Soil information to support sustainable food security in Africa: A case study in Burkina Faso

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Abstract

Crop performance and response to management are explained through yield gap analysis and codetermined by soil conditions. Agricultural productivity is limited by soil fertility and the response to soil fertility management is limited by soil water availability. Appropriately scaled soil information permits to extrapolate measured soil-specific response to management from a limited range of experimental site conditions to the wide range of environmental conditions that prevail on the agricultural land using models. The necessary information is being compiled at an increasingly fine resolution through various collaborative international frameworks, considering both historic and newly collected primary soil profile data. The Africa Soil Profile database compiles historic soil data for over 16,000 profile records. These represent only a portion of all the soil profile data that have been collected and documented over decades for the continent. Collaborative efforts are needed to develop comprehensive appropriate data and analysis tools.

Key words: yield gap, soil management, soil information, legacy data, Africa

Introduction

Sustainable food security is codetermined by agricultural crop performance, soil conditions and soil management. Sustainable food security requires within a socio-economically and cultural-politically conducive environment, response to soil management expressed in terms of enhanced soil conditions, or soil health.

Soil health is defined here as the capacity of the soil to function as a living ecosystem (FAO, 2011a or b?) which provides a range of supporting, provisioning, regulating ecosystem and cultural services (MEA, 1995; UNEP, 2012). It is a measure for soil condition and is expressed relative to benchmark criteria and reflected in soil organic matter content as commonly used indicator. Soil management to enhance soil health through increasing soil organic matter content, contributes both to sustainable food security and mitigation of climate change. It is necessary to produce more vegetative organic matter to enable sustainable increase of soil organic matter. The fundamental entry point here to are plants as they assimilate CO₂ through photo-synthesis, which justifies a continued focus on soil management to increase vegetative, crop, production, either directly or indirectly, for achieving and maintaining soil organic carbon accumulation rates exceeding decomposition rates.

The ongoing debate about improving food security in Africa is about how to enrich Africa’s soils (Sanchez, 2002; Gilbert, 2012). According to the Alliance for a Green Revolution in Africa (AGRA), crop performance in sub Saharan Africa is limited by nutrient availability on three quarter of the agricultural land. Nutrient balances need to be restored which relates to the restoration of organic carbon levels and requires integrated nutrient and water management practices (Smaling et al., 2011). AGRA’s soil health program particularly contributes to the wide spread implementation of integrated soil fertility management practices. Yield gap analyses point at temperature and water limited production largely exceeding nutrient limited and actual production in the vast majority of Africa’s farming systems, under given climate conditions, with a positive impact of crop residue management on simulated crop yield (Folberth, 2012).
Taking the spatial and temporal dynamics and cycles of organic carbon and nutrients into consideration one concludes that the overall soil fertility and soil health in the prevailing farming systems cannot be enhanced significantly without any spatial/temporal component of the farming system receiving external inputs in the form of mineral fertilizers. The core of the challenge is to judiciously combine mineral fertilizer use with organic and biological fertilizing practices, integrated into the prevailing risk-averse smallholder farming systems. Risk of investment may well be one overruling argument why resource poor smallholder farmers in Africa, and elsewhere, refrain from fertilizer use and enabling policies and settings are key to reduce the risk (Koning et al., 2001). Risk for insufficient response to costly external inputs, for example due to unpredictable rainfall, is codetermined by soil conditions and is to a certain extent manageable given appropriate soil specific information.

A wealth of primary soil data and derived soil information has been collected and documented in the form of reports and maps and is held in numerous national and international organizations and institutions. Collation of this wealth of legacy soil data into a consistent digital format would constitute a major asset for subsequent production of derived and harmonized soil information for assessing major issues such as sustainable food security under climate change in Africa, if made freely accessible. To collate such data in sufficient quantity and quality to coherently map Africa’s soil resources at an increasingly fine resolution, facilitative resources and collaborative frameworks need to be put in place to enhance capacity and active contribution and sharing of data, analyses and results. The current state of global and regional soil information has been reviewed for the Global Soil Partnership (Omuto et al., 2012), and includes a discussion of ISRIC’s emerging Global Soil Information Facilities (Batjes et al. 2013). For Africa, recent developments include the Africa Soil Profiles database (Leenaars, 2013) and products such as the Soil Atlas of Africa (Jones et al., 2013).

