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Khan Towhid Osman
Department of Soil Science
University of Chittagong
Chittagong, Bangladesh

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For my uncle
A. K. M. Abdur Rashid
Who was there by the grace of Almighty for
me and my family when we were in dire need

Preface

Management of Soil Problems is intended for students of all levels of Soil Science, Agronomy, Horticulture, Forestry, Geography and Environmental Sciences. The soil is a limited non-renewable resource, and the formation of one centimeter depth of fertile surface soil may need several hundreds to thousands of years in nature. Still the area of fertile and productive soils is continuously decreasing for increasing pressures on soils, land-use changes, and soil mismanagement. Moreover, only twelve percent of the global soil area has a few or no limitations to agricultural use; others have some sorts of problems of variable degrees. But, there are many misconceptions about soil use and management, particularly regarding the so-called problem soils and soil problems. Actually, there are a few soils that can be called problem soils in their natural state. If allowed to remain in an undisturbed condition, all soils can function appropriately in their own ecosystems. However, some soils can acquire, during their genesis and evolution under a set or sets of soil-forming factors, certain unique characteristics that may not suit our intended use. These are not the problems of soils themselves but their peculiarities; the problem lies with our dire need to use them for different purposes and in different ways. FAO Soils Portal on management of problem soils states, "Soils are neither good nor bad because the distinction is often based on their intended use. However, many soils have characteristics that make specific management interventions desirable to avoid problems for agricultural production or environmental degradation." The demands of land for agricultural, urban, industrial, and other uses have enormously increased due to an ever-increasing human population. High demands of food, wood, fiber, fuel, and other materials and services are causing continuous land-use changes. More soils having unsuitable properties with regard to agriculture are being brought at present and will be in future under crop production. Some soils offer serious limitations to their agricultural use; traditionally, these soils are known as "problem soils," for which special, innovative, and sustainable management practices should be adopted. Some soils develop problems due to misuse and mismanagement by humans.

Most soil problems are use-oriented. For example, many wetlands are valuable habitats of diverse flora and fauna; they are rich fishing and bird-nesting grounds;

they purify water and recharge aquifers; these uses pose no problem for them, but draining them for cropping offer many problems. I have found beautiful mangrove forests in acid sulfate and potential acid sulfate soils of Chakaria in Bangladesh; rice also thrives there, but using adjacent lands for shrimp culture has been a failure. Drought is a problem for farming, but not for constructing roads and highways. However, the capacity of performing normal ecological functions of some soils has been lost or deteriorated due to human activities with concomitant decline in soil quality; these soils are the degraded soils. Degradation may be reversible and irreversible. If irreversible degradation has occurred, it may need some centuries to return naturally to a state which might be economically and ecologically valuable again. It is very difficult and sometimes uneconomic to restore the original structures or functions of some moderately degraded soils as well. Drained wetlands and reclaimed peat in the north are good examples. In agricultural viewpoint, there are some specific soil types that limit the growth of crop plants, such as shallow soils, sandy soils, saline soils, acid soils, and peat soils. According to Natural Resource Conservation Service of the United States, common soil problems are compaction, crusting, poor drainage, salinity, acidity, and low-organic matter content. However, there are some limitations that can occur in many different soil types. For example, phosphate fixation, which reduces the availability of native and applied phosphorus to plants, can occur in acid soils, acid sulfate soils, calcareous soils, clay soils, metalliferous soils, and so on.

In this book, I have included thirteen chapters on major problems of soil use and their management preceded by an introduction (Chap. 1). In Chap. 1, several soil problems/soil limitations/soil constraints/soil stresses have been introduced and discussed. Soils posing specific problems mainly to agricultural use are discussed in Chaps 2–13 (Chap. 2 Dryland Soils, Chap. 3 Sandy Soils, Chap. 4 Shallow Soils, Chap. 5 Soils with Drainage Limitations, Chap. 6 Expansive Soils, Chap. 7 Peat Soils, Chap. 8 Soils on Steep Slopes, Chap. 9 Poorly Fertile Soils, Chap. 10 Saline and Sodic Soils, Chap. 11 Acid Soils and Acid Sulfate Soils, Chap. 12 Polluted Soils, and Chap. 13 Soils Degraded Due to Use and Misuse). In Chap. 6, the problems of expansive and dispersive soils associated with their engineering use were also discussed. According to the American Society of Civil Engineers, about half of the houses built in the United States each year are situated on unstable (expansive and dispersive) soil, and about half of these will eventually suffer some soil-related damage. Cracking of foundations, walls, driveways, swimming pools, and roads costs millions of dollars each year in repairs.

