Chapter 5
Soil Map Density and a Nation's Wealth and Income

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Abstract Little effort has been made to link soil mapping and soil data density to a nation's welfare. Soil map density in 31 European countries and 44 low and middle income countries is linked to Gross Domestic Product (GDP) per capita and the number of soil scientists per country. National coverage of exploratory soil maps (>1:250 000) is generally higher in the poorest countries and decreases with increasing GDP per capita, whereas the national coverage of detailed soil maps (<1:50 000) tends to increase with increasing GDP. GDP is larger in countries with more soil scientists per unit area, likewise, the number of soil scientists increases with increasing GDP. More soil scientists per ha of agricultural land was found to be related to higher crop yields. Obviously, there are many confounding and interacting factors but this analysis illustrates how proxies for soil map density can be used; it is suggested that appropriate indicators should also be developed for spatial data infrastructures and digital soil maps to demonstrate their effectiveness for society and human welfare.

5.1 Introduction

Some countries are poor, some are rich, and there a lot of countries in between. Explaining the differences is not easy and related to a whole series of factors. Wealth and income of countries is driven by macro-economics but also by, for example, geography and the richness of natural resources: e.g. soil, climate and mineral wealth (Sachs, 2005). It is hard to unravel the influence of each developmental factor – many of which are interacting and are also greatly affected by humans. If the wealth of a nation can be viewed as its accrued assets and inherent property, the income is the yearly money that is derived from that wealth. The soil is an obvious factor in the wealth and income of a nation and may have a clear relation to a nation's wealth

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and income. It is assumed that such relation not only holds for the wealth of soil resources itself, but also the wealth of information about those soil resources.

Little effort has been made to link soil information to developmental indicators or to quantify the effects of soil research on the wealth and income of nations. That is not surprising as the benefits of soil research have been poorly quantified (Greenland, 1991) as they are hard to measure and may be masked by other factors. Since soil science emerged in the mid 1800s, an enormous amount of information has been collected and insight has been gained in both the intrinsic properties of soils and the spatial soil distribution in different parts of the world. Relating intrinsic soil properties to crop productivity ($\approx$ yield, income) is relatively easy. For example, the economics of fertilizer applications or large-scale drainage scheme have been studied in most parts of the world and have shown to be essential for generating income and wealth. Currently, such efforts have reached a new stage with the rapid developments in soil sensors and precision agriculture (see Section 2.2 and 2.3 for an overview of new hardware and software). Given the quantitative nature of these studies and their associated uncertainty it should now be possible to accurately estimate the economic (and ecologic) benefits of soil management strategies. This mostly applies to the farm level although the variation and uncertainty in the information (McBratney, 1992) will affect the outcome of economic evaluations. Very few economic benefit studies are available at higher levels of aggregation (e.g. nations, continents) on which we mostly rely on old maps and old data. These maps were produced using traditional techniques and are generic and multipurpose so that is difficult to assess the economic benefits of the soil maps (see also Section 24.6).

There have been many claims, mainly by soil surveyors that soil surveys and mapping are economically beneficial. A problem with assessing the cost-benefit ratios of soil mapping is, however, that it is not possible to make precise generalisations about the costs of producing soil maps (Bie and Beckett, 1970). What is known is that the cost of soil survey (per unit area) rises sharply with the purity or uniformity to be achieved (Bie et al., 1973). Klingebiel (1966) reviewed a series of soil surveys and estimated that the benefit-costs ratios are larger than 50 for the USA, whereas Dent and Young (1981) also mentioned that these ratios for soil surveys are usually very high. Although only few studies have assessed the benefits of soil mapping and research (Giasson et al., 2000), there are several examples of projects that have failed because of a lack of soil information in all parts of the world (Bie and Beckett, 1970).

