Relevance of soil and terrain information in studies of major global issues

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Abstract
Society at large is increasingly aware of the need to make better use of the world's natural resources to secure and improve the livelihood of billions of people. The increasing amount of food and non-food commodities required from agro-productions systems will have to be produced on an ever-declining base of natural resources per person. Consequently, the use efficiency of natural resources will have to be enhanced drastically. The role of soils should be better understood and exploited to this aim. ISRIC - World Soil Information collects, stores, processes and disseminates global soil and terrain information for research and development of sustainable land use. It pleads to position soils more prominently in global debates by highlighting their functions in processes of global change and major development issues.

Key Words
Soil, water, nutrients, biodiversity, food production, climate change.

Introduction
The functioning of global agro-ecosystems is dependent on the epidermis of the Earth – the soil. This natural resource has often been undervalued but awareness of its importance is improving. In economic analyses, production in regions with high land prices is allocated to regions with lower prices, with virtually no attention paid to the inherent characteristics of different soil types. Analyses of global development issues, including climate change, food production and biodiversity, give limited consideration to soil and land information. However, plants, as primary supporters of life on earth, root in soils, which supply them with water and nutrients. Moreover, since soils contain many of the elements in global cycles, including carbon, oxygen, nitrogen and water, they play a major role in balancing global processes. The greatest biodiversity is also found in the soil.

Soil formation is a very slow process that requires roughly one century to form one centimeter of soil, whereas processes of degradation may occur at a much faster rate, leading to net loss of soils. Often, the top 20 cm of soils determine their productivity, highlighting the potentially large impact of degradation on soil productivity. Scenarios for maintaining or improving the functions of soils therefore should become an integral component in global analyses.

Land requirement
Agricultural land per person will continue to decrease due to population growth and loss of fertile lands to urbanization and physical and chemical degradation. The availability of suitable agricultural land is severely limiting in most Asian countries with little space for expansion. Asian countries will have to rely increasingly on food imports (WRR 1995). Latin America inherits large potential to export food, certainly with expansion of the agricultural frontier. Expansion of agricultural land however, comes at the expense of biodiversity and creates large emissions of greenhouse gasses (GHG). In sub-Saharan African countries, land is abundantly available relative to the low population densities, though overall soil quality is poor, heavily depressing yield levels.

The total arable area will need to increase by about 200-300 million ha in the coming two decades just to meet food demand (see Bindraban *et al*. 2009). Other requirements for land, such as from agro-energy, are not yet considered in these estimates, as are changes in soil quality. According to Bai *et al*. (2008), the decline in the quality of soil and vegetation, based on remotely sensed imagery, indicates that 24% of the global land has been degrading over the past 26 years - often in very productive areas. However, there is hardly any overlap with the qualitative GLASOD study that recorded the cumulative effects of land degradation up to about 1990 and indicated that 15% cent of the land area was degraded at the time (Oldeman *et al*. 1991). The numerous factors driving the change, such as rainfall, temperature, CO_2 concentration and indeed soil characteristics, and their strong interactions, should, however, be explicitly considered following production ecological approaches (Van Ittersum and Rabbinge 1997) to relate these changes to soil quality.

Location specific fertility
A shortage of several key nutrients in soils can limit yields. In Africa, for instance, food production systems are constrained by overwhelmingly low soil fertility. Following the concept of De Wit (1992) that 'most production resources are used more efficiently under improving conditions of resource endowment', synergies and interactions between production factors at various scales should be explicitly considered in analysis of production systems to arrive at agro-technical strategies for enhancing productivity.

Bindraban *et al* (2008) showed that yields in Europe were 3 t/ha in 1961 at high fertilizer rates and increased to 8 t/ha in 2000, at similar fertilizer rates because of improved overall management practices and advanced technologies such as improved varieties. Breman *et al*. (2001) illustrated that only the synergistic effect of the combined use of organic and inorganic fertilization was able to increase yield over time in the semi-arid Sahelian region due to increased nutrient supply. Similarly, many others reported synergistic effects between soil nutrients and soil water-nutrient interactions. These insights underline the need for soil information to be location specific and to report the availability of both macro and micro nutrients. This type of detailed soil information, will have to be collated by soil survey organizations with a national mandate, for possible incorporation into ISRIC's continental and global scale databases.

Green water
The linear relation between plant biomass and transpiration, implies that greater biomass production requires more water for transpiration. The total amount of fresh water needed for the production of food in the world in 2005 has been estimated at 4,831 to some 7,000 km^3. Some 1,800 to 2,660 km^3/yr is provided by irrigation water. Feeding 9 billion people in 2050 is estimated to require 6,800 to 8,500 km^3 (Bindraban *et al*. 2010). Assuming unchanged irrigation, a total of 5,000 to 6,500 km^3 from the 11,970 km^3/yr falling on arable land should be converted into transpiration.

