Global Land Resources & Population Supporting Capacity

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Anticipated advances in biotechnology and sustainable land management in combination with the availability of high quality lands suggests a level of food production that will sustain twice the current global population. However, lack of political will, insufficient investments in modern agriculture, and a general apathy to the tenets of sustainable land management threaten food security in Third World countries and in some, contribute to poverty and famine. From a global land-productivity point of view the specter of Malthusian scenarios seems unwarranted. Sadly, however, local and regional food shortages are likely to continue to occur unless mechanisms for equitable food distribution, effective technical assistance and infusions of capital for infrastructure development are implemented in some developing countries.

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There are many debates concerning the quality and quantity of natural resources required for sustaining human life (Durning, 1989, Durham, 1992). Perceptions of an acceptable quality of life determine the range of opinions. The world population is currently about 6 billion people of which about 2 billion are malnourished and an equal number live below the poverty level. The latter two categories include socially or economically disadvantaged people who eke out a living from a plot of land that in many cases does not belong to them. As pressure for land increases, these land-less groups move to more fragile ecosystems, often permanently destroying them to survive (Stewart et al., 1990). This group of land users is not amenable to modern conservation practices or technologies, is not receptive to or is unable to practice sustainable technologies, and in general does not contribute to the food and fiber needs of society as a whole. In many countries, this group is comprised of the forgotten persons, ignored by the bureaucracy and disowned by the affluent of the nation. However, in their struggle to survive, their long-term impact on soil resources and environment in general may be so detrimental that in reality they may control the quality of life of a nation as a whole (Eswaran et al., 1995). Pimentel et al. (1994) posed the question, "Does human society want 10 to 15 billion humans living in poverty and malnourishment or 1 to 2 billion living with abundant resources and a quality environment?" This reflects the opinion of other supporters of the Malthusian concept (Ehrlich et al., 1993; Brown, 1994) and suggests that the limits of the land resource are being reached. We already have exceeded the second option three fold. Our question today is, how many more people can the earth's land resources support so that most persons can enjoy an acceptable quality of life?

There have been several assessments of the population supporting capacity of earth. According to Buringh (1989) between 11 to 12 % of the land surface is generally suitable for food and fiber production, 24 % is used for grazing, forests occupy about 31 % and the remaining 33 % has too many constraints for most uses. A more recent assessment by the Food and Agriculture Organization (FAO, 1995) provides similar estimates. Lal (1989) estimates that to sustain the human population at an acceptable level, about 0.5 ha of cropland per capita is needed. Others also have used per capita land as an index of sustainability, food security, or carrying capacity. Generally, total land area is used, and this results in erroneous or misleading conclusions. Per capita arable land is a better indicator, and the reciprocal of this number is an estimate of the carrying capacity. The index that is sought should reflect the ability of a unit of land to support a number of persons, and in this paper, the term carrying capacity is used in this sense.

The oft-repeated challenge is to find means to feed and clothe the population without degrading the land and water resources. A first step is to obtain a better estimate of the quality of land resources and the population supporting capacity of this resource base. In the absence of reliable national resource inventories for most countries of the world coupled with less information on the quality of the resource base, it is inevitable to use available information, such as global level data, to make regional or national assessments.

The impetus for this study resulted from the conclusion of a meeting (Greenland et al. 1998) on "Land Resources: On the Edge of the Malthusian Precipice?" The concluding report indicates that, "if all the resources are harnessed and adequate measures taken to minimize soil degradation, sufficient food to feed the population in 2020 can be produced, and probably sufficient for a few billion more." We decided to evaluate the quality of global land resources and attempt to estimate the population supporting capacity. Interaction with other resources or other aspects of human needs are not considered in this preliminary appraisal. Previous attempts to answer this question have been limited by the absence of reliable databases and spatial analysis technology such as Geographic Information Systems. The purpose of this paper is to make an assessment of population supporting capacity based only on land area stratified by productive potential. It should be considered as a first step in the process towards a better assessment that provides for land degradation, changes in dietary patterns, contributions of technology, and energy inputs in agriculture. The present analysis is based on better databases that have become available recently and hence, unlike previous estimates, is more science-based.

The Approach

Each country has land of differing capabilities determined by the quality of the soil and its performance under the prevailing climate. The Food and Agriculture Organization Database (FAO, 1997; WRI, 1997) provides country assessments on quantity of arable land and other indicators for national and global assessments. Until recently, databases that provide such information were not readily available or accessible in a digital format. The FAO/UNESCO Soil Map of the World (FAO, 1971-1981), which is now digitally available (FAO, 1991), provides for the first time a digital database of global soil resources. The authors compiled a global climate database, comprising data from about 25,000 stations, and, using a water-balance model, the soil moisture and temperature regimes were computed. Using GIS, the soil climate information was overlaid on the soil map.

