Chapter 3
A New Global Demand for Digital Soil Information

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Abstract The question has to be asked why – given the substantial advances in quantitative techniques over the years – 'full' Digital Soil Mapping has not been mainstreamed further and harnessed to the problems soil information can help address. This paper suggests some reasons for a slow adoption, causes for optimism for a wider adoption than at present and – using a case study from Honduras – demonstrates the ease of further development at national scale. Finally, we propose how a major effort of digital soil mapping could support development in Africa, outlining the opportunities and obstacles that await contributors.

3.1 History of Quantitative Soil Information

3.1.1 From Geostatistics Through Soil-Landscape Mapping to Gaussian Processes

Quantitative soil mapping originated in the 1970's following a frustration with the limitations of conventional soil maps to provide quantitative information about soil properties that could be accommodated in 'normal' scientific thinking. Major problems had been pointed out in the transmission of information from conventional (choropleth) maps. These problems related to both the classification process (Webster, 1968) and spatial representation using conventional surveyor procedures (e.g. Valentine, 1983), since conventional soil survey methods used a wealth of tacit understanding that proved difficult for other users to re-interpret (Hudson, 1992). The products – soil maps, their legends and classification – though useful, could not be progressed further. Digital soil mapping offered a way out of this bottleneck by providing an explicit, quantitative expression of soil property variation. Thirty years later it appears to be in a strong position to deliver.

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A.E. Hartemink et al. (eds.), *Digital Soil Mapping with Limited Data*,

Many of the current approaches to quantitative soil prediction are based on kriging. Ordinary Kriging is a form of weighted local spatial interpolation that uses a Gaussian model to derive spatial estimates of variables supported by a data-set for the area being analyzed. Its main drawback is that it does not explicitly use knowledge of soil materials or soil formation processes that explain variation, hence relies largely on the support of samples in order to produce satisfactory results. There are extensions to this method that allow the use of ancillary data, but they are difficult (if not impossible) to extend to more than one ancillary variable. Some of the most promising approaches to predictive soil mapping are expert systems and regression trees. Expert systems use expert knowledge to establish rule-based relationships between environment and soil properties (Cook et al., 1996). They may not depend on soil data to determine soil-landscape relationships, but some approaches do. Regression Trees are decision trees with linear models in the leaves. They create a piecewise linear representation of the predicted variable. Using this method Henderson et al. (2001) obtained the best results in the literature, which are able to explain more than 50% of the variance of several soil properties such as pH, clay content and sand content.

While acknowledging the value of digitised 'conventional' soil information, such as the Digital Soil Map of the World (FAO, 2000), the question has to be asked why – given the substantial advances in quantitative techniques over the years – 'full' digital soil mapping has not been mainstreamed further and harnessed to the problems soil information can help address. This paper suggests some reasons for a slow adoption, causes for optimism that digital soil mapping could be much more widely adopted than at present and – using a case study from Honduras – demonstrates the ease of further development at national scale. Finally, we propose how a major effort of digital soil mapping could support development in Africa, outlining the opportunities and obstacles that await contributors.

3.1.2 Advanced Mapping Techniques: Supply-Driven or Demand-Driven

Despite the advances in quantitative soil mapping techniques, most soil maps continued to be produced using conventional techniques. Soil information is predominantly in the form of conventional soil maps, albeit often digitised and with expanded legends. A major reason for this seems to be that – as with many new techniques – research focuses on the search for new methods more than the demand for the information they produce. Experience with development of innovative techniques suggests that a period is required in which promising methods are proposed, trialed and improved in an iterative process of continuous development. The demand during this period also expands as the benefits are articulated more clearly.

Prior to this expression of demand, effort in digital soil mapping has tended to respond to the 'supply' of capability. Without a strong external demand for specific products, method development has tended to focus on case-studies where large sample data sets are already available, rather than by a purposeful development to meet a new 'demand'.

