pollution emanating from the two countries. The US is now committed to cut emissions to 26-28 percent below the 2005 level by 2025; while China has agreed to cap its output by 2030, or earlier if possible. In China, the world's most prodigious polluter, there is now a target to expand energy from zero-emission sources to 20 percent by 2030. This will mean around 1000 gigawatts of nuclear, wind and solar generation capacity by that date and that is more than all the coal-fired plants that exist in China today and is roughly equal to total US generation capacity. Together with the EU, which has pledged, in October 2014, to reduce GHG emissions by 40 percent below the 1990 level by 2030, the US and China hope that their collaborative effort will be a beacon for other major polluting economies.

Countries are now required to produce national plans for GHG reduction targets by March 2015, and whilst this is a positive stride forward, much detail remains unclear. For example, the Paris talks will need to define the legal aspects of enforcing the achievement of targets. Another vital discussion point, is the size of the UN Green Climate Fund (GCF) which is aimed at assisting developing countries to fund green energy production. At US$9.7 billion, developing countries complain that the GCF is currently too miserly and needs to be dramatically increased (by countries with developed economies). If this can be agreed in Paris, then the hope is that developing countries can make good progress towards achieving C-neutral economies. If not, and future development is fuelled by burning fossil fuels, then the prospects for emission reduction, and therefore control of global warming, are bleak indeed.

Much depends on the outcome of the UN COP21 summit in Paris. If it proves impossible to reach agreement on reducing GHG emissions, then the probability of not constraining global temperature rise to under 4°C is very high. The prospects of keeping temperature rises to below the 'safe' threshold of 2°C are even now painfully slim.

Brian Sims

The state of soil fertility in sub-Saharan Africa

Wim Andriesse and Ken E Giller

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Summary

An overview of the state of soil fertility in sub-Saharan Africa and how stakeholders are dealing with it: farmers, of course, but also traders, scientists, development workers, planners/policy makers and society at large. In addition, we discuss soil fertility management in the wider context of agricultural development in sub-Saharan Africa.

Background

The recent *Soil Atlas of Africa* (Jones *et al*, 2013) highlights soil degradation as a threat to about one quarter of the productive land of the continent. This degradation includes desertification and erosion, but most prominent is the decline of soil fertility through loss of nutrients and organic matter under continuous cropping. Nye & Greenland (1960) recognised that the fertility of virgin land declines to a new equilibrium dependent on the intensity of cropping. Soil mining had been encroaching in Africa as land was used more intensively and fallow periods shortened and disappeared; but, although the importance of soil fertility management was recognised, farmers, agricultural scientists and governmental agencies were preoccupied with erosion control and soil conservation. It can be argued that the crisis of soil fertility was triggered by donor enforcement of pan-African structural adjustment programmes in the 1980s; the increase in fertiliser prices brought about by removal of subsidies, together with the breakdown of national extension services and infrastructure, put fertiliser and other inputs beyond the reach of smallholder farmers – in contrast to Asia where the *Green Revolution* was fuelled by consistent government support.

In 1990, Stoorvogel & Smaling, uncovered alarming trends of nutrient losses in prevailing crop production systems in sub-Saharan Africa (SSA). They calculated that, every year on average, African crop production systems fell short of replenishing nutrient uptake by the crops by approximately 20 kg/ha N, 10kg P_2O5 and 20kg K_2O, up to a maximum of 40kg N, 20kg P_2O5 and 40kg K_2O, even when manure and fertiliser were applied. At around this time, Sanchez (1994) called for a *Second Paradigm* of soil fertility management to move away from back-breaking reliance on the recycling of nutrients in traditional smallholder farming, where additional nutrients in the form of chemical fertiliser were needed to replenish soil nutrient stocks and make farming systems sustainable while feeding an ever-growing population. Scrutiny of the case for replenishment of soil nitrogen (including the use of nitrogen fixing legumes: Giller & Cadisch, 1995) and soil phosphorus (Buresh *et al*, 1997) demonstrated that a one-time investment in nutrient replenishment is not efficient in either agronomic or economic terms. There was an avalanche of studies and high-level conferences on nutrient mining and the need for interventions to restore soil fertility in Africa. For instance, the *Africa Fertiliser Summit* in 2006, in Abuja, where Heads of State pledged to increase fertiliser use from 8kg to 50kg of nutrients/ha through national and regional strategies, subsidies and investments, quality control systems, distribution networks, extension services, *etc* (AU & NEPAD/NPCA, 2006). But this ended up being just another high-level initiative dealing with politics and institutions: it had little or no impact in the farmers' fields. Whereas in Kenya and Zambia, average fertiliser consumption increased from 21 to 33kg/ha and from 11 to 50kg/ha between 1990 and 2008, respectively; the average for SSA is still less than 10kg/ha.