I reviewed the recent and relevant literature for up-to-date information regarding all the issues discussed above in this book. Despite my efforts, I could not avoid some repetitions. Readers are certainly aware that some management options, such as organic matter addition, conservation farming, mulching, cover crops, and crop rotations, are common for the mitigation of many soil problems. They have appeared in different chapters although their relevance was always kept in mind. Readers should also be aware that management options for soils posing problems to a specific use need extra inputs. Poor farmers of the developing countries of Africa and Asia cannot adopt many effective but costly practices. Management depends on socioeconomic conditions, tradition, farm facility, cropping patters, etc. And some practices may not be profitable as well.

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November, 2017

Khan Towhid Osman

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Abbreviations

BSP	Base saturation percentage
CEC	Cation exchange capacity
CHN	Cold hardiness number
CPATSA	Centro de Pesquisa Agropecuaria do Tropico Semi-Arido (Agricultural Research Centre for the Semi-arid Tropics, Brazil)
DECCW	Department of Environment, Climate Change and Water
DLWC	Department of Land and Water Conservation
ECe	Electrical conductivity of saturation extract
EMBRAPA	Empresa Brasileira de Pesquisa Agropecuária (Brazilian Enterprise for Agricultural Research)
ESP	Exchangeable sodium percentage
FAO	Food and Agriculture Organization of the United Nations
FCC	Fertility capability classification
FYM	Farm yard manure
GPCR	Gas phase chemical reduction
GR	Gypsum requirement
GWT	Groundwater table
HRB	Highway Research Board (of USA)
ICIMOD	International Centre for Integrated Mountain Development
ICRISAT	International Crops Research Institute for the Semi-Arid Tropics
IDRAS	International Desert Research of Academia Sinica
ILCA	International Livestock Centre for Africa
IPCC	International Panel of Climate Change
ISRIC	International Soil Reference and Information Centre
KFUPM	King Fahd University of Petroleum and Minerals
LR	Leaching requirement
M ha	Million hectare
MAAT	Mean annual air temperature
MCD	Mechanochemical dehalogentation
NRCS	Natural Resource Conservation Service
NTCHS	National Technical Committee on Hydric Soils

PET	Potential evapo-transpiration
PVAL	Poly(vinylalcohol) copolymer
RSG	Reference Soil Group
RUSLE	Revised universal soil loss equation
SALT	Sloping agricultural land technology
SAR	Sodium adsorption ratio
SHNC	Superabsorbent hydrogel nanocomposite
SSSA	Soil Science Society of America
TDS	Total dissolved solids
UNCCD	United Nations Convention to Combat Desertification
UNEP	United Nations Environmental Program
UNESCO	United Nations Educational, Scientific and Cultural Organization
USCS	Unified Soil Classification System
USDA	United States Department of Agriculture
USEPA	United States Environment Protection Agency
USLE	Universal soil loss equation
VAM	Vesicular-arbuscular mycorrhizae
WRB	World Reference Base

Contents

Chapter 1
Management of Soil Problems: An Introduction

Abstract In this chapter several problems, constraints, limitations and stresses of soils associated with their different uses are introduced and discussed. Their general characteristics, productivity relations and some management options are indicated.

Keywords Problem soils · Soil problems · Soil limitations · Soil constraints · Land resource stress classes

1.1 'Problem Soils' and Soil Problems

People use soils for a variety of purposes including cropping, pasturing, gardening, forestry, agroforestry, constructing buildings, airports, roads, railways, golf courses, and the like. They always look for the most suitable soils to get the best outcome. For agriculture, humans have cleared forestlands and grasslands that seemed physically most suitable for the purpose. If these soils were fertile, they give good harvests; otherwise, they have to be abandoned, and the most fertile soils are needed for crop production. Desired yield of a crop could be obtained from a soil which is physically, chemically and biologically suitable or productive for that crop. A few soils are naturally very productive; and some soils, which do not have many limitations, can be made productive by appropriate soil and crop management practices. About ten percent of the total soil resources of the world have little or no considerable limitations to cropping, but most soils have some kind of limitations in their capacity or flexibility to grow crops. Some soils can be productive for only a limited number of crops, but offer serious limitations for others. Soils that have serious limitations to agricultural and other land uses are traditionally called problem soils; and they need special management techniques for their profitable and sustainable use. But in reality, hardly any soil can be called problem soils in their natural settings, because, if not disturbed, all soils can perform their respective ecological functions. During their genesis and evolution under a set or sets of soil forming factors, however, some soils can acquire certain unique characteristics that may not suit our intended use. These are their characteristics, not problems. It is the incompatibility of our desired use with the qualities or characteristics of a particular soil that poses the problem. So, most soil problems are use-oriented; for example, many