Notable example of demand-led digital soil mapping include high-risk engineering applications demanded the accuracy that only geostatistical estimation could provide. This expresses the second reason for the slow uptake of digital soil mapping – the perceived value of better soil information may be quite small compared with other sources of uncertainty in agricultural decision-making. It is perhaps instructive to recall that for many agricultural ministries, the imperative to undertake soil mapping derives right back to well-publicised disasters. Many other agencies in both the developing and developed worlds have commissioned soil survey on the basis of a general expectation of value rather than a clearly specified demand for accuracy. For reasons explained below, we believe that the time is right to re-examine the demand to meet the challenges of agricultural development in the many countries that still lack detailed soil information.

3.1.3 Programs in Many Countries are Considered 'Complete'

In many developed countries, soil survey has been 'completed', meaning that information at 1:50 000, 1:25 000 or even better is already available. It is increasingly difficult in developed economies to argue that agricultural production requires more systematic survey when the perception of policy-makers and key decision-makers is that adequate soil information is already available. Initiatives to improve the provision of new information by quantitative methods will prove a 'difficult sale' under such conditions. In Western Australia in the early 1990's, the realization that the agricultural economy was facing a widespread threat of land degradation triggered a program of soil mapping to guarantee soil information coverage of 1:250 000 or better, aiming for 1:100 000 or 1:50 000 in high value agricultural areas. With few exceptions, information was provided by conventional soil survey.

3.2 A New Demand for Global Soil Information

The lessons above suggest to us that the first requirement of digital soil mapping is to identify the clear demand for the information it provides. Without this, effort is likely to be inappropriate to its final use, or under-resourced and restricted to 'speculative' research of indeterminate value.

The basic rationale for soil mapping is to provide information to reduce uncertainty. Improved accuracy of soil measurement is only one form of uncertainty – metric uncertainty – that is removed for decision-makers. Others – explained below – are described by Rowe (1994) as temporal, structural and translational. Structural and translational uncertainty can be particularly difficult to appreciate, but in this case they could be taken to describe firstly, the importance of soil variation in relation to other biophysical factors; and secondly the value that decision-makers place on the improvement that such information enables. To reduce structural uncertainty it is necessary to show that soil variation is considered to be a prime source of uncertainty to a solvable problem. To reduce translational uncertainty it is necessary to show that this problem is considered to be 'important' by key stakeholders around the problem.

The future of digital soil mapping therefore seems to lie more in answering questions about the potential value of information as much as answering those about methodological capability. By comparison with some major challenges facing agricultural development in Africa, we demonstrate a four-stage test of demand that should help providers clarify what information is required, and why digital methods are necessary to acquire it, and then compare these against the current situation. For digital soil mapping to be recognised as a necessity, it should pass tests of significance, novelty, actionability and delivery.

3.2.1 Is the Soil Information Significant to the Problem?

The spatial soil information provided by digital soil mapping must be perceived as highly significant to major investors to compel its acquisition. That is, it must show that digital soil mapping will remove a major source of uncertainty. Further, the advantage of digital soil mapping over conventional methods must be apparent.

Decades of research, at a range of scales shows that soil variation impacts significantly on agricultural and environmental processes. This means that statements made about processes are imprecise to the degree that the effect of soil variation is not explicitly accounted for. Yet, site variation remains unexplained in agronomic experimentation, while other sources of variation are pursued to a level which is of little practical significance. Over recent years, the volume of direct observations of yield variation from precision agriculture technology gives a better picture of within-field variation, in which the effect of soil variation is dominant, is often extremely large, accounting for up to 3 or 4-fold yield variations – far greater than effect of the treatments. Experience suggests that even farmers are surprised by the scale of this variation. Micro-scale effects of soil variation are therefore highly significant.

