SOIL SCIENCE IN TROPICAL AND TEMPERATE REGIONS—SOME DIFFERENCES AND SIMILARITIES

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Little has been written about geographical differences in the progress and development of soil science, whereas such information is of interest for determining research priorities and for an improved understanding of the impact of soil science in various parts of the globe. This paper reviews some of the differences and similarities in soil science of the temperate and tropical regions. It is largely based on Anglo–Dutch literature and focuses on soil fertility research. The range of conditions under which soils are formed is as diverse in the tropical as in the temperate regions, but soil science has a different history and focus in the two regions. In densely populated western Europe soil fertility research started because there was little spare land, whereas in the Russian Empire and the United States land was amply available and soil survey developed. Since the second World War, soil science has greatly benefited from new instrumentation and developments in other sciences. Many subdisciplines and specializations have been formed, and soil science has broadened its scope in the temperate regions. Currently, much research

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is externally funded and has a problem-solving character. Soil research in tropical regions started later, and its scope has not changed much. The feeding of the ever-increasing population, land degradation, and maintenance of soil fertility are still important research themes. The amount of research in environmental protection, soil contamination, and ecosystem health is relatively small. More is known about the soil resources in the temperate regions than in the tropical regions despite the fact that one-third of the soils of the world are in the tropics, and these support more than three-quarters of the world population. Some of the common interests are the development of sustainable land management systems and appropriate land quality indicators, quantification of soil properties and processes, fine tuning of models, the sequestration of C in agricultural soils, and the optimum use of agricultural inputs to minimize environmental degradation and maximize profit. Nutrient surplus is a major concern in many temperate soils under agriculture, whereas the increase of soil fertility is an important research topic in many tropical regions. From a soil nutrient perspective it appears that soil fertility research in tropical regions is all about alleviating poverty, whereas in the temperate regions it is mainly about alleviating abundance and wealth. Although efforts have been undertaken to promote soil science to a wider audience, the impact of soil science on the society has been poorly quantified, and this applies to both temperate and tropical regions.

I. INTRODUCTION

The world would have been different if soil science had not emerged in the 19th century. It *grosso modo* applies to many—if not all—of the sciences, but for soil science its impact on society and the world at large has been poorly quantified. This is understandable, as it would be almost impossible to unravel the effect of different factors on the state of the world. Besides there are large regional differences. Soil studies are conducted in every agroecological region of the world, but soil science has mostly developed in the temperate regions. In tropical regions, soil science has followed its own path based on different needs and processes affecting soil conditions and plant growth.

Sanchez and Buol (1975) summarized some of the differences and similarities between soils and their forming factors in tropical and temperate regions. Aside from the lack of a difference between summer and winter temperatures, the range of conditions under which soils are formed is as diverse in the tropics as in the temperate regions. Similar rock types occur, and also erosional and depositional patterns are similar. In both tropical and temperate regions the time of soil formation may range from very recent on alluvial plains or volcanic deposits to very old on stable geomorphic surfaces. Arid and humid as well as warm and cold climates occur in both temperate and tropical regions. Nevertheless the extent of certain soil types is very different. Pleistocene glaciation and wind erosion have had a great impact on the soils in the temperate region, whereas many more soils in the tropics have intensively weathered and are often derived from Precambrian parent materials. Although the extent of recent volcanic ash deposits is greater in the tropics, there is a larger proportion of relatively young soils in the temperate regions. Generalizations beyond these statements begin to lose accuracy (Sanchez and Buol, 1975), and generalizations have done much harm in the advancement of soil science in tropical regions (Lal and Sanchez, 1992).

There have been several papers focusing on the developments in soil science in tropical or temperate regions (e.g., Greenland, 1991; Lal, 2000; Theng, 1991; Yaalon, 1997). Little has been written on a comparison of soil science in the temperate and tropical regions, whereas such information is of interest for determining research priorities and for an improved understanding of the impact of soil science in various parts of the world. This paper aims to partly fill the gap, and its objectives are (i) to compare some of the differences and similarities in soil science conducted in tropical and temperate regions, (ii) to give an overview of some recent trends in soil science of the temperate and tropical regions, and (iii) to discuss the impact of soil research in tropical regions.

The review is largely based on an analysis of Anglo–Dutch literature and focused mainly on soil fertility aspects. The paper does not aim to present a detailed and historical review of soil science in the tropical and temperate regions, but highlights the main developments and some of the striking differences and similarities.

II. SOIL SCIENCE IN TEMPERATE REGIONS

Practitioners of soil science could be roughly divided into those who made maps (pedologists, surveyors) and those who made graphs (the others). Such time has long gone, but the division had clear historical roots. At the beginning of the 20th century there were scientists studying soils in the field (agrogeologists), and there was a group studying soils in the laboratory who were often named agrochemists (van Baren *et al.,* 2000). These groups were found in different parts of the world.