The combination of soil and climate information was used to empirically assign the derived polygons (Wang et al., 1990) to one of 25 major land resource stress classes (details of the method will be published by Eswaran et al., 1999). Knowing the properties of the soils and the major stresses they experience, nine land quality classes are created using the matrix in Table 1. As management inputs are not considered, these reflect the inherent land quality. Table 2 explains the terms, and Table 3 elaborates on the 9 classes.

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

Table 2. Explanation of terms

Term	Explanation
LAND QUALITY	The ability of the land to perform its function of sustainable agriculture production and enable it to respond to sustainable land management. Class IX is the poorest and I is the class with the most desirable quality.
SOIL RESILIENCE	The ability of the land to revert to a near original production level after it is degraded, as by mismanagement. Land with low resilience is permanently damaged by degradation.
SOIL PERFORMANCE	The ability of the land to produce (as measured by yield of grain, or biomass) under moderate levels of inputs in the form of conservation technology, fertilizers, pest and disease control. Land with low performance is generally not suitable for agriculture.

Table 3. Properties of inherent land quality classes (Obtained by a combination of the performance and resilience attributes of soils)

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, particular 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 range and some localized areas can be used for recreational purposes. As in Class 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 IX, which is largely confined to the Boreal area, timber harvesting must be done very carefully with considerable attention to ecosystem damage. Class VIII is mainly the deserts. Risk for sustainable grain crop production is >80%.

This is a universal classification and several assumptions were made:

1. The assessment focuses on the inherent ability of the land to produce grain crops in a sustainable manner. With an emphasis on sustainability, fragile ecosystems, such as wetlands, the cold tundra zone, and deserts are excluded from the assessment.
2. The emphasis is on crop performance and response to management. Both are dependent on soil and climatic endowments. Thus a Mollisol in a humid temperate location is valued higher than its equivalent in the humid tropics.
3. Irrigation is not considered in this analysis. Globally about 17% of agriculture is under some form of irrigation. This includes irrigation of deserts as well as uplands in humid areas for rice production. The yield on these lands may be 4 to 8 fold higher than rain-fed agriculture. However, there is no spatial database that provides information on the location of irrigated land. Some advanced countries employ irrigation for high value crops while in many developing countries, such as Pakistan that has as much as 80% irrigated land, irrigation is largely for grain crop production.
4. Crops other than food crops are not considered. The acid soils of the tropics are good for rubber production but without high level of inputs, grain crop production is not sustainable. These countries sell the rubber and buy food from the food crop producing countries.
5. Productivity is a function of management, which varies among countries. For purposes of evaluating the response to management of the inherent land quality classes, the levels of input as defined in FAO (1976) are used.
6. Assessment of resilience is empirical, as there are few measurements of resilience available (Greenland and Szabolcs, 1994).
7. The need to maintain the integrity of the environment and to seek a rational balance between agricultural use and environmental management (Tinker, 1998) is an important consideration.
8. A general notion of risk is included. Though some values are given these are to indicate magnitudes rather than absolute numbers. The basis for this assessment is based on the concepts developed by Wetenschappelijke Raad regeringsbeleid (1994).

The Assessment

Some, such as Smil (1987), have argued that a country with less than 0.07 ha of arable land per person cannot feed its population in the absence of very intensive agriculture. This is equivalent to a population supporting capacity of about 14 persons per ha of land, which itself is perhaps an unrealistically high number. The energy inputs required to produce at this level would be excessively high for any meaningful output. There are countries, which have per capita land numerically close to 0.07, however, this does not imply that their agriculture is designed to support 14 or more persons. Nevertheless, the 0.07 ha estimate is now used by United Nations organizations as a threshold mark for evaluating the land’s carrying capacity.

From the global soil map and soil climate GIS information used in this study, about 38.5 million km^2 or 29.45% of the earth's ice-free land surface is too dry for sustainable human habitation (Beinroth et al., 1994). Advanced water and energy supply and irrigation techniques have enabled some use of these arid lands. About 20.2 million km^2 or (15.46%) of the land occur in the cold tundra zone, which are not easily amenable to normal agriculture. Most of these lands are included in the land quality Classes VIII and IX. There are other constraints, which prevent the use of soils for agriculture. Saline and alkaline soils, for example, occupy 3,105,000 km^2 or 2.4% of the land surface, and soil acidity affects 18,420,100 km^2 or 14.1% of the total land (Eswaran et al. 1997a). There are sloping lands, sandy soils, soils with low water and/or nutrient-holding capacity, soils with high organic matter (peats), etc. Some limitations are considered permanent or cannot be corrected by low to medium level inputs and in general, such soils are included in Classes VII, VIII, and IX. In the other classes, the limitations can normally be corrected; Class I land has the fewest number of constraints for agricultural use.