While there was a basic understanding of the utility of organic resources to supply crop nutrients and build up soil organic matter (Palm *et al*, 2001), it was clear that the nutrients available in crop residues or cattle manure were insufficient to sustain productivity. During the late 1990s, and until around 2005, legume green manures and improved fallows of fast-growing legume shrubs were actively promoted, but there is little evidence of their continued use. Participatory research has shown repeatedly that smallholders reject such technologies in favour of grain legumes or fertiliser application that give immediate benefits of food and/or cash (Ojiem *et al*, 2006).

Current initiatives on soil fertility in Africa

Research at farm and farming system level

Testing soil-fertility-improvement technologies on smallholdings led to a realisation that success was patchy, even in technical terms. In many cases, soils were so depleted of nutrients and organic matter that green manures and other soil fertility improving technologies resulted in little response in crop yield. Recognition of repeating gradients of soil fertility decline with increasing distance from the homestead led to a focus on whole-farm analysis of soil fertility constraints. These soil fertility gradients are caused by the shortage of manure, which is applied preferentially to home-fields for food self-sufficiency; and the differences in soil fertility have implications for the efficiency with which added nutrients are used by crops. This work under the *AfricaNUANCES Framework* recognised and characterised the diversity among farmers in any given locality, which had strong influences on their resource availability and use. Rather than promoting *best-bet* technologies, it was necessary to seek *best-fit* technologies that recognised the inherent diversity among farming systems, farmers, their farms and fields (Giller *et al*, 2011).

The need for integrated soil fertility management

A large body of research has coalesced around the need to use efficiently all of the nutrient resources available to farmers. This is defined as *Integrated Soil Fertility Management (ISFM): A set of soil fertility management practices that necessarily include the use of fertilisers, organic inputs and improved germplasm, combined with the knowledge of how to adapt these practices to local conditions, aimed at maximising agronomic use efficiency of the applied nutrients and improving crop productivity. All inputs need to be managed following sound agronomic principles* (Vanlauwe *et al*, 2010).

The goal is optimised crop productivity through maximising interactions that occur when fertilisers, organic inputs and improved germplasm, along with the required associated knowledge, are integrated by farmers. The proven assumption underlying ISFM is that increased production of plant and root mass, and returning this into the soil, increases soil organic matter with a beneficial effect on the soil's capacity to store water and nutrients, better aeration and infiltration of rainwater. This may be considered as a fourth principle needed to define Conservation Agriculture (Box1).

Box 1. Conservation Agriculture

In recent years, conservation agriculture (CA) has won the attention of an alliance of FAO, many largely church-based NGOs, and African governments. CA is based on three principles of zero-till or reduced tillage, mulch retention, and crop rotation (see Shaxson & Kassam, pages 21-25 in this issue).