In western Europe, there were limited possibilities for extending the agricultural area because the population was relatively dense. Research focused on the improvement of soil conditions in existing fields, e.g., the maintenance of soil fertility under continuous cropping. As a result, agricultural chemistry and the fertilizer industry developed in Europe. In other parts of the temperate region (United States and the Russian Empire) there were large areas of soils that could be used for agricultural expansion, and questions were centered on finding out what soils they had, how to select those responsive to management, and how to avoid wasted effort in farm development (Kellogg, 1974). There was a clear need for soil mapping and a better understanding of the concepts of the soils which resulted in the development of soil survey and soil genesis as subdisciplines of soil science. In the United States, soil science and in particular soil fertility research had a slower start than in Europe, as there was no urgency for maintaining the fertility and productivity of the soil—it was easier to move west (Viets, 1977).

A. After the Second World War

Early experiments with inorganic fertilizers were conducted in the mid-19th century at Rothamsted in England and in some other European countries. Acidulated phosphate rock and guano were mainly used, but in general, inorganic fertilizers were scarce in the 19th century. Inorganic fertilizers became widely used after the Haber–Bosch process had developed in Germany (Smil, 1999). It made fertilizers costs lower, and in addition new products were developed like nitrification inhibitors, new N compounds, coated fertilizers, and synthetic chelates (Viets, 1977). Inorganic fertilizer use in some selected European countries and in the United States is shown in Table I. In the Netherlands inorganic fertilizer use was already high at the beginning of the 20th century, but increased to almost 800 kg N, P_2O_5, and K_2O per hectare in the mid-1980s. The rate of increase in fertilizer consumption in Germany and the UK was similar, but inorganic fertilizer consumption in the United States has been low compared to European countries. It should be borne in mind that these are national averages and that inorganic fertilizer use between states and agricultural sectors may vary greatly.

A major development in soil fertility research took place after the second World War. Radioactive and heavy isotopes became available, and this was accompanied by the development of instrumentation like flame and atomic absorption spectrometers, emission and mass spectrographs, X-ray diffractometers and fluorescence, colorimeters, spectrophotometers, column and gas chromatographs, and

Table I

Inorganic Fertilizer Use in Some Selected European Countries and the United States in Different Periods[a]

	1913	1936	1986
Germany	47	64	427
Netherlands	146	320	784
United Kingdom	26	44	356
United States	6	8	94

[a]Modified after Knibbe (2000). Values in kg nutrients (N, P_2O_5, K_2O) per hectare y^{-1}.

computers (Viets, 1977). Advances in instrumentation allowed improved soil and plant tissue testing for better guidance of fertilizer use. Other developments which greatly aided soil fertility research were advances in statistical theory and designs of field experiments, theories on ion transport from the solid phase to the root surface, and the increased understanding of soil chemical and biological properties and processes.

Traditionally, soil science in the temperate regions was concerned with agricultural production (Cooke, 1979). The feeding of the post-second-World-War baby boom demanded a large increase in agricultural production, which resulted indirectly in a leap in soil knowledge. In the 1960s food production exceeded demand, and surplus production followed; and at the height of the cold war the optimism and positivism of the 1950s gradually vanished. Conservationists and environmental groups drew attention to the widespread deterioration of the environment (e.g., Meadows *et al.,* 1972). It brought about changes in the way the public and politicians looked upon agriculture and the environment. Since the 1970s rates of population growth have been declining in most temperate countries. Currently, the focus of attention is more on the problem of aging than on population growth per se (Tuljapurkar, 1997). Moreover overweight of the human population is a problem in many countries.

The shift of attention meant new opportunities for soil science (Tinker, 1985), and soil scientists became involved in studies of nonagricultural land use, nature conservation, pollution, contamination, environment protection, soil remediation, and soils in urban environments. An increased emphasis was placed on the relationship between soil processes and water quality, and soil scientists became caught up in global and regional environmental issues (Wild, 1989) and learned to interact with ecologists, economists, and sociologists (Bouma, 1993). Consequently, the focus of soil science was broadened in the temperate regions resulting in the development of various subdisciplines and specializations.

By its very nature soil science is an outdoor science, but with the introduction of the microcomputer, soil science has also become an office science where deskwork has increased, and this has occurred sometimes at the expense of laboratory and field work (Hartemink *et al.,* 2001). An emphasis is placed on the use of previously collected data in combination with functional or mechanistic modeling and the development of risk scenarios. Field work concentrates on advanced real-time measurements of soil properties as required for the development of precision agriculture, which is likely to have a large impact (Schepers and Francis, 1998), although its potential in Europe is still under debate (Sylvester-Bradley *et al.,* 1999). Invasive and noninvasive measuring techniques of soil properties require time before they will be fully developed, but progress has been made, particularly in the United States and Australia (Viscarra Rossel and McBratney, 1998). In western Europe there is perhaps more expertise in the environmental aspects and nonagricultural applications of soil science. Another major theme in the temperate regions is the role of soils as a sink and source of carbon in relation to global climate change (Lal, Kimble, Follet, and Stewart, 1998) and the development of quantitative techniques in soil science (McBratney *et al.,* 2000; McBratney and Odeh, 1997).

