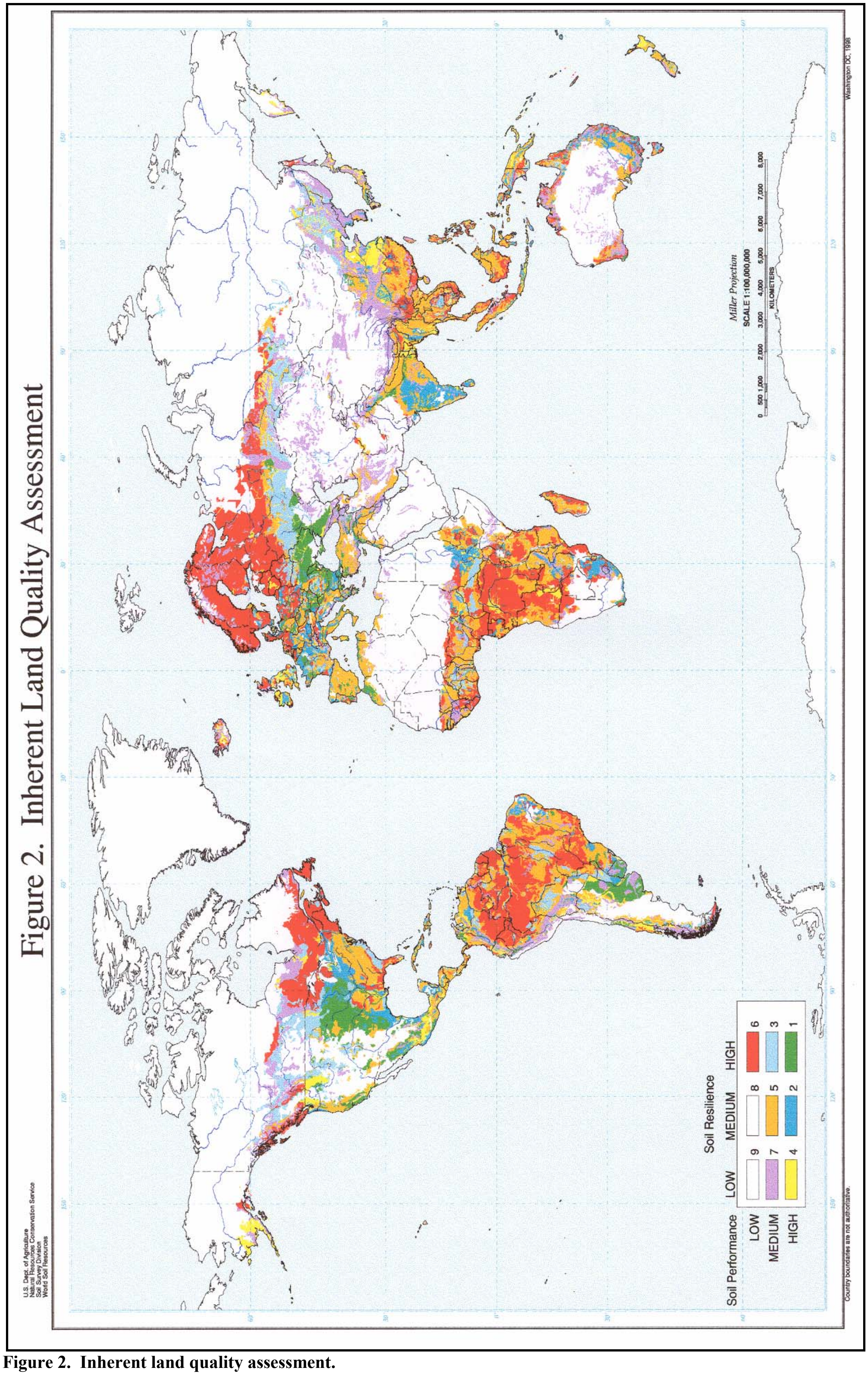

Figure 2. Inherent land quality assessment.

Table. 4. Estimate of population in designated land quality classes. Note: The global population density map is limited to latitudes 72°N to 57°S.

Land Quality Class (LQC)	Land area		Population	
	Million km^2	Percent	Millions	Percent
I	4.09	3.2	337	5.9
II	6.53	5.0	789	13.7
III	5.89	4.5	266	4.6
IV	5.11	3.9	654	11.4
V	21.35	16.3	1,651	28.8
VI	17.22	13.2	675	11.8
VII	11.65	8.9	639	11.1
VIII	36.96	28.3	103	1.8
IX	21.78	16.7	625	10.9
Global	130.6	100.0	5,759	100.0

The best agricultural soils (Class I, II, and III) are confined almost exclusively to the temperate zone (Fig.2). Class IV, V, and VI occur mainly in the inter-tropical areas. Class VII, VIII, and IX are in fragile ecosystems and include tundra and desert regions. Only a quarter of the world's population lives on land with a high potential for grain production (Table 4). Roughly half of the global population inhabits land with significant agricultural constraints, including long periods of soil moisture stress. And a quarter of the world's people must survive on lands that are considered unsuitable for grain production.

CONCLUSION

Policies and practices need to be developed that are conducive to sustainable land management. Part of this effort should include the development of monitoring techniques and early warning indicators of land degradation. The establishment of concerted internationally funded and implemented action programs in soil and land conservation, in analogy with, or under the umbrella of, the UN Convention to Combat Desertification should be explored.

The delegates at the conference on "Land Resources: On the edge of the Malthusian precipice" concluded that "If all resources are harnessed to minimize land degradation, sufficient food to feed the population in 2020 can be produced, and probably sufficient for a few billion more" (Greenland et al., 1998). This is a reassuring statement of principle and technical possibility. Realistically, however, the proviso makes the attainment of this goal doubtful. The statement nevertheless alludes to the urgent need to confront land degradation before irreversible deterioration renders it a losing battle.

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