Part I

Soil and sustainability

Managed well, soil circulates chemical elements, water, and energy for great human benefit. Managed poorly, it is impossible to imagine an optimistic future.

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Concerns about soil in the modern world

SOIL USE AND MANAGEMENT

In *Gulliver's Travels*, the ever reasonable King of Brobdingnag praised all those who toil to improve soil management (Swift 1735). The King emphasized the significance of soil management by pronouncing to a much impressed Lemuel Gulliver that

> . . . whoever could make two ears of corn or two blades of grass to grow upon a spot of ground where only one grew before, would deserve better of mankind, and do more essential service to the human race than the whole race of politicians put together.

On all continents, farmers, foresters, engineers, ecologists, and gardeners labor valiantly to improve soil management (Figure 1.1). Their efforts have been amply supported by creative technicians and inventors. To harness animal power, people domesticated and bred horses, oxen, llamas, and water buffalo, and developed sophisticated yokes and collars for animal-powered hauling and plowing. To improve crop plants, maize, rice, wheat, and barley have been bred for millennia based on yields, taste, and resistance to environmental stress. To improve irrigation, Archimedes developed a simple, highly efficient screw pump. To benefit plant seedlings, Jethro Tull (1731) and many others developed seed drills. To improve soil fertility, soil amendments such as lime, organic manure, and inorganic fertilizers were promoted by John Lawes and J. Henry Gilbert (Dyke 1991), Edmund Ruffin (1852), Eugene Hilgard (1860), and Justus von Liebig (1843).

Efforts to improve soil management continue unabated in every nation. As emphasized by the King of Brobdingnag, such improvements remain among the highest priorities for humanity. How else will we feed and sustain a world which may approach 10 billion people in just a few decades?

(a, i)

(Figure 1.1)

MODERN CONCERNS ABOUT SOIL CHANGE

Soil is a biologically excited, organized mixture of organic and mineral matter; the bio-mantle of unconsolidated material that makes life possible on planet earth. Soil is created by and responds to biota, climate, geomorphic and geologic processes, and the chemistry of the above-ground atmosphere. Soil is an open thermodynamic system, highly responsive to inputs and outputs of chemical elements and energy. Although soil can be degraded, it is rarely if ever completely exhausted, due to a continuity of inputs that include solar energy, organic matter, nutrients, water, and gases. The earth's soil helps control the circulation of the biosphere's chemical elements.

(a, ii)

Figure 1.1. Vast effort is expended to maintain and improve soil for crop and forest management: (a) *opposite and above* garden cultivation and wheat harvest in Canada (Hayward and Watson 1922; photographs Edith S. Watson); (b) *overleaf* soil stabilization by vegetative wattling on steep-cut slopes in California (Gray and Leiser 1989); (c) a small farmer's sugar cane cultivation and tree planting (*Terminalia amazonia*) near San Isidro in southern Costa Rica (photograph D.D. Richter); (d) improved grass management at the Park Grass Experiment at Rothamsted in southern England (photograph D.D. Richter).

Well functioning soils are directly responsible for much of the world's highest quality freshwater, the biological diversity of terrestrial and aquatic ecosystems, and the economic wealth of human societies. Soil not only produces an increasing amount of food and fiber, but also decomposes much of the burgeoning stream of human and animal waste. Soil provides the physical support for our homes, roads, and cities (Gray and Leiser 1989). It also can be a repository for pollutants, including many of high potential toxicity.

Soil has been used for agricultural and engineering purposes for nearly 10 000 years. Over this time, humanity has developed an intimate relationship with the earth's soil that is well illustrated in our most ancient and holy texts such as the Bible, the Torah, and the Rigveda. The Rigveda speaks poetically about this relationship: "Harness the plows, fit

(b)