B. Funding and Scope

Throughout past decades funding opportunities for fundamental soil research have been reduced (Mermut and Eswaran, 1997), and much soil research is externally funded with a strong problem-solving character. With this trend soil science has returned to where it started: little fundamental research and a main focus on adaptive research. There is some fear that this means that soil science will lose its dynamism and independence (Ruellan, 1997). Bouma (1998) finds, however, that the external funding trend should not be rigidly opposed, and he advocates research procedures where applied and basic research logically fit together in so-called research chains.

Current soil fertility issues are integrated nutrient management systems aiming to minimize environmental pollution through leaching and denitrification. In a broader sense, research in soil fertility focuses on a reduction of the environmental impact of farming by reducing losses and conservation of fossil fuel energy. Other important factors are the breeding of cultivars tolerant to less favorable soil conditions or heavy polluted soil. Also mine site rehabilitation, bioremediation, and precision agriculture have become important in soil fertility research in temperate regions. Since the mid-1970s, modeling has become a major tool in the advancement of soil fertility research. There is growing interest in biological farming in many western European countries, and although it may have the potential to reduce the environmental impact of farming, it is generally perceived that biological farming cannot feed a rapidly growing population.

There are large challenges ahead for soil science and in particular for soil fertility research in the temperate regions, e.g., the development of nutrient management systems, which are both environmental friendly and cost-effective. This need is the same for soil science and soil fertility research in the tropical regions, although the research focus is distinctly different.

III. SOIL SCIENCE IN TROPICAL REGIONS

Little was known about tropical soils some 100 years ago. Travelers saw landscapes and vegetation that was never observed in any of the temperate regions, and many tried to comprehend the differences. Between the wars, significant soil research took place in, for example, Trinidad (F. Hardy), East Africa (G. Milne), and India (H. H. Mann). A useful overview of early investigations in tropical regions is given by Hilgard (1906). Considerable soil research was conducted in Indonesia (e.g., by E. C. J. Mohr) which included the mapping, chemistry, and formation of tropical soils. Systematic research started after the second World War following rapid developments in soil surveying and soil chemistry, and an overall increased interest ocurred in the natural resources of the tropics. The interest was mainly pedological, and many tropical soil science books were not concerned with the soil as a medium for plant growth (Moss, 1968; NAS, 1972; Nye and Greenland, 1960). Soil fertility was mainly the research terrain of the agronomist.

A. First Theories

The theory on the fertility of tropical soils has gone through a number of stages. In the late 1800s and early 1900s it was assumed that soil fertility in the humid tropics must be very high because it supports such abundant vegetation such as the rain forest. In the 1890s, the *Deutsch Ost-Afrika Gesellschaft* based their research station in Amani in the East Usambara mountains (Tanzania), as they thought that underneath the rain forest there must be abundantly productive soils (Conte, 1999). The point of view was fairly popular by tropical agriculturists and was prominently mentioned in the book of J. C. Willis (Willis, 1909), which ran through several editions during the first two decades of the 1900s. The American soil scientist E. W. Hilgard together with V. V. Dokuchaev, founder of modern pedology (Jenny, 1961), thought that soils of the humid tropics were rich in humus because of the abundant vegetation supplying plant material (Hilgard, 1906). Continuous and rapid rock and soil decomposition was thought to be high under the prevailing climatic condition, hence providing a constant supply of minerals for plant growth (Hilgard, 1906). Also Shantz and Marbut (1923) stated that the soil under the tropical rain forest is relatively fertile. It is not surprising that such views existed, since virtually nothing was known about tropical soils at the beginning of the 1900s, and generalizations existed widely. For example, it was thought there were four major soil types which occupied the cultivated area in India, although Hilgard (1906) mentioned that "... it is hardly to be expected that so large an area as that of India ...could be even thus briefly characterized."

The high fertility theory was dispelled when the forest was cut and crops were planted, and it was discovered that yields were disappointingly low. In the subsequent period it was emphasized that soil fertility in the tropics was uniformly low and easily lost by cultivation (Jacks and Whyte, 1939). Travelers in the tropics noted that soils were lighter in color, and hence assumed that such soils had lower organic matter contents and chemical fertility. It is likely that these ideas about lower organic matter contents and soil chemical fertility are an aftermath of the 19th century humus theory, which was dispelled by Baron Justus von Liebig in the 1840s.

B. After the Second World War

After the second World War, research emphasis was placed on the improvement of soil fertility by the judicious application of inorganic fertilizers. A very large number of inorganic fertilizer experiments were conducted from the 1950s onward (Greenland, 1994; Singh and Goma, 1995; Traore and Harris, 1995). These experiments focused on the search for balanced nutrition, the economics of fertilizers, credit, subsidies, and marketing of fertilizers, and fertilizer training programs and extension. Attention was focused more on the rate and balance of fertilizer application than on the identification of nutrient disorders. Following the food production decline in the 1960s, FAO launched in 1961 the Freedom From Hunger Campaign (FFHC) which was partly financed by the world fertilizer industry. The FFHC's main target was to encourage the use of fertilizers by small-scale farmers through education and effective means of distribution and credit. The overall idea was that agricultural production cannot be significantly increased in the developing countries of the world without improving the nutrient status of most soils (Olson, 1970).