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wetlands are rich fishing grounds, there is no problem in them; but draining them for cropping may create many problems. Beautiful mangrove forests can thrive in potential acid sulfate soils; wetland rice can be grown successfully there too, but using them for shrimp culture and arable crops can be unsuccessful and environmentally hazardous. However, the capacity for performing normal ecological functions of some soils has been lost or deteriorated due to human activities, so that soil quality has considerably declined. It is very difficult and sometimes costly to restore them to their original structures or functions. As pressures on soil resources have enormously increased recently due to increased human population, many marginal and unsuitable soils have now been brought under cultivation. These soils deserve special attention to protect them from further deterioration (Eswaran et al. 2001).

Soil limitations to various uses may be physical, such as dryness, wetness, steepness, extreme textures, erosion hazard, compaction, shallowness, shallow groundwater table and flooding; chemical, such as acidity, salinity, sodicity, lack of fertility, phosphate fixation, and pollution; and/or biological, such as reduction in the activities of beneficial soil organisms, for example, earthworms and vesicular-arbuscular mycorrhizae (VAM), or an increase in pathogens or plant parasitic nematodes. Soil characteristics may impose limitations to growth and yield of crops directly through effects on germination, seedling emergence and early growth, or through the content of available nutrients and water. They may also do so through their effects on root development and functioning. Some soil limitations are difficult to alleviate (too cold, too hot, too shallow); some limitations can be alleviated in whole or in part (irrigation in dry areas, drainage of wet soils, fertilizing in poorly fertile soil, liming in acid soil), and alleviation of some limitations widens the range of crop suitability (draining wet soil, irrigating dry soils). Agricultural scientists have described management options for many different soil limitations. For example, Murphy et al. (2004) mentioned the following soil limitations to cropping: soil structure decline, wind erosion, water erosion, mass movement, acidification, soil carbon loss, soil contamination, soil fertility decline, acid sulfate soil, and dryland salinity. The Expert Consultation of the Asian Network on Problem Soils proposed the following 11 categories of problem soils (FAO/AGL 2000).

1. **Cold soils:** Land areas with a 24-hr mean temperature of less than 5 °C during the growing period.
2. **Dry soils:** Desert and semi-desert soils with growing periods which are rainless-dry.
3. **Steep soils:** Soils which have steep slopes in excess of 30 percent.
4. **Shallow soils:** Soils which have depth limitations within 50 cm of the surface caused by the presence of coherent and hard rock or hard pans.
5. **Poorly drained soils:** Soils which are waterlogged and/or flooded for a significant part of the year.
6. **Coarse textured soils (sandy soils):** Soils having coarse texture with less than 18 percent clay and more than 65 percent sand, or have gravel, stones, boulders or rock outcrops in surface.

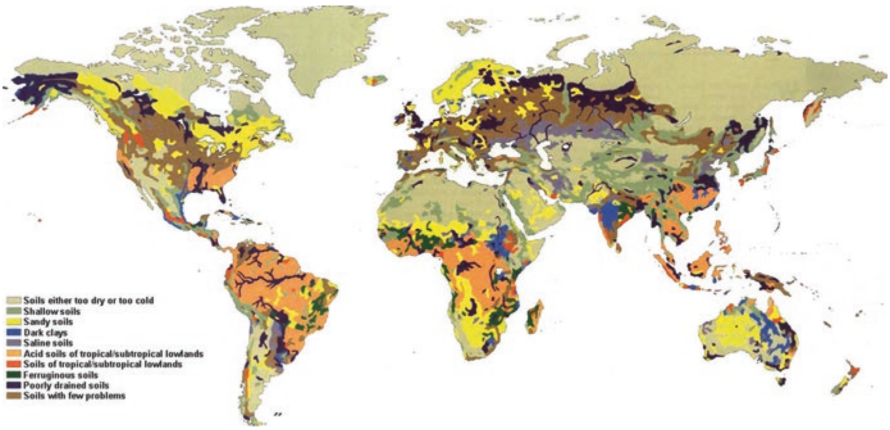

Fig. 1.1 Distribution of some 'problem soils' (Source: http://www.fastonline.org/CD3WD_40/INPHO/VLIBRARY/U8480E/EN/U8480E0B.HTM)