Molden *et al*. (2009) are cautiously optimistic about possibilities to improve water use efficiency as they warn that these will not be attained easily. Observed yields in a semi-arid Mediterranean-type environment are 100–400% below the maximum yield that can be obtained given the availability and best use of the rainfall (French and Schultz 1984). Other factors such as N, phosphorus (P), micro nutrients and diseases were greater limiters of yield than water availability. These findings are true in general for semi-arid regions. In order to increase and stabilize yields, seen the erratic nature of rainfall, soil water storage and retention properties should be improved using best management practices.

Soil biodiversity
Soils contain one of the most diverse assemblages of living organisms. Several soil organisms are known to be essential for the various chemical and physical processes, including decomposition of organic matter, immobilization of nutrients, and formation of pores. Whereas the diverse forms of life have their intrinsic value, it is important to understand the functionality of the organisms for the provision of goods and services.

Nitrogen fixation of bacteria in symbiosis with plants is a good example of such functionality. Quantitative plant growth can, however, be modeled on the basis of soil chemical and physical processes, that sufficiently accurately mimic the role of soil organism on soil processes. Some claimed that enhanced soil biodiversity would increase the use efficiency of (organic and inorganic) fertilizers. Langmeier *et al*. (2002) found however no such effect on two soils that were highly distinctive in terms of organic matter and biological activity, after 20 years treatment with organic manure and artificial fertilizers, separately. While positive impacts are also reported for specific conditions, Brussaard *et al*. (2007) state that the linkage between biological activity and C and N mineralization and stabilization as soil structure dynamics is not straightforward and that quantitative assessment of soil macro fauna on abiotic processes like water and nutrient fluxes appears hard. While it could be reasoned that the functioning of ecosystems may be impaired by the loss of soil biodiversity, evidence is ambiguous. As it is yet unclear what indicator should be used for soil biodiversity, information on this soil characteristics cannot (yet) be systematically collected.

From soil science to ground truth
Soil science has evolved from descriptive observations of field conditions to quantitative insights about physical, chemical and biological processes of soils. The collated information, however, often is not directly applicable by private enterprises, NGO's, researchers, nor suited to support policy decisions (Bouma and Droogers 2007).

Conventional soil surveys, including field description, sampling as well as selected soil chemical and physical analyses, lead primarily to reports presenting classification, soil maps and qualitative land evaluation. Other disciplines, including crop scientists and hydrologists, need more functional characteristics of soils to assess soil and land quality. However, for many regions, the necessary primary data simply are not available at the required resolution, in particular for soil physical analyses. Further, the available data have been analyzed according to a range of analytical procedures which need not be comparable.

To fill gaps in the measured data, providers of soil information need to apply transfer functions and expert judgment (e.g. Batjes *et al*. 2007; Van Ranst *et al*. 1995; Wösten *et al*. 2001); more sophisticated techniques are now being tested (Malone *et al*. 2009). Uncertainties associated with differences in measurement of, for example, particle size distribution and bulk density will be reflected in the accuracy of pedotransfer and other functions derived from the primary data. Cross-correlations between uncertain variables determine how uncertainties will propagate in a modeling study (Heuvelink and Brown 2006). Accuracy levels considered to be acceptable will vary with the scale and type of questions being asked (Finke 2006). Many of the ISRIC databases, such as e-SOTER and WISE, are specifically developed for applications at continental and global scales (1:500 000 or broader). More recently, finer resolution soil property maps are being developed in the framework of the GlobalSoilMap.net Project (Sanchez *et al*. 2009).

Knowledge and information needed to govern many current developments in the world call for integrated global analyses. Consistent global soil information systems are essential to assess issues such as global food production potential (WRR 1995), global agro-ecological zoning, estimation of global terrestrial carbon sequestration**,** or climate change processes. Expansion of agricultural land for the production of food and bio-fuel causing loss of biodiversity and emissions of Green House Gasses (GHG), displacement of poor people by large scale undertakings and the like call for global analyses (Bindraban *et al*. 2009). Soils play a major role in many of these processes but have so far been under-considered. More ground work has to be done by the soil science community to link up with these global developments.

ISRIC and World Soil Information

The concise description on land, water, nutrients and biodiversity indicate that much knowledge is available about specific processes, but application for global analyses call for more detailed, global soil database that would enable climatologists, hydrologists, crop modelers, foresters and agricultural scientists, among others, to better predict the effects of global change, with defined uncertainty ranges. ISRIC - World Soil Information will act as a coordinating institute in collecting, storing, processing and disseminating global soil and terrain information for research and development of sustainable land use; our current international projects (www.isric.org/UK/About+ISRIC/Projects/) will serve as vehicles to this aim. The Global Earth Observation System of Systems (GEOSS) will serve as a platform to communicate developments in world soil information to policy circles and the general audience.

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