Agriculture is seen as less and less important to the economy and life-style of people in the developed world. In the latter half of the 20th century, most soil maps in the developed world were produced for agricultural ministries, where possible, changing in the 1970's onwards to address problems of environmental management. Since most soil maps had been designed with the aim of supporting the former goals, this change was of mixed success. However, the global significance of agriculture, and the demands placed on it for soil information are greater now than before. Agriculture remains the mainstay of livelihoods in the developing world. Agriculture is the major driver of socio-economic development in most developing countries and accounts for 30–60% of GDP. Nash (2005) reported that 63% of global population (and 73% of poor, approximately 900 million) live and work in rural areas. Soil information can assist development by (a) enabling farmers to meet the threats posed by global climate change and increasing water scarcity and pressure of land degradation, and (b) identifying a pathway out of poverty through emerging opportunities to tap into markets.

The practical significance of meso-scale soil variation can be illustrated in relation to global climate change. Many consider that global climate change to be the greatest threat facing sustainable agriculture. The impacts seem destined to be distributed unequally such that impacts are likely to be most severe in sub-Saharan Africa (IPCC, 2001; Jones and Thornton, 2003) which, with almost 40% of people under-nourished already faces enormous problems of food insecurity (Pretty, 1999). The reality of climate change is likely to be felt most keenly at a local scale, where people who are considered to be amongst the most vulnerable in the world must strive to adapt to adverse change. It is now understood that adaptive change is the key to survival for such people, yet adaptation in ignorance of fundamental changes of risks to cropping, relating to interactions with soil water and nutrition – increases the risks of an already difficult existence. While endogenous information, generated through experience of adaptation locally, is a more powerful source of understanding, it seems clear that exogenous information is essential to accelerate its development.

An example of the type of information required is of drought risk, which is a major constraint to development in Sub-Saharan Africa and is cited by farmers as the principal hazard (Dercon, 2002). While drought risk is understood well by farmers, it is difficult to assess intuitively. Even the mere threat of drought risk slows down development, by encouraging alternative risk avoidance strategies that reduce productivity below the potential. Drought risk is influenced strongly by soil variation, yet the information is lacking on which to assess covariate risk within an area, and against which to improve predictive modelling. The uncertainty related to soil variation is highly practical.

3.2.2 Is the Information Novel?

The information must offering sufficient new insight from that which is currently available. At a micro-scale, a common obstacle to acquisition of information is that while soil variation is significant, soil maps fail to offer more information than ‘farmers already know’. At meso-scale, we perceive that soil maps are taken to answer all questions, even though such maps are often absent. At a macro-scale, digital soil mapping must offer substantial new insight to help understand soil-related problems such as carbon budgeting, management of scarce water resources or constraints to agricultural productivity.

The simplest illustration of this is provided at a micro-scale by experience of precision agriculture. Literally thousands of highly detailed maps have been produced of yield variation from North America, Europe and Australia, which in many cases, show significant variation that was not understood and of unexpected degree to experienced farmers. At a meso scale, it is easier to ensure that soil maps provide novel information where – as in the majority of areas – no such maps pre-exist. Certainly, in the developing world, virtually all soil information that is provided at this scale is novel where the best alternative is based on mapping at scales of 1:1 million.

At all scales, digital soil mapping provides novel information if it explains additional variation of soil attributes that cannot be adequately explained using more conventional information. This does not seem very hard with respect to specific soil variables, where conventional maps rely on soil classification.

3.2.3 Is the Information Actionable?

We use the term 'actionable' to distinguish information that is linked to specific decisions, such as a decision to invest in a particular area. The test of 'actionability' is perhaps the hardest to satisfy, because it relies on many other conditions that can influence the readiness to decide. The tests of significance and novelty specify the *potential* importance of digital soil information. While some soil maps may justify investment to satisfy a purely educative function, the predominant expectation is that information will ultimately promote specific actions. Sometimes these need spelling out.

In the context of developing agriculture, information can be acted upon in three ways: targeting of investment or aid; policy design or to direct action such as planting. In all cases, the decision to act is the result of interpreted soil information, rather than the raw information. For example, suitability maps directed soil information, with other information, towards a specific cultivation decision. Similarly, the World Food Program or USAID could use soil information, with other data, to help target activities to assist people in areas that are either drought stricken, or lower risk (hence more suitable targets for investment). An advantage of digital soil mapping is that information is not lost through soil classification, hence more easily re-interpreted with specific applications in mind. It is also easier to update provided the spatial infrastructure allows this. The problem seems to be that in making the information specifically actionable, there is a risk in over-specialisation, thereby restricting the range of potential users who will seek the information.