Globally, about two-thirds of the countries have been mapped at a 1:1 million scale or larger, but over two thirds of the total land area has yet to be mapped even at a 1:1 million scale (Nachtergaele and Van Ranst, 2003). That resulted from soil surveys conducted after World War II and up to the 1980s. At present, few traditional soil surveys are being carried out and many soil survey centres in the world have closed. There are great differences between countries in the status of mapped areas (extent, scale) but also in the status of digitising old information and combining it with other data layers to produce digital soil maps (McBratney et al., 2003) – see also Section 3.1.1. Fairly accurate data exist on the coverage of soil maps at different scales for most countries. In this chapter, soil map density at different scales is linked to GDP per capita and the number of soil scientists of 31 European countries and 44 low and middle income countries. Soil map density is used here as a proxy for soil data density. First, I shall look at the number of soil scientists per country because: no soil maps without soil scientists.

5.2 Soil Scientists per Country

The amount and quality of soil research is dependent on the number of soil scientists and their resources. It is possible to estimate the research resources of individual departments and centres, but quantifying the total money available and earmarked for soil science in a nation is hardly possible. Data on the number of soil scientists, however, can be obtained from national soil science societies and the International Union of Soil Sciences (IUSS). Van Baren et al. (2000) linked the number of IUSS members to total inhabitants and the agricultural land area for different countries. This information has been updated with recent figures from the national soil science societies (Table 5.1).

According to the IUSS membership data, the USA has the largest number of soil scientists (approximately 4000), followed by Germany (2311) and India (1846). Clearly, in all these countries there may be a few more soil scientists as not all of them will be members of the national societies, and not all members of these societies are active soil scientists. Some of the numbers are very small and probably wrong (e.g. underestimates for Brazil and China) Switzerland has the highest number of soil scientists per capita; roughly one in twenty thousand Swiss is a member of their national soil science society. The lowest number per capita is found in Brazil, India, Mexico, South Africa, and Turkey where less than 2 in 1 million inhabitants are member of their national soil science societies. A high number of soil scientists per ha agricultural land is found in Germany, Japan, the Netherlands, South Korea and Switzerland. The lowest number of soil scientists per ha agricultural land is found in Australia, Brazil, China, Mexico, Russia, South Africa, and Turkey. Clearly, there are a lot of "chicken and egg" type of relationships in this table. There is a fairly direct relation between the share of GDP spent on research and development and the average grain yield; countries that spent more on research have higher yields. The relation between the share of GDP spent on research and development and GDP per capita is strong, richer countries spend more money on research and vice versa. Also, GDP per capita relates very well to the number of soil scientists in a country. Richer countries have more soil scientists per capita. The total number of members of a national soil science society is well-correlated ($R^2 = 0.7^{***}$) with the number of inhabitants in a country. Also, members and the total area under agriculture are fairly well-correlated ($R^2 = 0.5^{**}$); countries with large areas under agriculture often have more soil scientists.

Table 5.1 Total members for each national soil science society, per unit land area, GDP per capita, research and development spending as % of GDP, and average grain yield per ha, for 30 countries

Country	Total no of members	Number of members per million inhabitants	Number of members per 1000 km^2 total area	Number of members per 1000 km^2 agricultural land	GDP per capita US$	R&D as % of GDP	Grain yield Mg ha^{-1}
Australia	496	24.7	0.1	0.1	32 000	1.70	1.9
Austria	183	22.4	2.2	5.4	32 900	2.33	5.4
Belgium	250	24.1	8.2	3.0	31 900	1.90	8.0
Brazil	200	1.1	0.0	0.1	8 400	0.98	2.4
Canada	255	7.8	0.0	0.4	32 900	1.93	2.8
China	1000	0.8	0.1	0.2	6 300	1.44	4.0
Denmark	70	12.9	1.6	2.6	33 400	2.63	6.2
Finland	203	38.9	0.6	9.0	30 600	3.46	3.5
France	413	6.8	0.7	1.4	30 000	2.16	7.2
Germany	2311	28.0	6.5	13.6	29 800	2.49	6.5
Hungary	200	20.0	2.1	3.4	16 100	0.88	3.6
India	1846	1.7	0.6	1.0	3 400	0.85	1.9
Israel	50	8.0	2.4	8.8	22 300	4.46	2.4
Italy	223	3.8	0.7	1.5	28 400	1.14	4.9
Japan	800	6.3	2.1	15.5	30 700	3.15	4.3
Mexico	50	0.5	0.0	0.0	10 100	0.40	2.7
Netherlands	409	24.9	10.0	21.2	30 600	1.85	7.9
New Zealand	63	15.6	0.2	0.4	24 200	1.16	6.3
Norway	50	10.9	0.2	4.8	42 400	1.75	3.9
Poland	200	5.2	0.6	1.2	12 700	0.58	2.5