The global distribution of the tundra (Class IX) and the deserts (Class VIII) are shown in Figure 1. Many soils in desert regions are irrigated but these are considered unsustainable. The contiguous areas of prime lands (Class I) in the world are in the United States, Argentina, Uruguay, and southern Brazil. Large areas are also present in Europe and in northern China. In Africa, only South Africa has a significant amount of Class I land. By definition, such lands are absent in the tropics, which explains the general low productivity of tropical soils. Class II and III lands are extensive in the tropics and in the temperate areas. Most of these lands are under some form of agriculture and irrigated, when possible, in the semi-arid parts. A major part of Class IV, V, and VI lands, particularly the Class V lands are in the tropics. In the Amazon basin, Central Africa, and in South East Asia, these form the large tracts of forests. Land clearing and shifting cultivation is gradually invading these regions. Use of these lands for low-input agriculture promotes land degradation and even desertification. As is evident in the map, countries with large areas of Class IV or poorer quality lands have few alternatives but to exploit them. With medium and high input levels, they can be managed and are productive (Buol and Eswaran, 1994). From the point of view of ecosystem integrity there is an obligation for the more fortunate countries to help in the wise use of the fragile lands of the poorer countries.

Only a few countries implement science-based land use planning. The former Soviet countries and other centrally managed economies developed good land use systems, as exemplified by Albania. In Albania, the flat valley bottoms were reserved for agriculture, the lower hill-slopes for housing and infrastructure, and the steeper hilly terrain for forestry. The land productivity was low, however, due to absence of inputs or poor management. With democratization and removal of societal controls, misuse of land is now the rule. In the more liberal societies, economic forces (constrained to some extent by zonation laws and ownership rights) frequently drive land use, which results in haphazard development of land exploited for agriculture. In the developing countries of the latter group, land-less people have been forced to exploit fragile agro-ecosystems.

Mismanagement of land and misuse of fragile lands have prompted global inquiries on the extent of degraded land. Oldeman et al. (1991) suggest that about 17 % of the global land area is degraded by human interventions. The consequences of land degradation not only affect the performance of the land for food and fiber production but also have grave consequences for the environment including biodiversity. Another resource, not addressed in the present assessment is water, which is closely related to the production potential of land. Water constraints are already slowing food production in some countries of the world. The 2.4 million km^2 of global irrigated land have been largely responsible for meeting the food needs of the burgeoning population. Some countries, such as India and Pakistan, rely heavily on irrigated lands to meet a major part of their respective requirements. Also many countries have reached or are nearing the limits of the land that can be irrigated due to lack or scarcity of water, costs of infrastructure development, environmental concerns, and the rapid rates of salinization of irrigated lands.

The area of land in each Land Quality Class is given in table 4. Class I land only occupies about 3.1 % of the ice-free land surface. Together with Class II and III lands, the 12.6 % of land represent the total land area that is generally free of constraints for most agricultural uses. They are, however, unequally spread around the globe with a larger portion in the temperate countries of the world. Class I and II lands generally have good resilience, are highly productive, and benefit from conservation technologies that are directed to preserving the favorable attributes. Many countries have very small areas of either Class I or II lands, or have utilized all available I, II, and III lands and consequently have to use more inferior lands.

Table 4. Land area of each Land Quality Class. (Global land area: 130,575,894 km^2)

Land Quality Class	Area million (km^2)	Cumulative land area million (km^2)	% Global (Cumulative)
I	4.09	4.09	3.13
II	6.53	10.62	8.13
III	5.89	16.51	12.64
IV	5.11	21.62	15.56
V	21.35	42.97	32.91
VI	17.22	60.19	46.09
VII	11.65	71.84	55.02
VIII	36.96	108.8	83.32
IX	21.78	130.58	100.00

Class IV, V, and VI land occupy a significant part of the earth's surface (36.8 million km^2) and also support more than 50% of the world's population. In the tropics, such as in parts of Asia, these are also the lands that approach the threshold of 0.07 hectares per person per capita land. At low levels of input, though their performance is low, adequate supply is still possible, as there is a large area of such lands. However, degradation of the resource base will slowly reduce its capacity unless additional land management practices such as agroforestry (Sanchez et al., 1998) are introduced.