C. Inorganic Fertilizer Use

The increased use of inorganic fertilizers in tropical regions was deemed necessary (i) to increase production per unit of land in the face of a growing shortage of arable land in many developing countries, (ii) to increase marketed food supplies or exports, and (iii) to raise incomes and return to labor (FAO, 1987). Furthermore inorganic fertilizers were needed to make full use of the new high-yielding varieties. The combined package of new crop varieties, pests and disease control, and the use of inorganic fertilizers caused a dramatic increase in crop yields in many parts of the tropics. There is no better summary than the "Fertilizer Guide for the Tropics and Subtropics" published in 1967 and 1973 containing over 5000 references to fertilizer trials throughout the tropics (de Geus, 1973).

Locally it was noted that inorganic fertilizers had little or no effect due to crop husbandry practices (poor seedbed preparation, improper seeding, delay in sowing, etc.) or because of wrong fertilizer placement, unbalanced nutrient application, incorrect identification of nutrient limitations, or weed and insect problems. Obviously these factors were eliminated when inorganic fertilizer trials were conducted on a research station, but surfaced when fertilizers were used by subsistence farmers. As an overall result, inorganic fertilizers gave a poor profitability which affected the widespread use.

Some of the inorganic fertilizers being used in the tropics were given as aid by the United States and western European countries. On the one hand this was meant to stimulate the use of fertilizers in tropical regions and increase crop production on the other hand European countries could maintain their fertilizer industry which suffered from the declining use of fertilizers by European farmers. It also meant that many of the aid funds were retained in Europe.

In the 1970s an 1980s environmental concerns about inorganic fertilizers were rising. Excessive use of inorganic fertilizers can have devastating effects on water quality, and a well-known example is the proliferate growth of algae following enrichment with phosphates. In the Netherlands this was, however, mainly due to the use of phosphate in washing detergents and not so much due to the use of excessive amounts of P fertilizers. A second concern is the nitrate content of drinking water which is said to create health hazards for humans under specific conditions (Addiscott *et al.,* 1991). Inorganic fertilizers have also been associated with the destruction of the ozone layer, as nitrous oxides resulting from denitrification can give rise to products which catalyze ozone destruction (Bouwman, 1998). In other words, inorganic fertilizers were regarded as environmentally damaging. Part of the public opinion was probably exaggerated and excessive as was the use of inorganic fertilizers by some farmers in western Europe. The negative image of inorganic fertilizers in the temperate regions probably had some effects on the use of fertilizers in the tropical regions, although the environmental consequences of the continued low use of fertilizers are more devastating than those anticipated from increased fertilizer use in the tropics (Dudal and Byrnes, 1993).

The FFHC, which was replaced in the late 1970s by the FAO's Fertilizer Programme, gradually ceased in the 1990s, and currently FAO has no such program. With few exceptions, large-scale and widespread inorganic fertilizer trials are no longer conducted. Instead of advocating the use of inorganic fertilizers, studies in the late 1980s and early 1990s focused on new arguments to justify the use of inorganic fertilizers. This was the case when nutrient balances were reintroduced as a research tool and widespread soil fertility decline and nutrient mining were being reported, particularly for sub-Saharan Africa (Smaling, 1993). Inorganic fertilizers are not only being advocated to correct the negative nutrient balance, but, integrated nutrient management is also advocated to improve the overall negative nutrient balance and the efficiency of nutrient use (Sanchez, 1994).

Fertilizer use in some selected Asian countries is given in Table II. Although the consumption of inorganic fertilizer use is much lower than that in some European countries (Table I), the data show that the rate of increase has been high in Asian countries. The increase in inorganic fertilizers runs parallel with the increase in food production. It is interesting to note that inorganic fertilizer use in Asian countries is on average higher than that in the United States. Inorganic fertilizer use in sub-Saharan Africa countries is lower than 15 kg ha^{-1}.

Summarizing the soil fertility paradigms in tropical regions, it can be noted that in the late 1800s and early 1900s it was perceived that tropical soils were uniformly rich. This was followed by a period in which it was believed that tropical soils were of inherent low fertility and quickly lost by cultivation. After the second World War, research efforts largely focused on the use of inorganic fertilizers to overcome low

Table II

Inorganic Fertilizer Use in Some Selected Asian Countries in Different Periods[a]

	1968–1970	1983–1985	1993–1995
India	16	61	105
Indonesia	16	111	135
Bangladesh	12	49	93
Thailand	7	20	70
Vietnam	36	62	170
Pakistan	19	79	124

[a]Modified after Hossain and Singh (2000) based on FAO databases. Values in kg nutrients (N, P_2O_5, K_2O) per hectare y^{-1}.

soil fertility, and a large number of trials were conducted. In the period that followed it was found that inorganic fertilizers, were not widely used, and as a result, soil fertility is being mined leading to a declining agricultural productivity, which particularly applies to sub-Sahara Africa.