7. **Heavy cracking clays (Vertisols):** Soils which crack at least 1 cm wide at 50 cm depth at some period in most years.
8. **Poorly fertile soils:** Soils which exhibit deficiencies in plant nutrients.
9. **Saline and sodic soils:** Soils with high salt content and high exchangeable sodium saturation, respectively within 100 cm of the surface.
10. **Acid sulfate soils:** Soils in which sulfidic materials have accumulated under permanently saturated brackish water conditions in general.
11. **Peat soils (Histosols):** Soils in which more than half of the upper 80 cm is composed of organic materials.

There are some other categories of problem soils as well, such as.

Eroded soils: Soils that have seriously suffered from water and wind erosion.
Polluted soils: Soils contaminated with inorganic and organic pollutants.
Compacted soils: Some soils are naturally compacted; others get compacted by the load of heavy farm machineries.

Figure 1.1 shows the global distribution of different so-called problem soils.

Some of the categories of soils listed above have multiple problems. For example, sandy soils are not only low water retentive and poorly fertile, some sandy soils are extremely acidic and very cold. Dry soils are found in arid and semi-arid regions where precipitation is very low. Dry soils are also usually sandy in texture, low in organic matter and poorly fertile. Peat soils are susceptible to subsidence, and many peat soils are submerged. Saline soils may have poor drainage or dryness problems along with salt problems. A soil posing problems to a certain land use may not do so for another land use. For example, some saline soils bear excellent mangrove forests in natural conditions, and soil salinity is not a problem there; but when these areas are cleared for agricultural crop production, they do not give satisfactory yields. Steep soils are not good agricultural lands, but they can support dense forest vegetation if they are left undisturbed. However, soil problems may be natural or acquired. Natural soil limitations usually arise from climate, parent material and topography related situations. Human actions have also created many soil problems including erosion, waterlogging, compaction, fertility depletion, salinization, acidification, pollution, etc.

1.2 Soil Constraints to Different Uses

Using the fertility capability classification (FCC), FAO (2000) listed eight soil constraint classes on the basis of inherent features which offer problems to soil use and management. These soil constraint classes are listed below.

1. **Hydromorphy:** poor soil drainage.
2. **Low cation exchange capacity:** low capacity to retain added nutrients.
3. **Aluminium toxicity:** strong acidity.
4. **High phosphorus fixation:** a high level of ferric oxides in the clay fraction.
5. **Vertic properties:** dark, expanding and contracting ('cracking' and 'expansive') clays.
6. **Salinity and sodicity:** presence of free soluble salts.
7. **Shallowness:** rock or a rock-like horizon close to the soil surface.
8. **Erosion hazard:** a high risk of soil erosion in moderate to steep slopes in association with erosion-prone soils.

According to FAO (2000), the four major constraints, each of which occupies 13–16 percent of the global land area, are in order of extent: erosion hazard, aluminium toxicity, shallowness, and hydromorphy. Four other constraints, each of which covers 2–6 percent of the area, are: salinity and sodicity, low cation exchange capacity (CEC), high phosphorus fixation, and vertic properties.

DECCW (2010) identified several landscape constraints, soil physical constraints, and soil chemical constraints for which special management practices need to be adopted for various uses.

Landscape constraints:	Steep slopes, water erosion hazard, flood hazard, acid sulfate soils, mass movement, wave attack, poor site drainage/waterlogging, general foundation hazard, shallow soils, rock outcrop.
Soil physical constraints:	Shrink-swell potential, low soil strength, low or high permeability, low plant available water holding capacity (water stress), stoniness.
Soil chemical constraints:	Salinity, acid and alkaline soils, sodicity, low fertility/nutrient availability, high phosphorus sorption (low P availability).

DECCW (2010) also identified five intensity classes of soil constraints ranging from very low to very high, and described their management strategies.

Very low	Very low constraint; low treatment costs; straightforward or no maintenance; associated with negligible financial, environmental or social site costs; very low residual risk.
Low	Low constraint; associated with minor financial, environmental or social site costs; straightforward or low maintenance; low residual risk.
Moderate	Moderate constraint; moderate financial, environmental or social costs beyond the standard; frequent maintenance erequired; moderate residual risk; marginally acceptable to society – other factors may intervene.
High	High constraint; high financial, environmental or social costs beyond the standard; special mitigating measures are required; regular specialist maintenance; moderate to high residual risks and costs.
Very high	Very high constraint; risks very difficult to control even with site-specific investigation and design; very high financial, environmental or social costs beyond the standard; regular specialist maintenance may be mandatory; high residual risk; generally not acceptable to society.