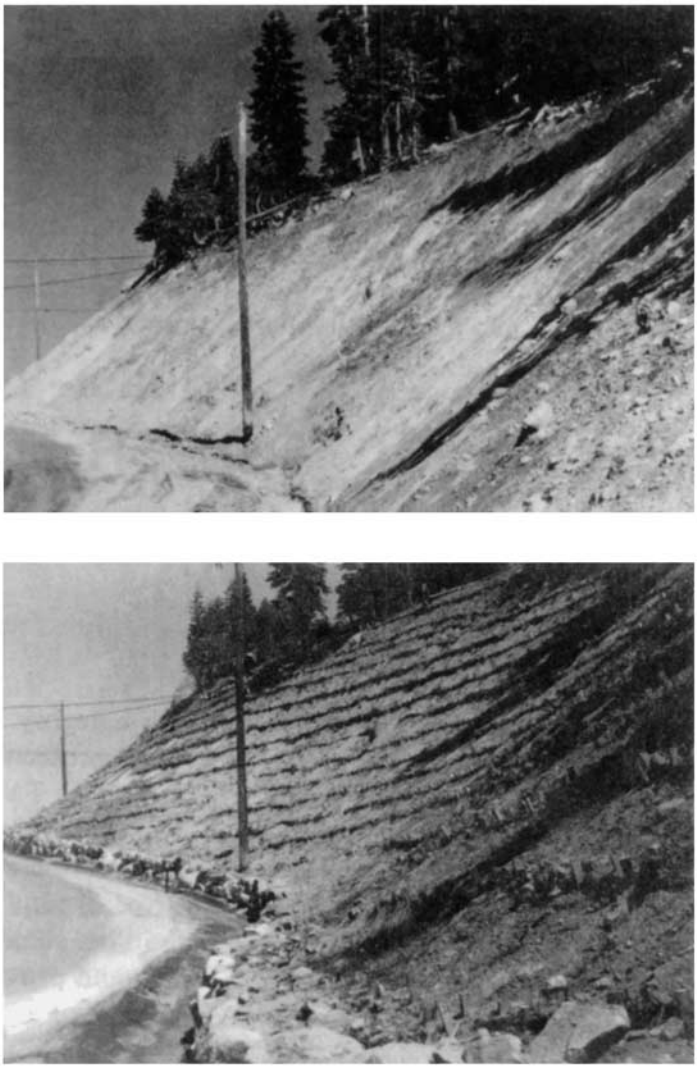

Figure 1.1 (*cont.*)

the yokes, now that the womb of the earth is ready to sow . . ." With such a close and long-continued dependence on soil, we are assured that soil can be managed productively and sustainably in a wide variety of ecosystems.

During the 20th century, land management greatly increased soil productivity (Figure 1.2). From cereals to fuelwood, the productivity of soil burgeoned. Human consumption of protein and calories doubled between 1960 and the 1990s (Figure 1.3), from about 190 to >380 billion

(c)

(d)

Figure 1.1 (*cont.*)

grams of protein per year and from 7 to >14 trillion calories per year. In much of the developing world, the average daily diet has gained nearly 0.5 g of protein per capita each year for the last 30 years (Figure 1.4). To achieve this production, soil inputs of N, P, and K increased 3- to 8-fold between 1960 and 1995 (Figure 1.5). Global fertilizer inputs in the 1990s totaled about 100 million metric tons (of nutrient elements) per year. In the 1990s, about 20% of the earth's arable land was irrigated, an area that nearly doubled in the final three decades of the 20th century.

Similarly, soils are being intensively managed for production of wood fiber. Industrial-wood harvests for sawlogs, veneer, pulpwood, and