D. Important Themes

In tropical regions, important soil science themes have not changed much in past decades, and soil science is still closely linked to agriculture and society at large. The feeding of the ever-increasing population, the decreasing food production per capita in some African countries, and soil degradation are as worthy themes today as they were 20 to 30 years ago. About 95% of the current population growth takes place in tropical regions, and a continuing increase in food production is required. Recently, some emphasis has been placed on nature conservation, in particular in relation to rain forests (biodiversity) and dry areas (desertification), but less in savannah areas. Increased contamination of soil and water environment is of particular concern in developing countries where both local industries and often foreign investors have shown a general lack of appreciation of the environment (Naidu, 1998). The amount of research in environmental protection, soil contamination, and ecosystem health is relatively small. Overall there has been an increase in process-oriented research, but the absolute amount is by no means comparable to that conducted in the temperate regions. Soil fertility research in tropical regions has, however, greatly benefited from developments in instrumentation and analytical techniques (Viets, 1977).

More is known about soil resources in temperate regions than in tropical regions, despite the fact that one-third of the soils of the world are in the tropics (Eswaran *et al.,* 1992), and these support more than three-quarters of the world population (Fischer and Heilig, 1997). There are a number of reasons that are discussed later, but first we will attempt to quantify the differences. Currently about 10,000 publications on soils appear in international and national journals each year (Hartemink, 1999). These are the publications in English only, but many more are written in other major languages in books, conference proceedings, and reports. In the late 1940s and 1950s there were about 1000 to 2000 soil science publications—so the number of soil science publications has greatly increased. This is due to the increase in the number of soil scientists (van Baren *et al.,* 2000), an increase in the number of soil science and agronomic journals (Hartemink, 2000), and an increased pressure to publish, which also resulted in the recycling of ideas and manuscripts. Above all, it demonstrates the enormous increase in soil science knowledge, which is also reflected, for example, in the development of the book—"Soil conditions and Plant Growth" (Greenland, 1997) and the extensive "Handbook of Soil Science"(Sumner, 2000).

E. Number of Publications and Soil Scientists

How many of journal publications deal with the tropics? Arvanitis (1994) estimated from French databases that about 22% of soil publications originate from the tropics. Yaalon (1989) mentioned that the share of all the Third World countries in soil research increased from 9 to 11% in 21 years. Searches through ISI's databases showed that more publications appear on Australia than on the whole of Africa. On average there are five times more publications on the Netherlands than on Tanzania, whereas the population of Tanzania is twice as large as that of the Netherlands. Three times more publications originate from Europe as compared to Africa. On average there are 30 to 40 times more publications on cancer than on poverty, and twice as many publications on cancer than on soils. There is, however, a clear increasing trend in the number of publications about soil. The increase is on average 5% per year, which was also noted by Yaalon (1989), and found when other literature databases were analyzed (Hartemink, 1999).

The difference in the number of publications on tropical soil research compared to soil research in the temperate regions is because, with some exceptions, soil research in the tropics started several decades later than in the temperate regions, and there are (and have been) fewer soil scientists with less advanced research facilities in tropical regions. Educational opportunities are also more limited in these regions. The amount of research funds differs largely between tropical and temperate regions, although exact figures are not available. In Africa the allocation of funds for agricultural research grew rapidly in the 1960s, moderately in the 1970s, and in general stagnated in the 1980s in most countries (Noor, 1998). Currently, developed countries spend on average about $200 a year per farmer on research and extension, whereas developing countries spend $4 (Young, 1998). Most developing countries face reduced funding and a wave of redundancies in the international research centers. There are no signs that the funding situation is

Table III

Number of International Society of Soil Science Members for Different Continents in 1974 and 1998[a]

	1974		1998		Difference 1974–1998(%)
Western Europe	1316	(33)[b]	2481	(35)	+89
Eastern Europe +USSR/CIS	351	(9)	379	(5)	+8
Middle East	104	(3)	233	(3)	+124
Africa	278	(7)	454	(6)	+63
Asia	280	(7)	881	(13)	+215
Australia + New Zealand	348	(9)	364	(5)	+6
Latin America + Caribbean	171	(4)	597	(8)	+249
North America	1110	(28)	1653	(23)	+49
Total	3958		7042		+78

[a]After van Baren *et al.* (2000) based on ISSS statistics.
[b]Percentage of total members is in parentheses.

improving, and, for example, the European Union reduced its contribution to the CGIAR system by U$16 million for the year 2000.

The number of soil scientists has greatly increased in the past century, although regional differences are large (Table III). Between 1974 and 1998, the total number of members of the International Society of Soil Science (ISSS) increased by 78%, whereas over the same period the world population increased by 42%, from 4.14 to 5.86 billion. More than half of the ISSS members are based in western Europe and North America. Large increases in ISSS members were found in the Middle East, Asia and Latin America, and the Caribbean, in which the number of members tripled between 1974 and 1998. Few changes in membership were registered in eastern Europe/CIS. The total number of members in Australia increased from 243 to 312 between 1974 and 1998, but the number in New Zealand decreased from 105 to 52 over the same period (van Baren *et al.,* 2000).