The zero-till or CA movement in the Americas may be characterised as big farms with intensive use of herbicides and fertilisers, reliant on 'Round-up Ready' GM soyabeans and maize. By contrast, CA in Africa has been portrayed as low-input agriculture – for instance under the FAO's Save and Grow paradigm. Whether CA is an appropriate technology for smallholder farmers is moot (Giller *et al*, 2009) because of the increased labour demand for weeding when soils are not ploughed: few smallholders have access to herbicides; and because crop residues are highly-valued for feeding to livestock. And no-till without mulch is disastrous! It leads to soil capping, extreme runoff within minutes of the start of a heavy shower, and precipitates rather than controls soil erosion.

In view of the high rates of dis-adoption of CA by farmers within a few years (Andersson & D'Souza, 2014; Arslan *et al*, 2014), a fourth principle may be needed to define CA highlighting the equal need for fertiliser to increase productivity (Vanlauwe *et al*, 2014).

Increasing scale and scope of developments

Recently, projects on soil fertility in Africa have become much larger. The *Soil Health* programme of AGRA (www.agra-alliance.org) started with initial funding of US$160M from the Gates Foundation; Dutch funding to the *2Scale* and *Catalist* programme under IFDC (http://www.ifdc.org) amounts to US$60M; and, in Ethiopia, the Dutch-Ethiopian *Cascape* program (www.cascape.org) receives €12M from the Netherlands. The *N2Africa programme: Putting Nitrogen Fixation to Work for Smallholder Farmers in Africa* (Giller *et al*, 2013, www.N2Africa.org) emphasises the inclusion of legumes in the cropping sequence to enhance biological nitrogen fixation in the crop-soil system that eventually benefits crop growth and yields, as opposed to investments in crop genetic improvement and markets; and has just started a second phase with Bill & Melinda Gates Foundation funding of US$30M. These initiatives, which often work together, apply comprehensive integrated approaches beyond ISFM *sensu stricto*, mostly in the perspective of value-chain development. Intervention areas include adaptive technology, access to finance, input market development, capacity building in extension organisation, agro-dealers and research, output markets and market information systems, and policy support. Moreover, the programmes are being implemented with a view to adapted replication in other environments.

Farmers' assets and environmental contexts

With respect to assets and environmental context, Berdegué & Escobar (2002) distinguish endowment categories as visualised in Figure 1. On the horizontal axis, environmental quality has been set out from unfavourable to favourable; on the vertical axis, access to labour, skills and capital assets ranges from low to high.

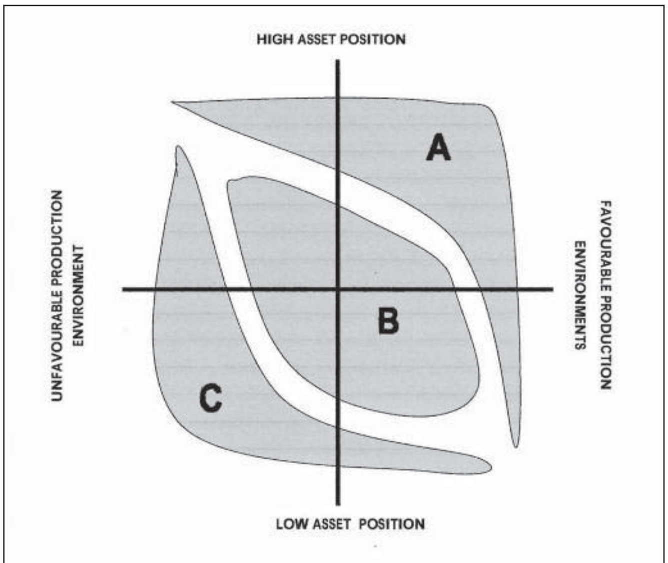

Figure 1. Differential strategies for the development of agricultural knowledge and information systems (Berdegué & Escobar, 2002)

Farmers in category A are mostly fully integrated in market economies and make substantial contributions to food production for national and international markets. Productivity is high as a result of important asset endowment paired with high investments in relatively favourable production environments; the prevailing soils are Luvisols, Lixisols, Nitisols, Cambisols, Acrisols, Vertisols and, in floodplains, Fluvisols (Jones *et al*, 2013). This category includes few smallholder enterprises, except for specialised production systems like vegetables and flowers (though the latter are mainly grown on substrates). In sub-Saharan Africa, category A environments include the former colonial lands that were, and still are, growing cash crops, with cattle reared on pastures. Over the past 10-15 years, much of this land in SSA has been captured by external investors for large-scale production for bio-fuel and food crops.