This paper discusses the relevance of soil data in support of sustainable food security, with a focus on yield gap analysis as illustrated by measured soil-specific crop performance for a case study in Burkina Faso and on the relevance of developing collaborative next versions of the Africa Soil Profiles database.

**Materials and methods**

**Assessing the yield gap**

Numerous options exist for improved land and water management, including soil management aimed at improving physical, chemical, biological and/or hydrological conditions (WOCAT, 2007; FAO, 2011; Milne, 2012). Soil management for sustainable food security and climate change mitigation aims particularly at maintained or improved soil health, represented here by as soil organic matter content as an indicator. Crop response to soil fertility management is codetermined by soil conditions, in particular the availability of water and nutrients.

**Results and discussion**

Figure 1 shows the cereal grain response to two soil fertility management options relative to the control treatment, as measured at the experimental station of Saria, Burkina Faso; high application rate of mineral fertilizers (FM) and high application rate of a combination of mineral and organic fertilizers (FMO). The response to FMO largely exceeds the response to FM and the responses vary strongly over the years. The actual crop performance under the control treatment is nutrient-limited and therefore relatively stable over the years. Alternatively, the multi-year variation of response to FM and FMO is clearly explained by the variation of the performance of the fertilized crop, which is water-limited; differences over the years are due to differences in available soil water associated with the natural variation in rainfall. The treatments should have been well explained beforehand before these results are presented.

Yield gap analysis provides a consistent framework for explaining measured, soil specific, response to management. The yield gap at a given location, or the difference between actual and attainable crop performance, is basically an expression of the degree to which the demand of the crop, for e.g. water or
nutrients, is met by supply. Figure 1 illustrates how the crop’s demand for nutrients varied more strongly over the years than the (control) soil’s supply of nutrients.

![Figure 1: Cereal grain yields measured for 24 years at the experimental station of Saria, Burkina Faso, under three soil fertility management treatments (after Pichot et al., 1981). What is the parameter on the y-axis? If the results by Pichot et al were published in 1981, why does Figure 1 show results for some years after 1981?](image)

Subsequently, a fertilizer experiment was setup at the same experimental station, in collaboration with national institutions (Bureau National des Sols and the Institut National des Etudes et Recherches Agricoles), to assess the relevance of soil conditions for explaining crop performance and response to soil fertility management. Average annual rainfall at Saria is 800 mm, potential evapotranspiration 2000 mm and the length of cropping season 100-120 days. A sorghum crop was grown on five plots along a toposquence, developed over granite, using different combinations of nitrogen and phosphorus fertiliser applications rates (see below for details), with four replicates. The soils of the plots differed in water holding capacity and native fertility. Water holding capacity, as determined by rootable depth, gravel content and water retention ranged between 20 and 100 mm. The native soil fertility, as reflected here by the organic carbon content of the A horizon, ranged from 1.6 to 8.1 g/kg.

The toposquence at Saria is described by Boulet (1975) and the soils are classified as ‘sols tropicaux ferrugineux lessivés et indurés’. Starting at the upper part of toposquence, plots HA and HB are shallow and moderately deep, gravelly soils on ironpan (skeletic petroferric Lixisols), followed by plots BA and BC with moderately deep to deep sandy clay soils on ironpan (petroferric Lixisols), and finally plot BD with deep sandy soils of limited rootability due to imperfect drainage (fluvic Lixisols).

The soil-specific crop responses to nitrogen application rates of 0, 30 and 90 kg/ha (with a phosphorus base gift of 39 kg/ha) are shown by Figure 2 in terms of grain yield and above ground dry matter production. Crop response in terms of grain yield is of immediate interest to the farmer, while the response in terms of dry matter will determine farmer’s options for soil organic matter management.

Under the control treatment (0 kg N/ha), the differences in crop performance between plots are explained by differences in native soil fertility. This is illustrated in Figure 3 by relating the above ground dry matter production to the topsoil organic carbon content. The differences in native soil fertility are also reflected in the nitrogen and phosphorus base uptake figures.

For the maximally fertilized treatment (90 kg N/ha), the differences in crop performance on the five different soils are largely attributed to the differences in soil water holding capacity, which is illustrated in Figure 4 by relating grain yield to the water holding capacity of the rootable soil. Post-anthesis
growth was determined by soil water availability in the experiments, because rainfall stopped at anthesis.

