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Global Perspective of Arable Soils and Major Soil Associations

Darwin Anderson, University of Saskatchewan
Guy Lafond, Agriculture and Agri-Food Canada, Indian Head

Summary

Soil is, without question, critical to the world, supplying virtually all the food and fibre that sustain the human population, and providing ecosystem services that support life. The world's arable land at 1.35 billion hectares seems vast, but is only 0.20 hectare per person, not evenly distributed. Africa and Asia, for example, have 46% of the arable land and 71% of the population and a dominance of low quality land with weathered and infertile soils. The world's more developed countries in North America and Europe not only have more land per person, but higher quality land and more resources for soil conservation. Conservation is essential with all lands. Despite much progress with modern practices such as conservation tillage, the problem of land degradation is serious particularly in areas with fragile, low quality lands. The Prairies of western Canada are blessed with a huge area of arable soils mostly of good quality. Similar to the world, all soils require good management to remain productive over the long term. Ten million hectares of Prairie soils are considered at risk in terms of both environmental and economic sustainability and require a continuing conservation effort and improved fertilizer management to remain productive.

Introduction

Professor Dennis Greenland[8], a British soil scientist who has worked in both developed and developing countries, writes that virtually all life on earth depends on soil, and that it is essential to conserve our soils and increase their productivity. Many civilizations of the past ended because of a failure to control soil degradation. The focus of this paper is to discuss the global supply of land and the characteristics of the soil in relation to use in agriculture. Although the perspective is global, a regional discussion of land in the Prairies of western Canada is included.

Global Perspective of Arable Soils

In July 2009, the world population reached 6.790 billion and the global arable land area is estimated as 1.351 billion hectares (3.339 billion acres)[22]. This implies that arable land per capita on a global basis is 0.20 hectares per person (0.49 acres per person).

Asia has the largest share of global arable land (32%) followed by North America at 17% and Africa at 14% (Table 1). Africa and Asia together have 46% of total arable land, 71% of the global population and the lowest amount of arable land per capita. Every year, 0.3–0.8% of global arable land is rendered unsuitable for agricultural production due to soil degradation and wind and water erosion accounts for 84% of this degradation[3,4]. 45% of arable soils worldwide are now affected by some form of degradation[11].

Uncultivated native Canadian prairie soils contained from 0.2 to 0.7% nitrogen and by the 1940s, 15 to 40 percent of it had been lost[14]. This trend continued such that by the 1980s, most prairie soils had lost more than 40 percent of their initial organic nitrogen content. Another form of soil degradation is urbanization. In 2008, more than 50% of the world's population lives in urban areas[16]. In Canada, between 1971 and 2001, 1.2 million hectares of agricultural land was consumed for urban uses and 18% of Ontario's best Class 1 farmland is now urban[10].

Currently, soil erosion rates from conventionally plowed agricultural fields are 1-2 orders of magnitude greater than rates of soil production[15]. No-till production systems produce erosion rates that are much closer to soil production rates[15]. At the most recent World Congress on Conservation Agriculture (CA), CA was endorsed as the key step to meeting the long-term global demand for food and feed. CA is defined as a farming system that does away with regular plowing and tillage and promotes permanent soil cover and diversified crop rotations to ensure optimal soil health and productivity.

Land is important to food supply. One estimate is that 99% of food consumed by humans comes from the land[18]. Smil[19], perhaps using different data, estimates that 2% of food energy and 7% of food protein comes from the waters, the rest from soil. Regardless of the exact proportion, our future depends on our ability to sustain and enhance our soil resource.

Major Global Soil Associations

There are two systems of soil classification that deal with all the soils of the world. One, known as the World Reference Base for Soil Resources (WRB) has been developed by the Food and Agriculture Organization of the United Nations in cooperation with the International Union of Soil Sciences and The International Soil Reference and Information Centre (ISRIC) at Wageningen University, Netherlands. Further details about the WRB and links to several land-related web sites are available at http://www.fao.org/ag/agl/agll/wrb/.

The second system that deals with soils globally is Soil Taxonomy, the soil classification system developed over the past five decades by the United States Department of Agriculture, Natural Resources Conservation Service. The following discussion will be based on the classification and related soil maps that are based on Soil Taxonomy, partly because of stronger connections to soil classification in Canada, and partly because it is more familiar to the authors. The web site for Soil Taxonomy is http://soils.usda.gov/technical/classification/taxonomy/.