Table 5.1 (continued)

Country	Total no of members	Number of members per million inhabitants	Number of members per 1000 km^2 total area	Number of members per 1000 km^2 agricultural land	GDP per capita US$	R&D as % of GDP	Grain yield Mg ha^{-1}
Portugal	237	22.4	2.6	6.3	18 600	0.78	2.7
Russia	360	2.5	0.0	0.2	10 700	1.17	1.6
South Africa	69	1.6	0.1	0.1	12 100	0.76	2.9
South Korea	520	10.7	5.3	17.6	20 400	2.64	4.4
Spain	408	10.1	0.8	1.4	25 200	1.11	3.6
Switzerland	354	47.3	8.6	23.2	35 300	2.57	6.6
Thailand	300	4.7	0.6	1.6	8 300	0.26	2.0
Turkey	50	0.7	0.1	0.1	7 900	0.66	2.3
UK	815	13.5	3.3	4.8	30 900	1.89	7.2
USA	4000	13.5	0.4	1.0	42 000	2.68	5.8

Member data from IUSS (R. Harris) 2004 and 2005; Agricultural land use 2003 from FAO FAOSTAT; Population data from 2005 www.census.gov; GDP data from 2003–2004 www.cia.gov; Research and Development data from World Bank and UNESCO 2001–2004; Grain yield equivalent data from 2000, FAOSTAT, FAO

5.3 Soil Maps – Europe

The first soil maps in Europe were made in the 1800s. They were mostly produced for agricultural purposes or the taxation of rural lands and emphasised surficial geology and the degree of weathering of the regolith (Stremme, 1997). The first task of the International Society of Soil Science (ISSS but since 1998: International Union of Soil Sciences, IUSS) established in Rome in 1924 was to produce a Soil Map of Europe. This was necessary to overcome language problems and differences in mapping approaches. Countries in Eastern Europe followed the Russian (= V.V. Dokuchaev and N.M. Sibirtsev) approach of mapping soils as natural bodies, whereas those in Western Europe – where systematic mapping started later – followed a more geological approach.

The first European soil map was published in 1928 at a scale of 1:10 million. It has 27 map units and was based on the geological map at a scale of 1:5 million. The map was presented at the first World Congress of Soil Science in Washington D.C. (USA) in 1927 where it was agreed to produce a more detailed map at a scale of 1:2.5 million. This map was published in 1937 and has 43 map units grouped in seven sets.

The next Soil Map of Europe was produced 30 years later by the Food and Agricultural Organization of the UN and the EEC (FAO, 1965). Systems of classification used in the different countries varied in approach but for the 1965 map a uniform legend was presented. The legend consists of soil associations composed of soil units. Many countries only started systematic soil surveys after the Second World War, and this map contains the best soil distribution information available at that time. The earlier maps of the 1920s and 1930s were not used in the 1965 European soil maps or in successive efforts.

The next European soil maps were produced in the framework of the 1:5 million Soil Map of the World for which preparation began in 1961 as a joint project of FAO and UNESCO following a recommendation of the ISSS. The complete set of the Soil Map of the World was presented at the 10th World Congress of Soil Science in Moscow in 1974, and publication of all 19 map sheets was achieved by 1981. The European volume was the last sheet that was published. Most of the European region was covered by systematic soil surveys but only Iceland, the northern parts of Finland and the USSR and Turkey in Asia were mapped at the reconnaissance level. On the 1:5 million map, units are associations of soil units (e.g. Arenosols, Vertisols) which were assigned texture and topography (slope class) of the dominant soil. Phases (e.g. stony, phreatic) are superimposed on the map units. At last, in 1985 a 1:1 million soil map of Europe was published (Commission of the European Communities, 1985). The map has 20 soil orders (major soil groups) like Gleysols or Luvisols and more than 60 great groups or soil units (e.g. Chromic Cambisols). The legend of the map shows 312 different map units which consist of associations of soil units occurring within the limits of a mappable physiographic entity.