There is a difference in the number of agricultural and soil scientists between tropical and temperate regions. In the 1960s, the number of research workers per 100,000 farm workers was about 1.0 in Cameroon, 1.2 in India, but 60 in Japan, and 133 in The Netherlands (Olson, 1970). In 1998, there were per 1000 km^2 agricultural land about 0.5 soil scientists in India, 1.2 in Brazil compared to 2.8 in The Netherlands and 55.1 in Japan (Table IV). A large number of soil scientists are found in China, the United States, Brazil, and Japan. However, the number of soil scientists per million inhabitants was highest in New Zealand, Australia, Israel, and Spain. With some exceptions the data show that the total number of soil scientists as well as the number of soil scientists per million inhabitants or hectare agricultural land are commonly lower in tropical regions than in temperate regions.

A criticism is that developed countries have paid little attention to the education of local soil scientists in tropical regions (Muchena and Kiome, 1995). With time

Table IV

Soil Scientists per Million Habitants and Agricultural Land in 1998 in Some Selected Countries[a]

Country	Total number of soil scientists	Soil scientists per million inhabitants	Soil scientists per 1000 km^2 agricultural land
Australia	1,000	53.7	0.2
Brazil	2,900	17.1	1.2
Canada	320	10.4	0.4
China, P.R. of	10,200	8.2	1.9
France	900	15.3	3.0
Germany	2,500	30.5	14.4
India	900	0.9	0.5
Israel	250	44.3	43.1
Italy	300	5.3	1.9
Japan	2,800	22.2	55.1
Mexico	700	7.1	0.6
Netherlands	450	28.6	22.8
New Zealand	430	118.6	2.6
South Africa	270	6.3	0.3
South Korea	930	20.0	49.7
Spain	1,450	37.1	4.7
Thailand	500	8.3	2.4
Turkey	225	3.5	0.6
UK	1,000	17.0	5.8
United States	6,050	22.4	1.4

[a]Modified after van Baren *et al.* (2000) based on ISSS statistics and agricultural databases.

the difference in the number of soil scientists may level out, as the number is declining in most countries of the temperate region. Changes in the number of soil scientists is of course directly related to the level of government funding. Arvanitis and Chatelin (1994) mentioned that the number of soil scientists in a country is probably inversely proportional to the pressures exerted on them. Soil scientists in the tropics are often required to conduct applied research in areas of direct national interest such as self-sufficiency and education, or they are even asked to participate actively in politics (Arvanitis and Chatelin, 1994).

F. Myths about Soils in the Tropics

In addition to the quantitative aspects of the number of soil scientists and publications, there are other causes which have restricted the advancement of soil science in tropical regions. Overgeneralizations about soil in tropical regions have led to many misconceptions about its potential (Lal and Sanchez, 1992; Sanchez and Buol, 1975). There have been a number of myths, and the myth of rapid laterization under cultivation is probably best known. Up to the 1930s it was thought that the tropics were covered by laterite crust and lateritic soils, because a number of often-quoted writers on laterite had never been in the tropics (Prescott and Pendleton, 1952). Research in Indonesia and East Africa dispelled the theory, but it took many decades before it was fully dispelled from soil science literature (Lal and Sanchez, 1992). Other myths were that soils in the rain forest were extremely rich and able to support the abundance of vegetation, that shifting cultivation was a backward type of agriculture (FAO-Staff, 1957) accelerating the formation of laterite (Vine, 1968), that all soils in the tropics were highly erodible (Jacks and Whyte, 1939), that tropical soils were very low in organic matter (Ruthenberg, 1972), very old, and intensively weathered due to year-round high rainfall and temperatures. These misconceptions were largely eliminated by the works of, among others, Mohr and van Baren (1959), Nye and Greenland (1960), Kellogg (1963), Sombroek (1966), Sanchez (1976), Sanchez *et al.* (1982), and Greenland *et al.* (1992). Some misconceptions are hard to eliminate. For example, the concept of zonality introduced by the Russian school of pedology is still being used in some standard texts on tropical forests (Burnham, 1985) and tropical agriculture (Webster and Wilson, 1980; Wrigley, 1982) despite its abandonment in the 1940s (Smith, 1983).

The lack of a universally used soil classification system also retarded the advancement of soil knowledge in tropical regions. For example, Latosols has a different meaning to different soil scientists, as it was used in both the national soil classification systems of Brazil and Indonesia. A tremendous effort has been made to develop soil classification systems, but it is unfortunate that the efforts have not resulted in something widely used and understood by nonsoil scientists or even nonpedologists. The World Reference Base for soil resources, which was presented at the 16th World Congress of Soil Science as the international soil classification system, might change the situation.

IV. DIAMETRICALLY OPPOSITE INTERESTS

There are a number of common interests in soil research in temperate and tropical regions. In both regions it is recognized that sustainable land management systems need to be developed (Eger *et al.,* 1996), and there is a search for appropriate land quality indicators (Doran and Parkin, 1996; Eijsackers, 1998). Another common interest is the sequestration of C in agricultural and forest soils (Lal, Kimble, and Follet, 1998) and the problems associated with global climate change. Tools and techniques developed in the temperate region are therefore of direct interest to soil science in the tropical regions, and some consider that soil science in developing countries should focus on soil technology adoption only (Yaalon, 1996).