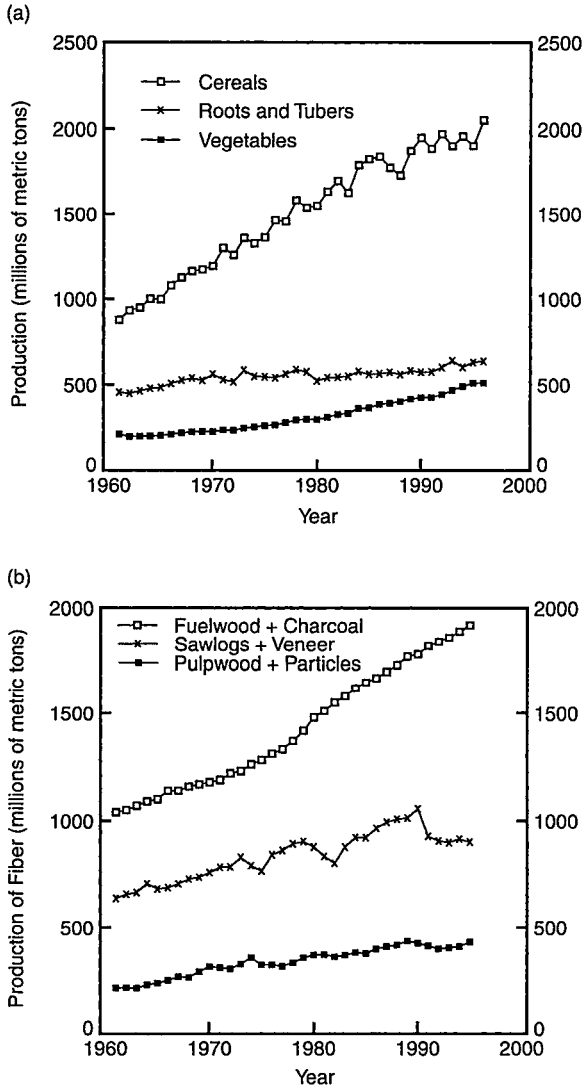

Figure 1.2. Food and fiber production are increasing rapidly and raise concerns about the soil that supports this production (UN–FAO 1998).

chips increased by 50–100% between the 1960s and 1990s (Figure 1.2b). During this same period, harvests for fuelwood nearly doubled to two billion metric tons of wood per year (Figure 1.2b).

Forest soils continue to be converted to a variety of non-forest uses. Although forestland conversion has significant uncertainties (e.g., Melillo *et al.* 1985), the Food and Agriculture Organization (FAO) reports

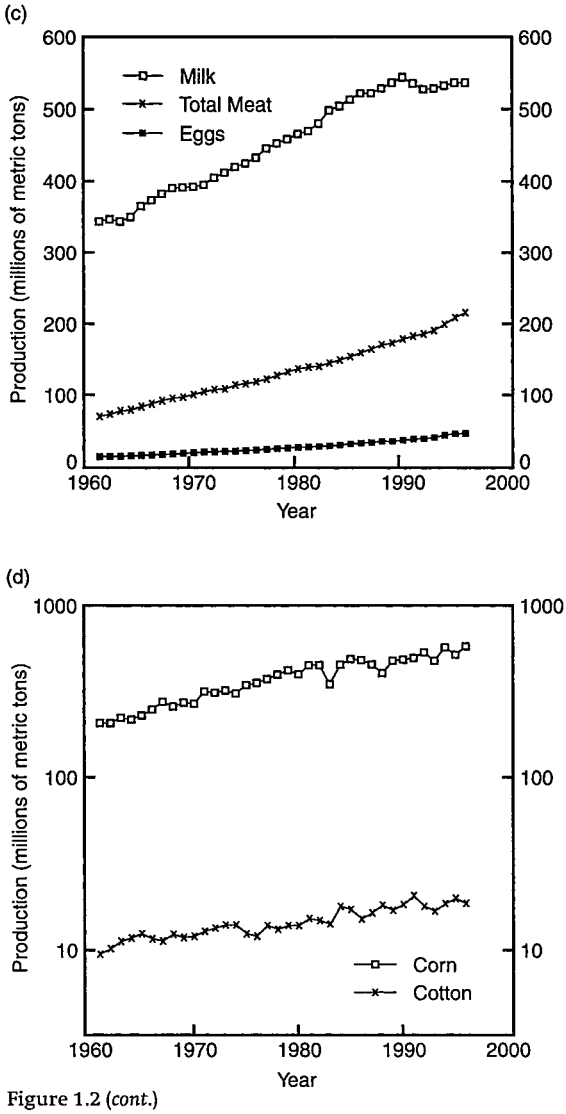

Figure 1.2 (*cont.*)

that forestland area in the 1990s is 200 million hectares less than it was in the early 1960s, mainly due to conversion to agricultural uses (Figure 1.6).

Urban impacts on soil are also intensifying as human populations are growing more rapidly in cities than in the countryside. Cities will be home to more than three billion people by 2010. To improve the quality of city life, we need to better manage soil compaction, erosion, flooding, chemical contamination, waste disposal, and runoff of polluted waters.