Many of the farmers in category B have skills and land but lack critical elements that enable entry into market-driven systems: access to credit to invest in quality seeds, fertiliser, implements and irrigation; access to output markets (poor infrastructure, poor market information, volatile prices); or access to post-harvest value-adding facilities (storage, processing, packaging). Nowadays, many donors and governments target farmers in this category, aiming to pull 'family farms' into market-oriented production – a panacea for public-private sector investment and local agri-sector entrepreneurship.

Category C comprises asset-poor smallholders in environmental contexts that are not conducive to economic growth and social development. For these marginalised farmers on marginal lands, conditions are gloomy. Conditions are adverse even for other economic activities: their land is remote from economic centres such as ports and industrial zones. Marginal lands in SSA include the shallow Plinthosols and Regosols of West and Central Africa, Ferralsols in Central and Eastern Africa, and shallow Leptosols in large parts of southern Africa. Average land holdings of these farmers are mostly less than 2 ha; labour is supplied by family members themselves and the food produced is largely for home consumption. Sustainable development options for farmers in category C are unlikely to be provided by the agricultural sector: mostly, family members derive extra income from working outside their own farms.

Each category requires specific strategies and policies to allow farmers in these different categories to make optimum use of assets. Therefore, the categorisation into high, medium and low resource endowment of farms has been adopted for fertiliser recommendations at the local level, for instance by Vanlauwe *et al* (2014), who used agronomic efficiency values in terms of unit weight of extra yield produced per unit weight of fertiliser applied, as recommendation domains for soil and crop management.

Input subsidy programmes and other fertiliser policies

In SSA, input subsidy programmes (ISPs) are re-emerging as a policy tool of many governments, in some cases with the support of international development partners (Jayne & Rashid, 2013) although, even in Malawi, Kenya and Zambia (countries with above-average fertiliser consumption rates) the benefits of ISPs during the post-2008 high-food-price years rarely exceeded costs. (Editor's note: *Agricultural input subsidies: the recent Malawi experience*, by Ephraim Chirwa and Andrew Dorward was reviewed in *Ag4Dev23*, 23-24.) Obstacles to higher economic returns on fertiliser include crowding out of commercial fertiliser demand, late delivery, poor management practices, lack of complementary inputs and unresponsive soils. Jayne & Rashid (2013) acknowledge the short-term political gain, but also observe that, once implemented, they have proven difficult to take away again.

Comprehensive data sets and analyses on the effects of various fertiliser policies on smallholder consumption in SSA are few and not up-to-date. However, there is a measure of agreement on the need to improve agronomic response to manure and fertiliser, better communication to extension agents and farmers, the need for less-volatile and higher output prices, and lower fertiliser costs (Kelly, 2005; Meertens, 2006; Ariga & Jayne, 2006). The latter authors point out that, although the amounts of fertiliser used are often still small, some 70 percent of smallholders in Kenya were using fertiliser in 2003-4.

Conclusions and recommendations

- Western hegemony of prescribing what is good, is not good for Africa. Stories of failing donor-driven interventions abound (Box 2).

Box 2. Farmers' uptake

When one of us (KEG) started working in Tanzania in the mid-1980s, he sought out soil scientists who had been involved in earlier soil fertility research. Alan Scaife, who conducted hundreds of on-farm fertiliser-response experiments with maize in the early 1960s, recalled that when he asked a farmer in northern Tanzania what he thought of the spectacular increases in maize growth and yield, the farmer replied with a shrug of his shoulders: *'White man came here before the war and showed the same thing!'* We have to remain modest in our claims, but hope that the current investments to assist farmers in gaining access to inputs and knowledge to use them efficiently will have some lasting impacts.