The completion of the Soil Map of the World by FAO-UNESCO has been one of the main contributions of the ISSS (Van Baren et al., 2000) and has since its completion found wide applications, like for example: assessment of desertification, delineation of major agro-ecological zones, evaluation of global land degradation, calculation of population supporting capacity, creation of a World Reference Base for Soil Resources, and the creation of a digital global Soils and Terrain Database (SOTER) (Oldeman and van Engelen, 1993).

5.3.1 Three Generations of Soil Maps

Table 5.2 summarises the available soil maps for Europe. The first generation maps of the 1920s and 1930s have a strong agro-geological base and were based on limited soil survey work. These soil maps stimulated soil survey and research in most European countries of which the fruits were harvested for the second generation of European soil maps (1965–1985). These developed in the heydays of soil survey and were based on hundreds of detailed national and regional maps. The second generation is now being replaced by a third generation of maps – digital soil maps in which full use is made of existing soil and other information with advancements in GIS, remote sensing and quick and accurate soil observations using a range of sensors (McBratney et al., 2003).

When comparing the 1965 soil map of Europe to the 1981 and 1985 maps there is much more detail reflected in the number of mapping units and scale of the map. All three soil maps summarize soil survey activities in each country and soil survey was at its zenith. Then the mapping was more or less over as most governments withdrew their support for multi-purpose and generic soil surveys. As a result, little traditional soil mapping (auger, spade, stereoscope) took place since the 1980s.

The coverage of detailed (1:50 000) and exploratory (1:250 000) maps was linked to the size of 31 countries in Europe. It seems that smaller countries have better coverage of both exploratory and detailed soil maps (Fig. 5.1). About 45% of the countries have complete coverage with detailed soil maps and 9 countries in Europe have less than 20% of their total area mapped at 1:50 000 and these include France, Spain and Sweden. More than 60% of the countries have 100% coverage with exploratory soil maps.

Table 5.2 Soil maps of Europe, their scale, number of legend units and map sheets (Hartemink, 2006b)

Year of publication	Map scale	Number of map units	Number of map sheets	Reference
1928	1:10 million	27	1	Stremme (1928)
1937	1:2.5 million	43	12	Stremme (1937)
1965	1:2.5 million	34	6	FAO (1965)
1981	1:5 million	> 700	2	FAO-Unesco (1981)
1985	1:1 million	312	7	Commission of the European Communities (1985)
2005	1:1–1:6.5 million	163	17	European Soil Bureau Network of the European Commission (2005)

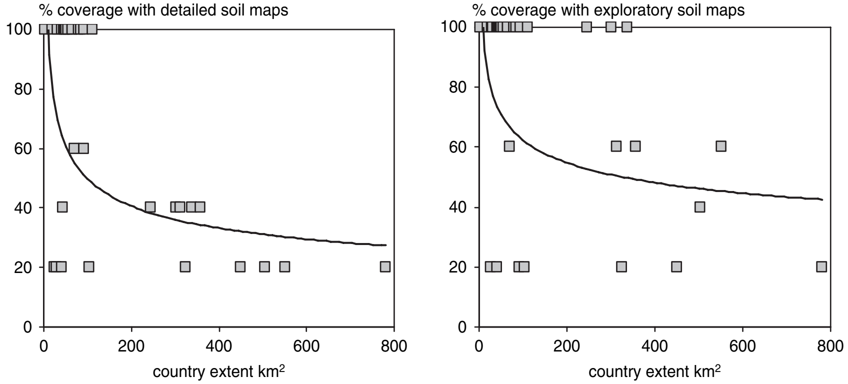

Fig. 5.1 Relation between size of 31 EU countries and the coverage with detailed soil maps (<1:50 000) and exploratory soil maps (>1:250 000)