There are 12 orders in Soil Taxonomy; their general characteristics and areal extent globally are presented in Table 2. Almost 10% of the world's land surface has Gelisols and Histosols. They occur mainly at high latitudes, the former with permafrost, and the Histosols in peatlands, supporting just slightly less than 1% of the global population[1]. Canada has disproportionately large areas of the approximately equivalent Cryosolic and Organic order soils, only the latter used for agriculture and only to a small degree. These soils, however, contain a large proportion of the global soil carbon store as peat deposits or frozen within the permafrost. They are thought to be a present day sink for carbon dioxide, although a warming and drying of high latitude climates could result in the decomposition of the organic matter, exacerbating already increasing concentration of carbon dioxide in the atmosphere.

By contrast, three soil orders, Ultisols, Alfisols and Entisols occupy about 44% of the land surface and support 70% of the population[1]. These soils occur generally in areas with warm to temperate and moist climates and are reasonably well suited to agriculture. Many of the productive lands of southern Ontario and adjacent states, as well as much of Western Europe have Alfisol soils. North America, particularly the USA and Canada have a large proportion of arable soils globally (Table 1), and the soils are mainly productive Alfisols in once-forested eastern regions, and the productive and resilient Mollisol soils of the grasslands in the Great Plains and Prairies .

The soils of the grasslands include Mollisols and Vertisols. Mollisols, approximately equivalent to Chernozemic soils, occupy 6.9% of global land area and support 6.7% of the population globally. They are generally resilient and productive soils particularly when managed with conservation tillage as is occurring today[1]. The Mollisols of the Great Plains of North America are lands that support a very productive agriculture with a high proportion of the food (cereals, oilseeds, pulse crops and meat) exported. Interestingly, worldwide, Mollisols support a population density of 90 people per km^2 and still export food. Vertisols are productive soils that occupy only 2.4% of the global land area, and support 5.65% of the people, especially in the Sub-Tropics and Tropics. The Vertisolic soils of the Prairie region of Canada are well-suited to large scale, highly mechanized farming because of the level landscapes, good fertility and moisture storage capacity. In contrast, many of the Vertisols of the developing world are farmed with draft animals and simple ploughs, a much bigger challenge for the farmers.

The mostly Mollisol soils of the grasslands have not always been farmed in sustainable ways. The introduction of stronger and sharper ploughs led to the exploitation of the world's grassland soils starting in the 16^{th} to 19^{th} century, and continuing in Canada into the early 1900s[13]. The land in the Eurasian steppes, the North American grasslands, and the Pampas of South America had been used mainly for grazing until then. The breaking of the prairie sod resulted in the second great wave of erosion globally, as cultivation exposed the generally fertile soils to erosion, particularly wind erosion. There were disastrous consequences in the Great Plains, from Oklahoma to Saskatchewan. The desperation of the 1930s resulted in a huge government effort for better soil conservation, with the PFRA active in Canada, and the Soil Conservation Service in the USA. Despite improved land management practices such as stubble mulch tillage, strip cropping and shelterbelts, the situation remained uncertain until the widespread adoption of conservation tillage systems starting in the 1990s.

Agriculture has been practiced on Entisol (equivalent to Regosols in Canada) soils for thousands of years, especially on the alluvial plains and deltas such as those of the Nile and Mekong rivers. These are some of the first soils used for agriculture. Alluvial soils are periodically rejuvenated by the addition of fresh soil materials by flooding. On the negative side, many of these productive lands are just above the present sea level, making them at risk if sea level does rise with the melting of the Greenland and Antarctic ice sheets. According to the World Bank, a three-foot rise in sea level will cover half the rice fields in the Ganges Delta of Bangladesh, a country of nearly 160 million people. Such an increase would also inundate much of the Mekong Delta, which produces half the rice crop in Vietnam, the world's No. 2 rice exporter[2].

Andisol soils form on volcanic deposits and occur on many of the islands associated with areas of intense volcanic activity, such as the Pacific rim of fire. Andisols account for only 0.7% of global soils, but have the highest population density, at 106 persons per square kilometre, despite the uncertainty of living near a volcano. Both New Zealand and Japan have large areas of Andisols and productive agricultures.

Many of the upland soils of the sub-tropics and tropics are reddish colored, strongly weathered, acidic and infertile soils of the Ultisol and, especially, Oxisol orders. The large proportion of the world's arable land in Asia, Africa and South America (Table 1) does not present a complete picture of soil resources available for agriculture, in that the more weathered and generally less fertile Oxisols and Ultisols account for a high proportion of the arable land on those continents.