Because of population pressures and the desire to provide land for the land-less, countries consciously use poorer quality lands to achieve regional equity within the country. Where irrigation could be established, some Class VIII lands have been brought under agriculture, particularly in North Africa and the Near East. Actual land use is not estimated in this assessment. In fact, from a sustainable agriculture point of view, Classes IX, VIII, and VII are not recommended for agriculture, though small areas may currently be used. Table 4 also provides the cumulative percentages of land from Class I through VI. These percentages provide an estimate of the land as they are successively consumed.

Fischer and Heilig (1998) estimate that the available land area with some potential for rainfed crop cultivation is about 5.55 million km^2 in developing countries. They do not provide an estimate for global land area available for cultivation. In our estimate (Table 4) the total global land area suitable for cultivation is 60.2 million km^2. WRI (1997) estimates that about 49.77 million km^2 were under cultivation (or 'domesticated land' as they refer to) in 1995. This suggests that the amount of available land, globally, for future cultivation is only about 10 million km^2 some of which must be shared with forestry, wilderness and for urban use. Thus the amount of land available for agricultural use is expected to correspond to the estimate of Fischer and Heilig (1998).

Land has been and will continue to be used for purposes including forestry, recreation, and urban needs. Ideally, partitioning land for its multiple uses should be based on societal values and economic considerations. Table 5 is an empirical partitioning of land based on its quality and its potential uses. There is always strong competition for land for its multiple uses and usually economic factors determine the final land use. In societies with strong social commitments, the economic forces are frequently required to compromise or look for other options. In many parts of the world, Class I land is under siege and the rate of consumption for non-agricultural uses is very high. Globally, about 50% of Class I land may still be used for agriculture. Based on the amount of land used for grain crop production (Table 5), the population supporting capacity is discounted proportionately. The adjusted population supporting capacity is shown in Table 6. Class I and II lands together would be able to support about 9 billion persons.

The optimal population supporting capacity of each land quality class is shown in Table 6. The optimal proportions for each of the land use classes will vary with the country and determined by the socioeconomic demands. However, if environmental considerations and biodiversity, as expounded by Szaro and Johnston (1996) are emphasized, then one has to provide for these aspects of humanity. The values in Table 6 are empirically derived but based on expert judgement on the productivity of soils and other considerations. The idealized population supporting capacity for each land quality class in Table 6 is the best estimate at this time and is derived from estimates of per capita arable land and gross domestic product (GDP), using data cited by WRI (1997) and relating these to the general land quality. The per capita arable land is an estimate of intensity of land use and the per capita GDP was used as an estimate of levels of input. Countries were assigned to one of the three levels of inputs of FAO (1976) using a GDP of < $1,000 to indicate low levels of input, $1,000 to 10,000 a medium level and >$10,000 a high level of input. In the absence of land resource specific data, these proxies provide the basis for assessment. The quality of such an assessment becomes enhanced with better databases, which may not be forthcoming in the next few decades particularly in developing countries. The adjusted population supporting capacity is then calculated using the empirical proportions of agricultural lands in Table 5.

Table 5. Idealized land use pattern (percent of land)

Land Class	Agriculture (Grain crops)	Biodiversity Zones		Urban / industry / infrastructure
		Forestry	Wilderness	
I	70	20	5	5
II	60	30	5	5
III	50	35	10	5
IV	45	40	10	5
V	40	45	10	5
VI	30	50	15	5
VII	10	50	35	5
VIII	5	60	30	5
IX	5	30	60	5

Table 6. Idealized population supporting capacity (persons/hectare)

Level of Inputs	Land Quality Classes								
	I	II	III	IV	V	VI	VII	VIII	IX
Low	4	3.5	3.0	2.0	1.5	1.0	0	0	0
Medium	6	5	4	3	2	1.5	0	0	0
High	10	9	8	7	6	5	0	0	0

Table 7 provides the final estimates. Land quality classes VII, VIII, and IX are excluded, as they are considered unsustainable to attempt to use these lands for grain crop production. Irrigation of deserts is also ignored in this study. Class I, II, and III lands together, would be able to support about 3.2 billion persons under a low-input scenario and about 4.6 billion persons under a medium-input scenario. Most of these lands are in the part of the world with a temperate climate. Land quality classes V and VI are the most extensive of the nine classes. They occupy large areas in the tropics but their contribution to the total population supporting capacity is low. Classes I to VI land cumulatively can support about 6.2 billion people, which is close to the current world population, under low-input technologies. With medium input technologies, this increases to about 8.7 billion persons. Uniform high-level technology input across the globe will not materialize in the next millenium. Thus, the realistic level is an intermediary situation between the medium- to high-level input in Table 7. This suggests that it would not be unrealistic to expect the global land resources of being able to support a population between 9 to 20 billion persons. There will be an adequate supply of grains to feed the 9 billion persons who will inhabit the earth in the year 2025; this does not imply that all will be fed.