Table 5.3 Correlation (R^2) between coverage of soil maps at a scale of 1:50 000 or 1:250 000 and country size, total population and population density of 31 European countries. Data extracted from: European Soil Bureau Network of the European Commission (2005)

	Size of the country	Total population	Population density
1:50 00 soil maps	0.364*	0.358*	0.743***
1:250 000 soil maps	0.472**	0.492**	0.795***

*,**,*** indicates significance at $P < 0.05$, $P < 0.01$ and $P < 0.001$, resp.

Correlation between a country's population density and the availability of soil maps is fairly strong and highly significant (Table 5.3). Small, highly-populated countries in Europe have the most detailed soil information; large, less densely populated countries like France, UK and Germany generally have less detailed soil maps. Correlation between number of soil scientists in 1998 or 2005 and the coverage of soil maps in 2005 is poor. However, the coverage of soil maps in 2005 is related to the number of soil scientists in 1974 (Fig. 5.2). The larger the number of soil scientists per unit area of agricultural land in 1974, the greater the coverage of soil maps, particularly exploratory soil maps in 2005.

5.4 Soil Maps – Low and Middle Income Countries

Coverage of soil maps in low and middle income countries is shown in Table 5.4. The Gambia, Jamaica and Trinidad & Tobago are covered with detailed soil maps (scale >1:25 000). About one-third of the countries have soil maps at a scale of 1:100 000–1:500 000 but these countries have hardly any maps on a larger scale, that is 1:50 000. Some countries like Congo and Algeria have very limited soil maps at any scale.

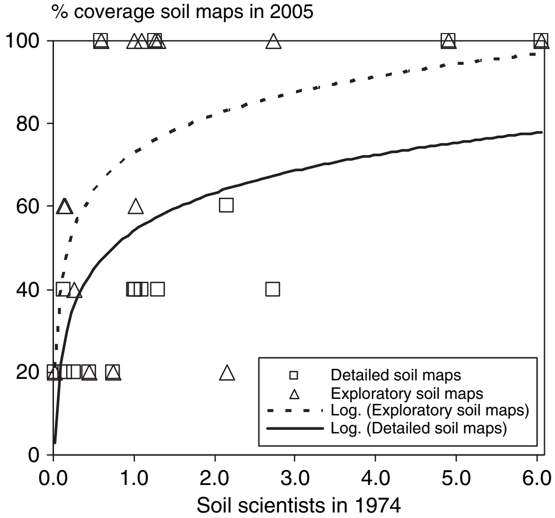

Fig. 5.2 The number of soil scientists per 1000 km^2 agricultural land in 1974 and the coverage with detailed soil maps (<1:50 000) and exploratory soil maps (>1:250 000) for 16 European countries in 2005

5.5 Soil Maps and GDP

Gross Domestic Product (GDP) per capita is often used as an indicator for a country's welfare. GDP is defined as the market value of all goods and services produced within a country in a given period of time; all other things being equal, standard of living tends to increase when GDP per capita increases. Economic data from UNDP was combined with data on the status of soil mapping in different countries (Nachtergaele and Van Ranst, 2003; Zinck, 1995). National coverage of soil maps is linked to GDP per capita (2001 data) for 44 countries (Fig. 5.3). Although the data are scattered, regression suggests that national coverage of exploratory soil maps is generally greater in the poorest countries and decreases with increasing GDP per capita; the national coverage of detailed soil maps tends to increase with increasing GDP. However, total coverage is very low in most of these countries (<20%).

GDP is larger in countries with increasing number of soil scientists (Fig. 5.4) – of course, the other way around is reasonable as well: the number of soil scientists increases with increasing GDP. More soil scientists per ha agricultural land often lead to higher yields (Fig. 5.5). Correlation between soil map density and grain yield equivalents was very low.