The Oxisol soils are mainly under tropical rain forest and have been used traditionally in shifting cultivation. Small fields are cleared and generally burned, with the ashes from the vegetation providing many of the nutrients required for growing crops for a few years, then the forest is allowed to grow back. This system worked reasonably well as long as population densities were low and the fallow periods long. The increase in population after 1945, and especially in the last two or three decades has resulted in a much more intensive use of the Oxisol and Ultisol soils, even those on steeply sloping land subject to horrendous erosion. This has been termed the third great wave of erosion[13]. Personal experience (Anderson) in the 1990s and in this decade, in Thailand, Vietnam and Ethiopia, has been observing desperate farmers moving ever further up the hillsides and mountains, clearing soils of marginal productivity and extreme susceptibility to erosion, with near disastrous consequences.

Soils of deserts are Aridisols[1] (an emphasis on 'arid'), and occupy 12% of the global land, supporting 5.5% of the population at a density of about 20 per km^2. The degradation of productive land to from deserts is known as desertification and is a threat worldwide, and especially in sub-Saharan Africa, where the frequency of droughts is increasing. Desert regions are often used for grazing, with herds moving long distances seasonally in search of grass. Productive agricultures in deserts regions are irrigated. The historical record of irrigation in dry regions is not good, with large areas of once productive land no longer productive because of salinity, water logging or loss of water. One of the great concerns today is the much-reduced flow of rivers fed by mountain glaciers, the main source of much of the water used for irrigation.

Land Quality Classes and Global Agriculture

Land quality classes are based on the land's capability to perform a particular function in relation to use. The function that is most important for human well-being is the production of food (mainly grain) and to respond to management practices conducive to sustainable land management. Land quality classes based on grain production may be used to evaluate global food production, now and into the future.

Only 2.4% of the land worldwide is considered Class I, or prime land with few management-related constraints and with soil temperature and moisture conditions ideal for annual crops[1]. These lands occur mainly in tropical regions, are used intensively for grain production, and produce 40% of global food and feed output. Land quality classes II and III account for 9.5% of global land resources, and have minor limitations to use. These lands occur mostly in temperate regions with moderate climates, and respond well to good management, with low to moderate risk of land degradation providing that conservation tillage is practiced and fertilizer use managed carefully. The management of fertilizer inputs is extremely. Industrially fixed nitrogen by the Haber-Bosch process accounts for 40% of the protein produced in agriculture, and supports a world population 40% larger than possible without N fertilizer[20]. Increased productivity must result as much from better management of fertilizer as from increased fertilizer applications. No-till farming systems have the potential to substantially enhance the sustainability of these lands, as discussed in detail both in terms of practices and areas of adoption in a Special Publication No.3 of the World Association of Soil and Water Conservation[6].

Classes IV, V and VI cover just over one-third of the world's land area, mainly in the tropics, supporting 54% of the world's people[1]. These lands have serious limitations for grain production, with a high risk of degradation unless appropriate conservation measures are adopted. Many of the soils are short of plant nutrients and fertilizers are essential. The Class IV, V and VI lands represent perhaps the biggest challenge for farmers, researchers and extension workers because high levels of production are needed, but within the context of serious difficulties, very substantial inputs such as fertilizers, and a high risk of land degradation. It is likely that these lands account for a high proportion of the 45% of arable land that are being degraded today[11].

Land quality Class VII accounts for 9% of the world's land, and include areas with shallow soils (often on steep slopes), soil salinity and peatlands that are not suitable for agriculture. Although most Canadians regard peatlands as northern ecosystems where peat builds up because of wet and cold environments, many peatlands occur in tropical regions, especially in Southeast Asia. An estimated 1.5 million hectares of peatlands have been drained and used for growing palm oil in Indonesia, resulting in the permanent loss of the ecological functions of peatlands and a huge emission of carbon dioxide to the atmosphere (http://www.wetlands.org). Class VII lands support 11.5% of the world's people, and are increasingly being used for farming as landless people are forced onto fragile and marginally productive soils in order to feed their families, as mentioned earlier.

Land quality classes VIII and IX together account for almost one-half of the world's land, which is disappointing from the perspective of food production. These lands have fragile soils that are not suitable for use in grain production, and should be retained in their natural state[1]. Class VIII includes the tundra and boreal ecosystems, many of them in Canada, and still important for many reasons, including their vast carbon store.