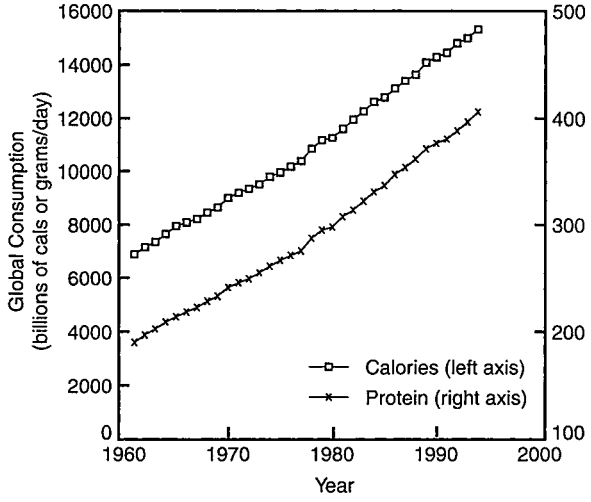

Figure 1.3. Total daily human consumption of protein and calories has increased by about 200 billion grams and 8 trillion calories between 1960 and the mid-1990s (UN–FAO 1998). Most proteins and calories consumed by humans are derived from the soil (UN–FAO 1998).

And by the end of the 1990s, mining affected on the order of a million hectares of land per year, each year creating severely disturbed landscapes in need of soil reconstruction, reclamation, and stabilization (Antonovics *et al.* 1971; Bradshaw and Chadwick 1980; Hosner and Hons 1992). Modern systems of mining have begun to integrate soil-management regimes into reclamation programs to better stabilize waste-rock dumps and tailings. Nevertheless, opportunities for soil management in mine reclamation programs remain under-developed.

HOW ARE SOILS CHANGING?

We have entered an age in which more than half of the earth's 13 billion hectares of soil are being plowed, pastured, fertilized, limed, irrigated, drained, fumigated, bulldozed, puddled, compacted, eroded, leached, mined, reconstructed, harvested, or converted to new uses. If these managed soils are not simply to degrade with use, we have much to learn about the biological fertility, chemistry, and physical stability of soil. We cannot take for granted that soil will produce ample and increasing yields of high quality food, fiber, and water over many generations' time (Greenland and Szabolcs 1994).

Gone are the days when we can readily abandon land after exploitive use and move on to "fresh soil." To preserve soil already in use, and

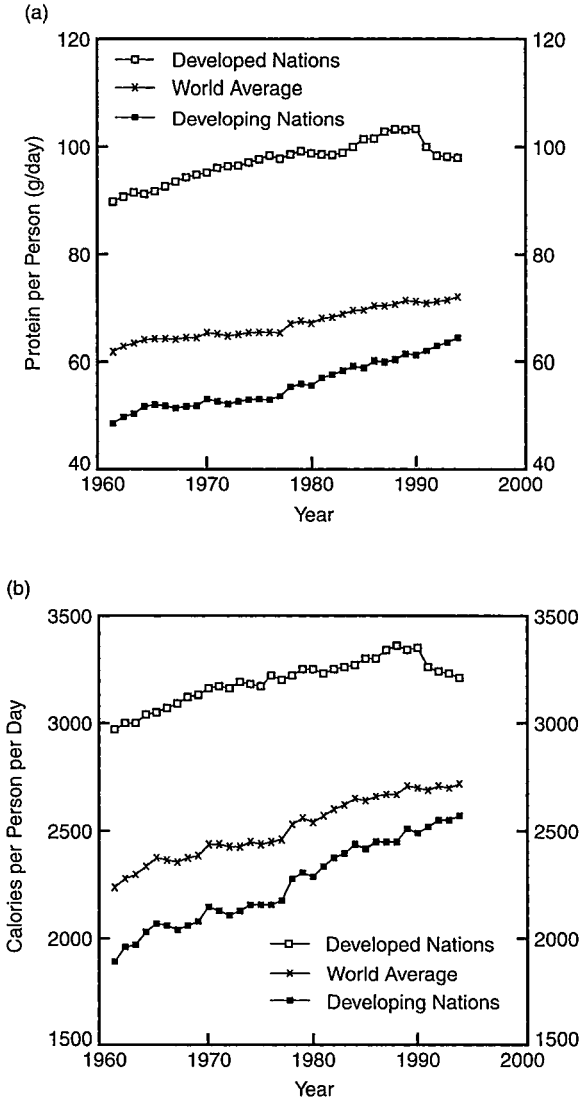

Figure 1.4. Recent global increases have been rapid in per capita, daily human consumption of (a) protein and (b) calories (UN–FAO 1998).

to improve management control over soil coming into use, we must greatly increase our technical understanding of how management alters soil over time. We have entered an age in which soil and ecosystem research is indispensable for continuing and improving land management.