3.2.4 Can the Information be Delivered to Stakeholders?

Having demonstrated the *potential* demand of digital soil mapping, the final test is to consider the practicalities of delivering information to the user. There is increasing recognition of the importance of providing free access to information to a very wide range of potential users, from policy-makers to farmer representatives. The need to transmit actionable digital soil information to users presents major operational challenges of design. In the developing world, operational problems ensue as a result of the so-called digital divide, leaving many areas without access to information delivery. While access to Information Communication Technologies (ICTs) is growing in some regions (e.g. Latin America and South East Asia) through the increasing use of internet cafes and cellular phones, for many parts of the developing world, regular access to such information does not exist beyond regional cities.

A second aspect of deliverability is the ‘self-financing’ character of information. Experience in development with the adoption of tele-communications, microfinance and micro-insurance (all information-rich instruments) suggests that if the instrument is robust and of evident value to users, delivery occurs with remarkably little promotion – people at all levels work out how to use the instrument. The challenge therefore is to.

3.3 Capability Improved

We now mention some technological developments that increase the potential of digital soil mapping to contribute substantially to agricultural improvement. These comprise new data; new processing and delivery capability and new understanding of decision support needs.

3.3.1 New Data: Topography, Climate and Vegetation

New opportunities for digital soil mapping originate from a data revolution which is providing more data on environmental variables at higher resolutions (spatial and temporal), for the entire globe. The three principle advances are for higher resolution topography, climate and vegetation data. These include:

- SRTM: High resolution terrain model (90 m, spatial resolution – improving to 30 m). Processed and downloadable from http://srtm.csi.cgiar.org (Jarvis et al., 2004).
- WorldClim: 1 km spatial resolution climate data. Processed and downloadable from http://www.worldclim.org (Hijmans et al., 2005).
- MODIS: high temporal resolution thermal and spectral imagery providing global images of vegetation every 16 days, with a spatial resolution of 250 m.

There are numerous other types of data that have become available over the past decade and many are reviewed in Chapter 2.

3.3.2 New Processing and Delivery Capability: Web-Based Delivery of Very Large Data-Sets

IDIS (Marchand, 2006) is a web-based system that delivers large spatial datasets from several major river basins around the world for use by researchers, policy-makers and others. The system delivers a large variety of geo-referenced data and is envisaged as a medium for discussion and development of methods to further interpret the mass of data that is delivered by collaborators. Similar methods could be deployed to exploit the information coming from digital soil mapping, and to encourage a transparent development of interpretations from a broad constituency of users.

3.3.3 New Understanding of Decision-Support Needs

The third advance we note is the improvement in understanding of the nature of change in agriculture, from which we could expect a fuller appreciation of the potential roles for information. While some soil maps have doubtless proved extremely valuable to specific instances, there are probably an equal or greater number of instances when information has lain unused in filing cabinets, or that users felt they were not provided with the information required. Difficulties of communication between providers and users of soil information can reflect a mis-comprehension that change in agriculture is a linear process, whereas it is now viewed as a more complex process of adaptive management (Douthwaite, 2002). This is good news for providers of digital soil mapping which has flexibility to provide soil information suitable to be accommodated in a dynamic learning process. Since all observations during such a process are influenced, to some degree, by site conditions, the opportunity exists to use soil information to help explain variation of observed change and to accelerate further change towards 'preferred sites'.

3.4 Case Study Using New Data

Pracilio et al., 2003 illustrate the use of digital soil information, coupled to crop simulation modelling, to represent spatial variations in soil water balance in an annual cropping system over a catchment in Western Australia. The catchment extent was about 500 km^2 and the mapping process could have been repeated over similar areas within the region for which input data was available. In this case, input data comprised a terrain model, pre-existing (low resolution) soil map, a geology map and partial coverage of airborne geophysical data. Several features distinguish the spatial information provided by the digital soil mapping from a conventional soil map, should it have been available.