5.6 Discussion

The soil science community has not clearly demonstrated the benefits of soil science for society (Greenland, 1991; Hartemink, 2006a). If everyone were convinced that

Table 5.4 Coverage of soil surveys in 44 low and middle income countries. Adapated from Nachtergaele and Van Ranst (2003) and Zinck (1995)

	Small scale 1:500 000–±100 000	Medium scale 1:100 000–±50 000	Large scale ≤1:25 000
	(%)	(%)	(%)
Algeria	0	5	5
Bangladesh	95	0	0
Benin	100	10	2
Botswana	40	5	0
Brazil	35	5	5
Burkina Faso	100	25	0
Burundi	100	0	0
Cameroon	30	5	1
China	100	100	0
Colombia	85	5	5
Congo	10	5	0
Costa Rica	100	20	5
Egypt	100	10	10
Gabon	30	0	0
Gambia	100	0	100
Ghana	95	0	0
India	80	0	0
Indonesia	40	10	0
Iran	0	10	10
Jamaica	0	100	100
Kenya	100	25	0
Malaysia	100	10	0
Mali	50	0	0
Mexico	75	40	0
Morocco	0	40	20
Myanmar (Burma)	100	20	2
Nigeria	70	35	0
Pakistan	85	3	0
Panama	50	0	0
Papua-New Guinea	5	10	0
Peru	50	0	0
Philippines	100	10	0
Rwanda	100	100	0
South Africa	70	0	0
Sri Lanka	100	10	2
Swaziland	100	10	5
Tanzania	50	0	0
Thailand	0	100	20
Togo	80	20	0
Trinidad-Tobago	0	0	100
Uganda	100	0	0
Uruguay	20	20	0
Venezuela	90	5	2
Vietnam	0	40	30

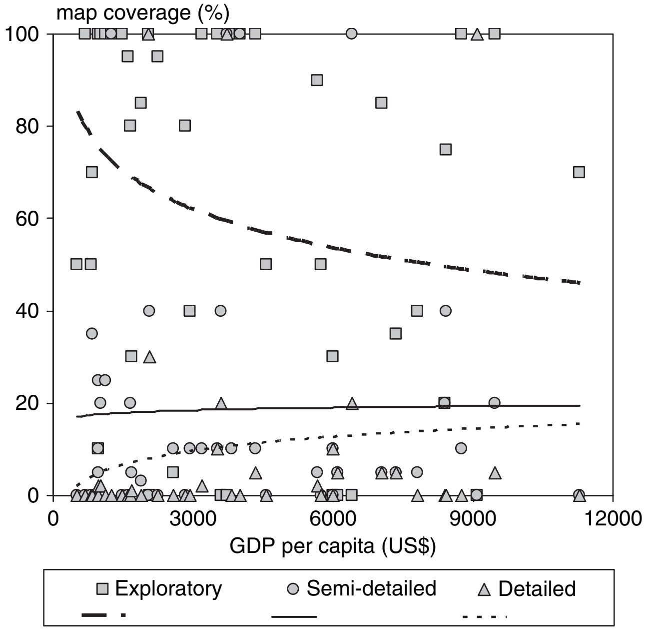

Fig. 5.3 Relation between GDP per capita (2001 data) and national coverage of exploratory soil maps (≈ 1:100 000–1:500 000), semi-detailed soil maps (≈ 1:100 000–1:50 000) and detailed soil maps (≈<1:25 000) of 44 low and middle income countries (<US$ 12 000 GDP per capita in 2001 – UNDP data)