Canada is in many ways a scaled down version of the global land picture. Canada is a huge country, just under 10 million Km^2 in area, with only 8% used for and suitable for agriculture, about 6% in cropland and 2% in rangeland[5]. This may be difficult to believe while travelling the Trans-Canada Highway across the fertile Prairie Ecozone between Calgary and Winnipeg, but one becomes convinced gradually somewhere between Winnipeg and southern Ontario in the vast expanse of the Boreal Shield Ecozone. Just like it is globally, a relatively small proportion of the 67.5 million hectares of cropland is prime agricultural land (Canada Land Inventory Class 1). These lands are generally productive and resilient and in relatively mild climates. The major threat to many of these lands is loss to urban expansion, particularly in southern Ontario and the Lower Mainland of BC. Losses of prime land to urban uses are large for major urban areas, such as greater Toronto that will require an additional 900 km^2 as it expands from a 1986 population of 3.73 million to six million in 2021[7]. Even larger nationally is the expansion of Canada's many small urban areas often onto prime land.

Almost 80% of Canada's cropland occurs in the Prairie Provinces[12]. Of the 52 million hectares of farm land, 23 million hectares are cultivated and considered to be economically and environmentally sustainable with good management[17]

High quality arable lands are Rangeland and improved forages. They occupy a further 22 million hectares, considered to be a sustainable land use. Of greatest concern is the 4 to 6 million hectares in cropland where economic sustainability is questionable, and the 3 to 5 million hectares where both economic and environmental sustainability are problematic, mainly CLI capability classes 4, 5 and 6[17]. These ten million hectares of land in the Prairies require a focus on soil conservation in order to be sustainable. Conservation tillage has gone a long ways towards more sustainable land use[12], but other practices such as conversion to perennial crops (grass or trees) should be considered as well. These lands are in the rural Prairies and, unlike many areas of the developing world, are experiencing a population decline as farms become ever larger and transportation systems improve. One wonders if a larger population might be beneficial, in that small areas of fragile lands could receive special conservation measures such as shelterbelts, forage planting or wetland restoration, all with a potential to enhance both sustainability and biodiversity.

Considering the huge expanse of land in Canada that is not suitable for agriculture allows one to consider those other functions or ecosystem services that soil contributes to. Many of the lands support forests and supply wood and fibre to human society. Beyond that, there is the role of soils in the functioning of ecosystems, as listed by[21]. "(a) recycling of organic materials in soils to release nutrients for further synthesis into new organic materials; (b) partitioning of rainfall at the soil surface into runoff and infiltration; (c) maintaining habitat diversity of pore sizes, surfaces, and water and gas relative pressures; (d) maintaining habitat stability, including a stable structure, resistance to wind and water erosion, and buffering of habitat against rapid changes of temperature, moisture, and concentration of potentially toxic materials; (e) storage and gradual release of nutrients and water; and (f) the partitioning of energy at the surface, which is important in global circulation processes." A thorough discussion of each ecosystem function that soil contributes to, thereby providing ecosystem services to society, is much beyond the scope of this article. They are listed to stress the importance of soil, directly providing food and fibre to human society, but even in the hinterlands in ways that must not be overlooked as we focus on working toward sustainability on the world's soils.

Despite the huge expanse of land in Canada's north, possible climate warming will not result in large increases in potentially arable land. Much of the land is within the Boreal Shield Ecozone has shallow, rocky, often sandy, acidic and generally infertile soils. There are lands with potential such as the soils of the 'northern clay belt'[9]. Silty to clayey glaciolacustrine deposits occur in patches within the Canadian Shield from Saskatchewan to Quebec, with a total area of about 10 million hectares, perhaps one-third of that in blocks suitable for agricultural development.

Table 1. The global distribution of arable land, world population and arable land per capita by continents and select countries.