The first feature was that the data was presented as a grid of higher spatial resolution than can be provided by normal soil maps. Effectively, terrain and geophysical data greatly improved the spatial resolution of soil information. This proved valuable to aid visual interpretation of patterns of variation in catchment hydrology and helped farmer groups, for whom the information was produced, understand the hydrologic consequences of changes in cropping patterns.

The second feature was that it was possible to accommodate the uncertainty of information about continuous variation, by using a probabilistic formulation, in ways that are difficult in conventional soil maps. A range of potential simulation model outcomes was designated for each grid cell, according to the strength of supporting evidence. This produced spatial information of outputs that accurately captured hydrologic variation. Should it have been required, uncertainty of input data could have been traced through the modelling process to identify error propagation.

The third feature was that the more transparent and flexible management of spatial soil data enabled Pracilio et al. (2003) to work ‘backwards’ from the demands of simulation modelling to determine what soil information was valuable. This contrasts to the conventional use soil maps which starts with soil map units and interprets forwards. The question that was asked was as follows: ‘Given a set of hydrologic behaviours that are associated with a known set of soil conditions, determine where these conditions are likely to be distributed over the catchment, hence the likely hydrologic behaviour’.

3.5 Conclusions

We draw the above observations together with consideration of a proposal to provide high resolution digital soil information for Africa, and show how digital soil mapping could respond to some major challenges facing agricultural development in Africa.

1. What significant problems would digital soil mapping help address?

Digital soil mapping could significantly reduce uncertainty to help address a range of major problems such as drought, adaptation to global climate change and improvement of production systems through improved nutrient management. For most parts of Africa, soil information is available at reconnaissance scale only, and then based on broadly based soil classifications that are of general, rather than specific application. digital soil mapping could provide information at more detailed spatial scale required to support local participatory initiatives that are seen as key to change. digital soil mapping could provide soil information in a more flexible and dynamic interpretative format that could help address the specific questions of groups of stakeholders.

Given the dearth of detailed soil information for most of the continent, the test of novelty (see Section 3.2.2) is easy to satisfy. Digital soil mapping would provide a huge lift of novel insight into sub-regional and local variation of agricultural performance relating to soil variation.

2. What specific actions could be supported by this information?

The range of actions supportable by digital soil mapping spread from broad support for policy design, consistent with best available information of risks and opportunities for agricultural change as they are likely to be expressed on the ground. Digital soil mapping could be used to improve targeting investment in specific agricultural technologies, starting with effective fertilizer use where the lack has constrained improvements in crop productivity. Finally, digital soil mapping could be used to vary the design of financial instruments to help manage production risks of drought and erosion such as the drought protection offered by site (and soil) specific insurance, whereby premiums could accommodate a range of risk profiles from most droughty to most retentive soils.

3. How will information be delivered?

This is perhaps the major practical challenge facing digital soil mapping because – despite the potential value of such information – it is difficult to envision national institutions having the financial or intellectual capacity to provide this information, nor the political will to invest in programs of mapping, hence development of capacity. Information would need to be coupled to specific demands for information to generate the political support and revenue necessary to initiate and sustain a program of digital soil mapping, while at the same time, a broadly-based program of capacity-building would be needed to address the major problems such as adapting to Global Climate Change.

Several options exist to encourage development:

- Development of high resolution data with global coverage, likely to be of value for digital soil mapping. Examples include SRTM, Worldclim data and coverages of soil maps such as the FAO Digital soil map of the World. Derivatives of this data are likely to be more valuable than the raw data itself.
- Case studies of digital soil mapping, linked to specific applications that are likely to be of broad significance. Examples might include the use of digital soil mapping to development of targeted adaptation to global climate change funded in their own right.
- Development of specific instruments, or derivates, that convert digital soil mappings into directly utilizable information to support decisions. An example is the incorporation of soil information into site-specific drought insurance premiums (Diaz-Nieto et al., 2006).

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