Gugino et al. (2014) listed the following soil constraints that need specialized management: Physical: low aggregate stability, low available water capacity, high surface density; Biological: low organic matter content, low active carbon, low mineralizable nitrogen, high root rotting; and Chemical: unfavorable pH, low P, K, and minor elements, high salinity, and high sodium content. They put forward some short-term and long-term management suggestions (Table 1.1).

Following are the major soil constraints specific to different regions:

Sub-Saharan Africa:	Aluminium toxicity and low cation exchange capacity
North Africa and Near East:	Salinity and sodicity
Asia and the Pacific:	Aluminium toxicity, hydromorphy, salinity and sodicity
North Asia, east of Urals:	Hydromorphy, salinity and sodicity
South and Central America:	Aluminium toxicity, high phosphorus fixation, and hydromorphy
North America:	Hydromorphy and aluminium toxicity
Europe:	Hydromorphy

The global extent of problem soils/soil constraints are given in Table 1.2.

A brief description of some soil problems/constraints are given below:

Stoniness

Stoniness refers to the presence of rock fragments, such as gravel, stone and cobbles in high proportion. These materials do not provide or retain nutrients and moisture. They offer physical resistance to movement of agricultural implements and restrict tillage operations. They reduce the workability of a soil and hinder cultivation.

Table 1.1 Soil constraints and suggested management practices

Suggested management practices		
	Short term or intermittent	Long term
Physical concerns		
Low aggregate stability	Fresh organic materials (shallow-rooted cover/rotation crops, manure, green clippings)	Reduced tillage, surface mulch, rotation with sod crops
Low available water capacity	Stable organic materials (compost, crop residues high in lignin, biochar)	Reduced tillage, rotation with sod crops
High surface density	Limited mechanical soil loosening (e.g. strip tillage, aerators); shallow-rooted cover crops, bio-drilling, fresh organic matter	shallow-rooted cover/rotation crops; avoid traffic on wet soils; controlled traffic
High subsurface density	Targeted deep tillage (zone building, etc.); deep rooted cover crops	Avoid plows/disks that create pans; reduced equipment loads/ traffic on wet soils
Biological concerns		
Low organic matter content	Stable organic matter (compost, crop residues high in lignin, biochar); cover and rotation crops	Reduced tillage, rotation with sod crops
Low active carbon	Fresh organic matter (shallow-rooted cover/rotation crops, manure, green clippings)	Reduced tillage, rotation
Low mineralizable N (Low PMN)	N-rich organic matter (leguminous cover crops, manure, green clippings)	Cover crops, manure, rotations with forage legume sod crop, reduced tillage
High root rot rating	Disease-suppressive cover crops, disease breaking rotations	Disease-suppressive cover crops, disease breaking rotations, IPM practices
Chemical concerns		
Unfavorable pH	Liming materials or acidifier (such as sulfur)	Repeated applications based on soil tests
Low P, K and Minor elements	Fertilizer, manure, compost, P-mining cover crops, mycorrhizae promotion	Application of P, K materials based on soil tests; application of organic matter; reduced tillage
High salinity	Subsurface drainage and leaching	Reduced irrigation rates, low-salinity water source, water table management
High sodium content	Gypsum, subsurface drainage, and leaching	Reduced irrigation rates, water table management

Rock outcrop

Rock outcrop impedes working for developments, such as construction of roads, buildings and the cultivation of land for cropping and plantation forestry. It may also restrict recreational uses, particularly sporting fields. Rock outcrop reduces the space for growing plants in a landscape. There is less yield of crop or pasture per hectare of land. It often becomes a significant limitation where it covers over 20 percent of the land surface.