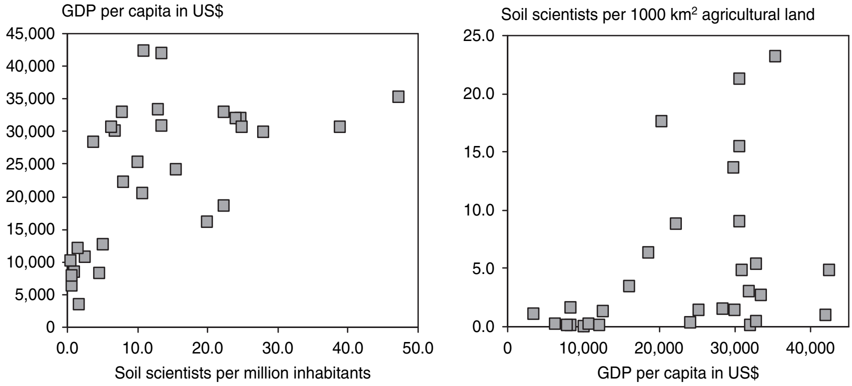

Fig. 5.4 Relationship between soil scientists per million inhabitants and GDP per capita; and between GDP per capita and the number of soil scientists per $1000\,\mathrm{km}^2$ agricultural land

soil science is essential for human welfare perhaps this demonstration would not be needed (see also Chapter 3), but I fear that is not the case. Decreasing funds for soil research, and the inability of the soil science community to effectively show the benefits has resulted in fewer soil scientists and far fewer students in many universities across the globe but in particular in the USA and Canada (Baveye et al., 2006).

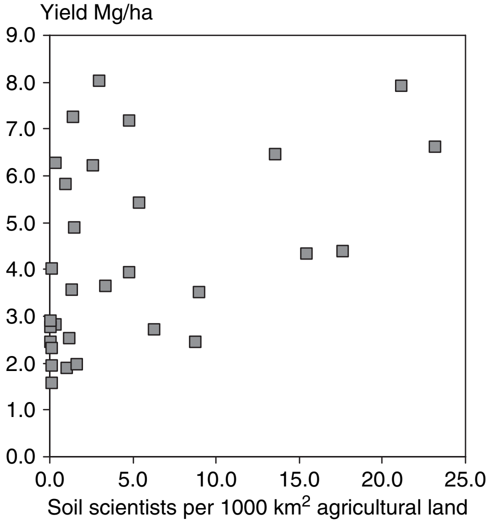

Fig. 5.5 Relation between soil scientists per 1000 km^2 agricultural land and average grain yields (FAOSTAT data)

Soil science has distinctly different foci in the developed compared to developing countries (Hartemink, 2002) whereas Chapters 22–34 show that there are many similarities in approach and problems that are to be tackled. This chapter has shown that there are large differences in these regions in terms of soil data density. Some poor countries have very good data and maps (for example, Rwanda); some rich countries are poor in data. For both groups it is imperative that the usefulness of soil information for development is illustrated. The development of digital soil maps takes places in both regions (Lagacherie et al., 2006) and it is important that appropriate indicators are sought to illustrate the effectiveness of digital soil maps. The methodologies (Chapters 13–21) exist and are continuously being developed but the extent of digital soil maps needs further increasing (Section 1.7.1).

This chapter has show a link between soil science information (maps) and GDP and some other variables. Although there are many confounding factors, these relations warrant further investigation. Clearly, few people would deny the use and relevance of soil information for agricultural project development or urban city planning but quantifying the economic benefits remains a large task (Giasson et al., 2000). Previous studies (e.g. Klingebiel, 1966; Dent and Young, 1981) have shown high benefit-cost ratios for soil surveys but these studies were based on traditional survey methods. Bui (2007) gives some cost estimates for traditional soil surveys in Australia and compared these ratios for producing digital soil maps. Costs for traditional surveys were AU\$12–28 per km^2 whereas the digital approaches were costing AU\$3–9 per km^2. Most of the reduction in costs was achieved by fewer person years to map the same area. These costs excluded infrastructure or the computer network and the costs for training a new generation of digital soil surveyors. She concluded that in a country with an aged workforce the uptake of digital soil mapping will be slow (Bui, 2007) – see also the Foreword of this book. This applies to many countries reviewed in this chapter. The real challenge for digital soil mapping is not the aging workforce but the training of a fresh generation of soil scientists that will widely use and advance new techniques (Section 6.4). Given the benefits of soils and soil information for humankind and a nation's wealth and income that new generation has a bright future ahead.

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