**Figure 2**: Response to nitrogen fertiliser application on five different soils, with a base gift of 39 kg P/ha (Saria toposequence, Burkina Faso)

**Figure 3**: Above ground dry matter production (kg/ha) for the control treatment (0 kg N/ha) as a function of soil organic carbon content (g/kg) of the A horizon of five different soils of the Saria toposequence, Burkina Faso

The grain response to nitrogen application was largely explained by the difference between the nitrogen supply from the soil and the crop’s nitrogen, the latter being driven by the soil water supply. Or, in
other words, “no water, no response to soil fertility management”. The higher the soil water availability, the higher the nitrogen use efficiency was in terms of kg grain (and dry matter) produced per kg nitrogen applied. This was also observed for the underlying uptake efficiency and physiologic efficiency. Vice versa, fertilisation improved soil water use efficiency by the crop.

Figure 4: Grain yield (kg/ha) for the ‘maximally fertilised’ treatment (90 kg N/ha) as a function of the water holding capacity (mm) of the rootable soil (Saria toposequence, Burkina Faso)

As illustrated by the above example, the framework provided by yield gap analysis permits to explain measured soil-specific responses and year-specific responses to management, with the “maximally fertilised” treatment mimicking conditions for water-limited production and the control treatment mimicking those for nitrogen limited production. Once captured through agro-ecologic modelling, and regionally validated, yield gap analysis permits to identify those (soil) conditions that limit crop performance to assess the likeliness of crop response to soil management options, applicable over the wide range of agro-ecologically different conditions that prevail over Africa, given the availability of appropriately scaled and model-specific information on those agro-ecological conditions. With respect to soil conditions, such information is being collected and compiled at continuously increasing resolution, considering both historic primary data and newly collected primary data, in the context of national international initiatives and collaborative frameworks such as AfSIS, Global Soil Map, SOTER, and the Global Soil Partnership (e.g., Sanchez et al., 2009; FAO et al. 2012; Omuto et al. 2013; Vagen et al., 2013). As the World Data Centre for Soils, ISRIC – World Soil Information is contributing to these collaborative efforts, among others by making the Global Soil Information Facilities available to partners (Batjes et al. 2013). The Africa Soil Profiles database, and the associated Africa Soil Maps database, will be discussed here as an example.

Africa Soil Profiles database
The Africa Soil Profiles database, with profile data for over 16,000 profiles (Leenaars, 2013), was compiled within the context of the Africa Soil Information (AfSIS) project. The profile inventory specifies the full lineage to the data sources and data providers. In conjunction with this, the Africa Soil Maps database is being developed: an inventory of legacy soil maps held in various holdings, including those of ISRIC, FAO, WOSSAC, IRD, and University of Ghent (Figure 6). Together, these databases represent an increasingly comprehensive inventory of the legacy soil data for Africa, including both soil maps and associated reports, permitting for digital collation of soil mapping units and profile data. Since the mapping units are derived spatial representations of the profile data, the latter can be georeferenced as points as well as polygons, allowing for a range of applications as, for example, the
development of region-specific Soil and Terrain databases (SOTER), ultimately allowing for updates of the Harmonised World Soil Database (FAO et al. 2012), and digital soil mapping (Hengl et al., 2013).

The Africa Soil Profile database describes a range of soil properties necessary for a wide range of analyses, including yield gap analysis: soil depth, soil gravel and tension specific water content, as well data on organic carbon, nitrogen, phosphate and potassium content and pH, CEC and data on morphology and classification where originally provided. For details, see the Technical Report by Leenaars (2013).

Quality of data and information is context or use specific. Typically, the quality of the data, and the functions derived from them (Wösten et al. 2013), are considered appropriate to support analyses at continental and national scale. However, they may not be adequate to support the formulation of farm or field specific soil management recommendations, for which more extended and detailed data sets are needed (Paterson and Mushia, 2011). It is the intention to extend the Africa Soil Profiles database through collaborative action, upon the identification of funding, leading to joint next versions of the database and derived products.

Conclusion

Legacy soil data, once digitally presented at the appropriate scale, permit to explain crop response to management and to assess sustainable food security and climate change mitigation and adaptation, for example within the setting of the Global Soil Partnership and similar.

The process of identification, collection, collation, standardization and quality screening of legacy soil data, from a wide range of national and international holdings, is labour intensive yet critical. It is considered cost effective when compared to the collection of new soil data.

References


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