Table 1.2 Total areas of different types of soil problems of the world

Problem soils/soil constraints	Million hectares (M ha)
Hydromorphy (wet soils)[a]	1738.2
Aluminium toxicity[a]	1986.7
Eroded soil (water erosion)[b]	1094.0
Eroded soil (wind erosion)[b]	548.0
Low CEC[a]	615.1
High P-fixation[a]	542.1
Vertisols[c]	335.0
Peat soils[d]	400.0
Acid sulfate soil[e]	17.0
Salt affected soil[f]	950.0
Polluted soils[g]	21.0
Compacted soils[g]	68.0
Degraded soil[g]	1965.0

[a]FAO (2000)
[b]Lal (2001)
[c]Spaargaren (2008)
[d]Bain et al. (2011)
[e]Andriesse and van Mensvoort (2006)
[f]Eswaran et al. (2001)
[g]Oldeman (1994)

Shallowness of soil
Shallowness of soil refers to the presence of a thin soil layer over the bed rock or a hard cemented layer/horizon or a root restrictive layer near the surface. The depth of shallow soils varies from 30 to 50 cm depending on the rooting depth of crops grown. These soils are often stony or gravelly, prone to desiccation, and frequently occur on steeplands. These soils were formerly called Lithosols, Rendzinas and Rankers. Now, FAO (2006) classifies these soils as Leptosols in World Reference Basefor Soil Resources. In Soil Taxonomy (USDA-NRCS 1999), they fall in several Soil Orders.

Low soil strength
Soil strength represents the ability of the soil to support loads. It is related to wind-throwing of trees, bearing capacity of farm animals and machineries, and as foundation of buildings, roads and highways. The rating applied is taken as the most limiting (worst) of the following three attributes: (i) plasticity – highly plastic soils are unsuitable for foundation of buildings and road materials. (ii) low weight bearing strength accounts for low capacity to support loads when wet (iii) organic- peats or peaty soils have low weight-bearing strength and may be subject to contraction. The Unified Soil Classification System (USCS) is a relatively simple classification of soil materials and is widely used for low level engineering purposes (Hicks 2007).

Steep slopes
Land gradient has a major influence on land uses; almost all land-use operations become increasingly difficult as the slope increases, particularly above >20 percent. The greater the slope, the greater is the potential for erosion due to the increased amount and rate of runoff, reducing infiltration and the increased gravitational force on the soil particles. Steeper slopes mean that access is more difficult and cumbersome, especially where heavy machinery is required or heavy loads are being transported. Preparation of site for construction work is more difficult and require greater cut and fill operations.

Erosion
Erosion greatly reduces land-use efficiency. It is more prominent in areas of steep slopes (8–30 percent) and very steep slopes (>30 percent) in conjunction with an abrupt textural contrast in the soil profile, denoting these as having a severe erosion hazard. The total world area having high erosion hazard is somewhat greater than for the other major soil constraints: shallowness and aluminium toxicity.

Mass movement
Mass movement includes landslides, earth slumps and rock falls and is a serious threat to many land uses including grazing, shifting cultivation, forestry and construction of roads and bridges. It may involve the collapse of a slope at one point and the accumulation of the failed material further downslope. Mass movement may demolish houses causing injury or loss of life and damage of infrastructure. Mass movement occurs in several forms, but it occurs basically when wetting soil materials increase the weight in upper slopes beyond the restraining capacity of the underlying substratum. It frequently occurs during periods of rainfall when the weight of the ground material has increased and the internal friction has been reduced. Construction, particularly cuttings into slope bases, may exacerbate this hazard (Rosewell et al. 2007).

Vertic properties
Vertic properties are the features of Vertisols which swell on wetting and shrink on drying. They are also called shrink-swell soils and expansive soils. In India, dark colored Vertisols were formerly called 'black cotton soils'; the dark color of these soils was due to humus complexes with dispersive clays. Vertisols produce wide and deep cracks upon drying. The cause is a high clay content coupled with >50 percent 2:1 lattice (montmorillonitic) clay minerals. The distribution of Vertisols is highly localized, being linked with mafic (basic) rocks, semiarid climates, or both these conditions. The greatest absolute extents are found in India (the lavas of the Deccan), Australia, and Sudan (especially the Gezira zone). Twelve countries, in all the major continental regions, have over 10 percent of their land with vertic properties, Uruguay and India having the highest relative extent (FAO 2006).

Flood hazard
Flooding is a major constraint to many land uses. It can damage or destroy crops, farm houses, infrastructure, and other assets. Flash floods rapidly builds up water flow in narrow and confined valleys, typically in hilly or mountainous areas, while

riverine floods are the more extensive inundation of floodplains adjacent to rivers following heavy rains in the catchment, and coastal floods are the inundation of low lying coastal lands by ocean or estuarine waters, resulting from severe storm events and/or unusually high tides (NSW Government 2001).