Table 7. Population supporting capacity (in no. billion persons) of each Land Quality Class under low input agriculture. (Current global population: 6 billion persons).

Land Class	Low Level Input		Medium Level Input		High Level Input	
	Optimal population supporting capacity	Cumulative population supporting capacity	Optimal population supporting capacity	Cumulative population supporting capacity	Optimal population supporting capacity	Cumulative population supporting capacity
I	0.982	0.982	1.472	1.472	2.45	2.45
II	1.371	2.353	1.959	3.431	2.351	4.801
III	0.884	3.237	1.178	4.609	2.695	7.496
IV	0.460	3.697	0.689	5.298	1.610	9.106
V	1.601	5.298	2.135	7.433	6.405	15.511
VI	0.861	6.159	1.292	8.725	4.305	19.816

Other refinements can be made in this process of evaluating the population supporting capacity of global land resources. Degradation state and levels of technology in different countries were not considered in this assessment. Country level estimates, which will be made in a follow-up study, will include some aspects of these additional controls of population supporting capacity.

Discussion

Land is a limiting resource in many countries, particularly considering the fact that there are only about 5 million km^2 available for future sustainable land use. With time the situation will worsen due to soil degradation, which reduces the performance of the soil. Exponential growth of urban centers consumes large areas of prime land as the centers originally developed on lands that had potential to feed the community. Those countries, which have opted for large scale irrigation programs to complement their food producing capacity, are generally at risk due to salinization and or alkalization which slowly but surely accompany irrigation in arid and semiarid environments. In the drier countries of the world, supply of water may become a limiting factor before the inability of the land to produce is felt (Postel, 1989). Waterways traversing nations, or even states as in India, become sources for conflict when limits of the resource are reached. Further, the increasing requirements of non-agricultural water use will inflate prices, resulting in stringent irrigation policies that will be reflected in efficiencies of production. Inadequacies or inefficiencies of irrigation (World Bank/UNDP, 1990) continuously reduce the effective amount of land that can be used for food production.

The land resources provide about 96% of world food, and the remaining food comes from rivers, lakes, and seas (Pimental and Hall, 1989). For the global land resource to continue to produce and feed and clothe the population, using only the bare minimum of land for this purpose, a number of conditions must be in place:

- Research investments must contribute to new knowledge and more productive means of food production;
- Appropriate national and international policy environments must exist to enable access to food through a fair and equitable market system so that countries can capitalize on niches;
- An active program of assessment and monitoring of land degradation must be instituted to provide accurate and unbiased information;
- A proactive commitment to sustainability must be made, partly through wise land-use planning and implementation, to ensure biodiversity is maintained and environments are preserved and protected; and
- It must be recognized that the human carrying capacity of the land is not merely a national problem, but a global one, since it impacts every aspect of human society.

From a global land-productivity point of view the spectre of Malthusian scenarios seems unwarranted. Sadly, however, local and regional food shortages, particularly in Asia, are likely to continue to occur and the population succumb to Malthus' nightmare (Malthus, 1798) unless mechanisms for equitable food distribution, effective technical assistance and infusions of capital for research and infrastructure development are implemented (Swaminathan, 1986). The current trend of the globalization of the world economy and international agreements such as the Global Agreement on Trade and Tariff offer some hope that global food security can be achieved. This initial assessment, at least from the distribution of land resources, supports the earlier study of Eswaran et al. (1997b) that many countries in Africa have the potential to be food exporters if the systems are permitted to do so.

Conclusion

The conclusion of this study is that famine and starvation of people of some countries are not the result of the innate inability of global land resources to produce the necessary food but because of an absence of political will in most countries. In most cases, poverty, starvation, and famine are generally due to inadequate natural resource endowments and the lack of capital to mitigate these constraints. Endemic poverty or inability to feed the increasing population occurs mostly in those countries where the poor quality of land prevents even a subsistence form of agriculture. Knowing the ability of each country will help the development of appropriate strategic plans by both the countries themselves and also the global community. Such studies will also help countries develop land use plans that are environmentally sound and also enable international donors to mount a strategic program to ensure food security in all nations.

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