Continent	Select Countries	Percent of Global Arable Land[1]	Percent of Global Population[2]	Arable Land area per capita	
				acres	hectares
Asia	**All**	**31.94**	**56.7**	**0.28**	**0.11**
	India	10.74	17.1	0.31	0.13
	China	10.26	19.8	0.26	0.10
	Kazakhstan	1.64	0.2	0.31	0.13
	Indonesia	1.49	3.5	0.21	0.08
	Pakistan	1.41	2.6	0.27	0.11
	Thailand	1.04	1.0	0.53	0.22

North America	**All**	**17.09**	**6.7**	**1.28**	**0.52**
	United States	12.21	4.5	1.34	0.54
	Canada	3.08	0.5	3.09	1.25
	Mexico	1.80	1.6	0.55	0.22
Africa	**All**	**14.16**	**14.2**	**0.50**	**0.20**
	Nigeria	2.23	2.2	0.51	0.21
	Sudan	1.19	0.6	0.99	0.40
	South Africa	1.09	0.7	0.75	0.30
	Niger	1.07	0.2	2.70	1.09
Europe	**All**	**11.31**	**8.8**	**0.64**	**0.26**
	Ukraine	2.40	0.7	1.74	0.71
	France	1.35	0.9	0.73	0.29
	Spain	1.00	0.6	0.83	0.34
	Poland	0.91	0.6	0.79	0.32
	Germany	0.86	1.2	0.35	0.14
Eurasia	**All**	**10.72**	**3.2**	**1.68**	**0.68**
	Russia	9.02	2.1	2.14	0.87
	Turkey	1.70	1.1	0.79	0.32
South America	**All**	**7.88**	**5.8**	**0.68**	**0.27**
	Brazil	4.34	2.9	0.74	0.30
	Argentina	2.09	0.6	1.72	0.70
Australia	**All**	**3.47**	**0.3**	**5.51**	**2.23**
Middle East	**All**	**2.40**	**3.0**	**0.40**	**0.16**
	Iran	1.18	1.0	0.60	0.24
	Iraq	0.42	0.4	0.50	0.20
	Syria	0.34	0.3	0.57	0.23
Carribean	**All**	**0.45**	**0.6**	**0.38**	**0.16**
Central America	**All**	**0.43**	**0.6**	**0.35**	**0.14**
Oceania	**All**	**0.15**	**0.2**	**0.38**	**0.15**
	New Zealand	0.11	0.1	0.88	0.36

[1] The global arable land area is estimated as 1.351 billion hectares (3.338 billion acres)(World Factbook 2009).
[2] The global population is estimated as 6.790 billion people (World Factbook 2009).

Table 2. Global soils distribution based on the soil orders of Soil Taxonomy.

Soil Order	General characteristics	Area globally[1] (%)	Equivalent Soil Order in the Canadian classification	% of soils represented on the Canadian Prairies
Gelisols	Soils of permafrost regions	8.6	Cryosolic	0
Histosols	Soils of peatlands	1.2	Organic	~5
Spodosols	Acidic forest soils with B horizons enriched in iron, aluminum and humus.	2.6	Podzolic	0
Andisols	Soils formed on volcanic PMs	0.7	none	0
Oxisols	Highly weathered soils of the tropics	7.5	none	0
Vertisols	Cracking clay soils	2.4	Vertisolic	~10
Aridisols	Soils of arid (desert) regions	12.0	none	0
Ultisols	Acidic, weathered forest soils of mid-latitudes	8.5	none	0
Mollisols	Mainly grassland soils with dark, organic matter enriched surface horizons	6.9	Chernozemic	70[2]
Alfisols	Weakly acidic mainly forest soils with clay-enriched B horizons	9.7	Luvisolic	8
Inceptisols	Less developed, brown forest soils	9.8	Some Brunisolic	<1
Entisols	Very weakly developed soils	16.2	Regosolic	~5

[1]Not included in the table are shifting sand (4.1%), rocky land (10.0%) and glaciers and water bodies (7.7%). The data are from Blum and Eswaran (2004).
[2] Includes Brown and Dark Brown Chernozems, 18%; Black and Dark Gray Chernozems, 20%; Solonetzic, 7%; and Gleysolic, 10%.

Conclusions

Despite a huge area of arable land in the world, an ever-increasing population results in only 0.20 hectares of farm land per person. Arable land, both quantity and quality, is not distributed evenly. Many of the developing countries in Asia and Africa have rapidly growing populations, and serious land degradation as farming moves to ever more fragile and infertile soils. Climate warming threatens land in two ways. One is a loss of productive lands in river deltas such as those of the Mekong and Ganges rivers and with a rising of sea level as the great ice sheets of Antarctica and Greenland melt. A second, the retreat of mountain glaciers puts in question the future supply of water to the world's irrigated lands. There is little doubt that an ongoing conservation, both globally and locally in the Prairies, is essential to food supply in future.

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