Hydromorphy

Hydromorphy or wetness in the soil profile for all or part of the year is generally found in flat and low-lying areas with respect to the surrounding land. These lands include alluvial and coastal plains, deltas, and river valleys, including valley floors, peat bogs, marshes and other wetlands. About 20 countries have a substantial proportion (>25 percent) of land affected by hydromorphic constraints, with the highest proportions (>50 percent) in the Falklands, the United Kingdom, and Bangladesh (FAO 2000).

Low cation exchange capacity

Soils that have a low organic matter content, low clay content, clay minerals with low CEC, or all these properties in surface soil possess low cation exchange capacity. These soils have a low inherent fertility and also a low capacity to retain nutrients added as fertilizers. Generally, these include highly sandy soils (Arenosols), and tropical soils dominated by kaolinite clay and sesquioxides. In humid and subhumid regions there are extensive areas of sandy or highly-weathered soils having low CEC.

Soil acidity and alkalinity

A soil pH value below 7.0 indicates acidity and a value above it denotes alkalinity. Acidity and alkalinity influence the growth of plants and microorganisms, and affect chemical transformation, nutrient availability, and elemental toxicity. At soil pH below 4.5, aluminium and many heavy metals are released into soil solution and nitrogen, phosphorus, potassium and other nutrients becomes virtually unavailable. Different plants have different levels of tolerance to acidity and alkalinity, but most plants thrive at pH levels between 6.0 and 7.5. Levels below 4.5 or above 8.5 present significant limitations for growth of most plants (Fenton and Helyar 2007). Highly acidic or alkaline soils are not suitable for agriculture.

Acid sulfate conditions

Acid sulfate soils offer serious limitations to most uses. They usually develop in estuarine margins inundated with brackish water and supplied with plenty of organic matter. They are a potential constraint to land uses involving excavation or soil disturbance. Potential acid sulfate soils contain pyrite (FeS_2) which reacts with atmospheric oxygen to form sulfuric acid (H_2SO_4) on exposure to air through drainage. It creates extreme acidity that causes the release of toxic materials, including aluminium and heavy metals. Acid sulfate soils may also be highly saline.

Salinity and sodicity

Soil salinity and sodicity occur naturally in semi-arid to arid regions. They are also found in coastal lowlands. The state of salinity is caused by the accumulation of free salts in the profile, and sodicity due to dominance of the exchangeable sodium on colloidal surfaces. Of the 21 countries with over >15 percent of their land affected, 13 lie in a broad belt extending from the African Sahara and its bordering Sahel zone through the Middle East and into Central Asia. Sodicity appears to be even more strongly localized, with six countries (three of them in Central Asia) affected over more than 10 percent of their extent (FAO 2000).

Aluminium toxicity

Soils with aluminium toxicity have the exchange complexes dominated by alumina. This occurs with a soil reaction of pH <5.5, often <5.0. This problem is commonly associated with strongly acid soils. The main cause is intensive weathering and strong leaching under high rainfall. This is predominantly a problem of the humid tropics, although found also in the subhumid tropics and in a few temperate-zone countries with areas of high rainfall, e.g. New Zealand. It affects some 800 M ha in South America and 400 M ha in both Africa and Asia. The most affected eight countries lie largely or entirely in the rain forest zone. More than 50 countries have >25 percent of their territory affected by aluminium toxicity (FAO 2000).

Phosphorus fixation

The problem of phosphorus fixation in soils is generally associated with high content of free iron oxides (Fe_2O_3) in the clay fraction, which insolubilizes phosphate ions and renders it unavailable to plants. It is a dominant feature of strongly acid soils, and hence found often in conjunction with aluminium toxicity. The eight countries with more than 20 percent of land affected by high phosphorus fixation are also affected by aluminium toxicity (FAO 2000). Acidic and high Al containing soils are highly phosphate fixing.

Low soil fertility

Low soil fertility refers to the inadequate supply of available nutrients due to low nutrient availability, imbalance of nutrients, and presence of some kind of toxicity. The low fertility results from strong weathering, low cation exchange capacity, low organic matter content, strong soil acidity, strong phosphate sorption capacity, and strong nutrient leaching or nutrient imbalances (Asher et al. 2002). Low supply of micronutrients causes considerable constraints to food production in the tropics.