Nevertheless, it sometimes appears that soil science in temperate and tropical regions has diametrically opposite interests, and two striking examples are discussed here.

A. Soil Acidity

In upland soils in tropical regions soil acidity is a major problem which can have pedogenetic (parent material, age) or anthropogenic causes (ammonia-N fertilizers). The upland soils are nevertheless considered the largest remaining potential for future agricultural development (Theng, 1991; Von Uexküll and Mutert, 1995). Several strategies to manage soil acidity have been developed in order to increase and sustain food production on these soils (Myers and de Pauw, 1995; Sanchez and Salinas, 1981). Research has focused not only on methods to increase the pH but also on the development of acid-tolerant crop cultivars (Sanchez and Benites, 1987).

In temperate regions, it has been recognized since before Roman times that chalk or marl spread on acid soils improved their fertility, and this was widely used during the 18th century by the pioneers of the English agricultural revolution (Bridges and de Bakker, 1997). This practice lapsed when agricultural lime became available in the 19th century. So the soil acidity problem in the temperate regions was largely overcome through application of pH increasing substances over decades or even centuries. Research interest in soil acidity increased in the 1970s because of the problems associated with acid rain (Reuss and Johnson, 1986). Acid rain studies made many people aware that environmental problems cut across national borders. With falling emission and deposition of N and S (Jenkins, 1999), interest in soil and surface water acidification decreased, and climate change became the new focus of attention.

Currently there is renewed interest in soil acidity because of the set-aside policy whereby agricultural land is taken out of production and restored to heathland or forest. In some soils in Scotland restoration to heathland meant that the pH, which was increased through many years of lime applications, had to be reduced by 2 to 3 units for which heavy applications of elemental sulfur were used (Owen *et al.,* 1999). Set-aside problems are unknown in tropical regions where the need for more land has increased because of the growing population (Harris and Kennedy, 1999; Krautkraemer, 1994; Seidl and Tisdell, 1999). The only example from the tropics is the use of elemental sulfur in neutral soils at tea plantations, since tea requires a strongly acid soil (TRFK, 1986).

Another example for the renewed interest in soil acidity comes from The Netherlands, where about 25,000 ha or 1% of the total area under agriculture was taken out of production between 1993 and 1996. When sandy soils previously under intensive horticulture with heavy applications of biocides were set aside and not cultivated, these soils naturally acidified. As a result mobile Cd originating from the biocides increased, and regular lime applications are needed to these soils to reduce the Cd solubility and mobility (Boekhold, 1992). It is an interesting example how nature restoration—not agriculture—brings to surface the so-called chemical time bomb.

B. Soil Nutrients

Nutrient enrichment, particularly N and P, has occurred in many agricultural soils of western Europe, and nutrient management is a topic of major political interest (de Walle and Sevenster, 1998; Kuipers and Mandersloot, 1999). In most intensive crop and livestock production systems, the input of nutrients exceeds the output resulting in considerable mineral surpluses in the soil. Inorganic fertilizers are relatively cheap, and there is a large import of nutrients with stock feed resulting in more manure than can be spread on the land. Many of the problems in the intensive agricultural systems of western Europe are therefore structural rather than local and cannot easily be solved by transport of manure to other regions (de Walle and Sevenster, 1998).

In the 1980s and 1990s, evidence has accumulated that nutrient depletion is a problem in many tropical soils (Dudal, 1982; Greenland, 1981; Lal, 1987; Pieri, 1989; Sanchez *et al.,* 1997). The major cause is the drain of nutrients with the crop yield, erosion, and losses through leaching or denitrification, while little or no inorganic fertilizers are being used. Also the use of manure is insufficient to cover the drain of nutrients, and this shortage is further aggravated as livestock numbers generally decrease with increasing population.

Thus, where the soil scientist in the temperate region is concerned with N leaching causing groundwater contamination and eutrophication of surface waters, soil scientists in tropical regions are concerned with leaching because of the loss of N for crop production. There is a common interest in reduction of nutrient losses, although the motives are diametrically opposed. Where in the temperate soils under intensive agriculture P saturation is a concern, the low levels in many tropical soils warrant a similar level of interests in the complex chemistry of soil P. And where the soil scientist in the temperate regions is interested in soil changes when the land is deliberately taken out of production and not cultivated, a key question in the tropics is how the soil can be kept productive when continuously cultivated, and what needs to be done to make, and keep, marginally suitable soils productive.

The soil nutrient situation is even more deplorable if it is realized that in the intensive livestock production systems of the temperate region soils are being used as a dumping ground for nutrients, whereas some of these nutrients originate from tropical countries where many soils are chemically poor and few inorganic fertilizers are being used (Bouwman and Booij, 1998; van Diest, 1986). From a soil nutrient perspective it appears that soil fertility research in tropical regions is all about alleviating poverty, whereas in the temperate regions it is mainly about alleviating abundance and wealth. The soil appears as a fitting metaphor for the economic differences between the two regions.