Eswaran et al. (2005) recognized some ‘edaphic constraints’ to food production while discussing problems and prospects of utilizing sandy soils of Asia. These constraints include some intrinsic and induced stresses. Intrinsic stresses result from physical (high susceptibility to erosion; steep slopes, shallow soils; surface crusting and sealing; low water-holding capacity; impeded drainage; low structural stability; root restricting layer; high swell/shrink potential), chemical (nutrient deficiencies; excess of soluble salts – salinity and alkalinity; low base saturation, low pH; aluminum and manganese toxicity; acid sulfate condition; high P and anion retention; calcareous or gypseous condition) and biological conditions (low or high organic matter content; high termite population) of the soils, climatic conditions (low rainfall, high evapotranspiration; excess rainfall, extreme temperature regimes; insufficient length of growing season) and catastrophic events (floods and droughts;

landslides; seismic and volcanic activity). Induced stresses occur due to physical, chemical and biological processes of soil degradation and modification of the landscapes.

1.3 Land Resource Stress Classes

Using soil and climate information, Moncharoen et al. (2001) and Eswaran et al. (2003) defined 25 broad land resource stress classes (Table 1.3) in the global context. Each of these stress classes requires a different level of management for agricultural use. A stress class may have several problems at the same time. For example, areas designated as 'continuous moisture stress', which essentially are the drylands, may have soils with salinity problems and sandy or skeletal soils that have low water holding capacity.

Agriculture in the developed countries is being practiced at present on the most suitable soils according to their intended uses. And, due to steadily rising productivity of these soils, EEC countries and the USA have even been able to reduce their cultivated land area. However, in the developing countries, the trend is almost the reverse. There, although the productivity of the better soils could still be improved substantially, much of the agriculture takes place on soils that are unsuitable or only marginally suitable. In large areas of Asia and Africa, the overall productivity is declining because of soil exhaustion and because areas with soil limitations are being used for cultivation. By drawing attention to these soils and emphasizing the ways their properties affect their reclamation and improvement, we can have a better understanding of the problems encountered and the risks involved when such soils are used for agriculture. More than two billion people depend on the world's arid and semi-arid lands. Preventing land degradation and supporting sustainable development in drylands may have major implications for food security, climate change and human settlement (Foreword by the United Nations Secretary-General, United Nations 2011).

Sources: Moncharoen et al. 2001; Eswaran et al. 2003

Finally, a list of problems of soil associated with various uses is presented below:

Physical problems Steep slopes, Erosion, stoniness, coarse texture, stiff very fine texture, extended dryness, extended wetness, shallow depth, poor soil structure, low infiltration, impermeability, compaction, crusting, root restrictive layers, dispersion, vertic properties, low soil temperature, high soil temperature, shallow groundwater table, poor drainage, etc.

Chemical problems Low organic matter, poor fertility, soil acidity, acid sulfate condition, soil alkalinity, salinity, sodicity, low CEC, low BSP, low buffering capacity, high Al, high P fixation, nitrate leaching, micronutrient deficiency, nutrient toxicity, soil pollution, etc.

Table 1.3 Description of major land resource stresses or conditions

Stress class	Land quality class	Major land stress factor	Criteria for assigning stress
25	IX	Extended periods of moisture stress	Aridic Soil Moisture Regimes (SMR), rocky land, dunes
24	VIII	Extended periods of low temperatures	Gelisols
23	VIII	Steep lands	Slopes greater than 32 percent
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	Anionic subgroups, acric great groups, oxidic,
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
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 percent
11	V	Seasonal moisture stress	Ustic or Xeric suborders but lacking mollic or umbricepipedon, 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 Soil Temperature Regime (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

Biological problems Low biological activity, low organic matter decomposition, low mineralization, high denitrification, etc.

Some problems are associated with the engineering aspects of soil use. In many states of the USA, building structures are damaged due to construction on expansive (shrink-swell) and collapsing soils. Cracking of foundations, walls, driveways, swimming pools, and roads costs millions of dollars each year in repairs. American Society of Civil Engineers suggests that about half of the houses built in the United States each year are situated on unstable soil, and about half of these will eventually suffer some soil related damage. In the last decade or so, swelling and shrinkage in clay soils have caused losses of up to 3 billion pounds in Britain (Bell and Culshaw 2001). Buildings, roads, farms and human habitations are often damaged by slope failures.

Soil constraints and management of major problems resulting from its use are discussed in different chapters of this book. For convenience and in order to avoid repetition, management of soils with multiple problems is treated in a single chapter. For example, problems of Al toxicity, soil acidity and acid sulfate conditions are discussed in Chapter 11. The readers must be aware that there are some management options common for several soil problems. For example, mulching, cover crops, and conservation tillage are applied in agricultural use of all of dryland soils, sandy soils, shallow soils, etc. Some repetitions could not, therefore, be avoided.

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