V. IMPACT OF SOIL SCIENCE

The understanding and knowledge of soils kept pace with the dramatic increase in population and enormous changes in global land use of the past 100 years. Despite this success, the general public has never been widely interested in soils, and there is a deep concern about the public profile and appreciation of soil science (White, 1997). It was noted that soil science goes through a period of reduced funding and public interest, and several conferences and committees were dedicated to the question of how soil scientists should cope with this situation (Mermut and Eswaran, 1997; Sposito and Reginato, 1992; Wagenet and Bouma, 1996). Most authors are optimistic and positive; for example, Mermut and Eswaran (1997) stated that "... we believe that the future of soil science is stronger than before and the demand for soil scientists will be greater than before." Largely absent in these forward-looking publications is the future development of soil science in tropical regions. That is particularly unfortunate as less is known about tropical soils, and evident problems are evolving because of population pressure (Young, 1998). It is in the tropics where soil scientists can have the largest impact on society and where there is incomplete understanding of the soil and a paucity of hard information (Theng, 1991).

Although it is generally accepted that soil science is of great importance, very little has been written about the contribution to knowledge and, hence, to society, arising from the scientific study of the soil (Greenland, 1991). This particularly concerns the impact of soil science in tropical regions, and much more is known about agricultural research and the role it has played in the advancement of agriculture and land use in Europe (Porceddu and Rabbinge, 1997). Many soil scientists are concerned by the lack of impact, and authoritative knowledge about soils has failed to reach many government administrators, financial organizations, planners, educational authorities, and land users who would most benefit from the knowledge (Bridges and Catizzone, 1996). Such impact is of course hard to measure directly, but Lal (1995) mentioned that it can be judged from agricultural and food production trends and from the use of science-based input. Much of the credit for the agricultural production increase has deservedly been given to the plant breeders, but demonstration of the importance of proper nutrient management and of the potential to intensify cropping systems and develop new lands was due to soil scientists. If it were not for soil scientists, Thomas Malthus would have been right according to Greenland (1991).

The situation is different in different continents. In large parts of Asia agricultural productivity has increased largely due to new crop cultivars and other products from the Green Revolution (Table II). Food production in some African countries has been falling (Greenland, 1997; Pinstrup-Andersen, 1998), which could be because the Green Revolution had fewer inroads (Lappe *et al.,* 1998). Or does it imply that soil scientists had limited impact in Africa? We do not know; but quite likely there would have been many more East African Groundnut Schemes if soil science had ignored Africa, although the failure of the scheme was an important stimulus to the use of soil surveys in development projects (Young, 1976).

Muchena and Kiome (1995) discussed the role of soil science in agricultural development in East Africa and concluded that it has played a modest role. Unfortunately this role goes largely unquantified. They conclude that despite the activities of numerous foreign experts, there is still inadequate expertise in some key disciplines such as soil physics, land evaluation, and water management. More research is needed. However, a convincing plea for the increasing need for soil research in the tropics should not be based on areas where expertise is inadequate but on a quantitative analysis of the impact of soil science. That may be much needed since donors are less eager to fund soil research in the tropics, and large international organizations like FAO essentially stopped collecting soil data because of the lack of funds from the UNDP and bilaterals for field projects. In past decades, many national soil science institutes in tropical regions have emerged, but the need remains to maintain an active international soil science network for effective exchange of information and to cut costs. The developed world is reducing its willingness to contribute to the development of science in the tropical regions, and this may hinder the advancement of soil science in the tropical regions. A possible option to reverse this trend is to quantify the impact of soil science on development in tropical regions. There have been a number of initiatives to actively promote soil science, but too few studies have quantified the impact of soil science, and that, unfortunately, applies to both tropical and temperate regions.

VI. CONCLUDING REMARKS

More is known about soil resources in temperate regions than in tropical regions, despite the fact that one-third of the soils of the world are in the tropics and support more than three-quarters of the world population. In addition, 95% of the population growth takes place in tropical regions. Therefore it is in the tropics that soil scientists can have a large impact on society, because there is an incomplete understanding of the soil and insufficient hard information.

In temperate regions, the focus of attention is currently shifting to population aging, whereas in tropical regions the increasing population and the associated need to increase food production remain important subjects for soil science. Most attention needs to be given to yield increases, as there is limited potential for an expansion of the agricultural area in most tropical countries. Also environmental soil science in tropical regions needs to be further developed.

Some of the common research interests in the temperate and tropical region are the development of sustainable land management systems and appropriate land quality indicators, quantification of soil properties and processes, fine tuning of models, sequestration of C in agricultural soils, and optimum use of agricultural inputs to minimize environmental degradation and maximize profit. Close cooperation on these subjects is of interest for soil science in both temperate and tropical regions. However, it seems that the developed world is reducing its willingness to contribute to the development of science in tropical regions, and this may hinder the advancement of soil science in tropical regions.

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