- What research can offer to farmers is choice and, in participatory approaches, facilitation of access to fertiliser and to post-harvest technologies and markets once the farmer's investments result in higher yields. Such research is relevant, especially if it is implemented in close partnership between local and international research and development organisations and universities.
- There is need for a much stronger engagement from African Governments in the design and implementation of agricultural strategies beyond the level of declarations, as well as for a much more critical and more transparent monitoring system of the implementation of national, regional and pan-African strategies. Most of the big agricultural development programmes, including those focusing on IFSM, are donor-driven, with limited financial support from national governments beyond the basic salaries of governmental employees (and these salaries are mostly being topped-up in order to retain staff capacity, at least for the lifetime of the programmes).
- The international fertiliser industry has an active role to play, together with national governments and development partners like IFDC and AGRA, in developing a range of products that matches smallholders' needs for tailored fertilisers, both in terms of composition, form, distribution and bag sizes at retail level. Market-led competition among distributors will keep the prices down but quality control mechanisms need to be enforced by national governments.
- A strong knowledge base has been built across SSA on the need, the utility and the appropriateness of soil-fertility-improving technologies. We remain optimistic that the current impetus for improving the fertility of Africa's soils will lead to lasting impact and share this optimism with Pedro Sanchez in his recent note to *Nature: 'En route to plentiful food production in Africa'* (Sanchez, 2015).

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International Agricultural Research News

Improving soils

Soil science in the CGIAR has a chequered history. The application of the International Board for Soil Research and Management (IBSRAM) to join CGIAR was rejected in 1990 on the grounds that *'involvement in adaptive research and development activities of national programs ...is not a desirable evolution'*. IBSRAM was wound up a decade later, although it was formally incorporated into the International Water Management Institute (IWMI) in 2001, its soils research programme was phased out. The Tropical Soils Biology and Fertility programme (TSBF) fared somewhat better. Following its merger with the Centro Internacional de Agricultura Tropical (CIAT), also in 2001, it continued its programme on integrated soil fertility management (ISFM) and sustainable land management, focussing on generating soil information, mapping soil properties and ecosystem health. Although TSBF no longer exists as an independent programme, soils research remains one of CIAT's three principal research areas.

In recent years soil science has seen something of a renaissance within the CGIAR with several Centres, especially IITA, seeking to strengthen their soils programmes. A major boost occurred in 2012 with the creation of the CGIAR Research Programme (CRP) on Land, Water and Ecosystems. Research on soils is an integral component of the new programme's effort to sustainably intensify agricultural production and improve resilience while maintaining vital ecosystem functions. Outside the CGIAR, the International Fertilizer Development Centre (IFDC), a member of the Association of International Research and Development Centres for Agriculture (AIRCA), is the only independent international entity with a primary focus on soils, working especially in the areas of environmentally sound crop nutrient technology and agribusiness.

Following are three recent examples of international soil science in action:

Soil organic matter

The upper 1m of soil is estimated to hold about 2,000-2,500 Gt of carbon worldwide, with 60 percent being in the form of soil organic carbon (SOC). This is about three times the amount of carbon bound in the above-ground biomass. It is often assumed that the introduction of measures to sequester more carbon in agricultural soils, such as through Conservation Agriculture, would make a significant contribution to reducing atmospheric CO_2 far into the future. However, a recent study by CIAT soil scientists (Sommer & Bossio, 2014) found that increasing carbon sequestration by agricultural soils has a finite potential to contribute to the mitigation of climate change (CC) and the global effects of SOC-sequestration measures will only be felt over some decades.

The study calculated the global SOC sequestration potential of agricultural land for the period up to 2100, based on both an optimistic and a pessimistic scenario regarding the rates of carbon sequestration that could be achieved. Over the period, approximately 31 Gt of carbon would be sequestered under the pessimistic scenario and 64 Gt under the optimistic scenario. These extremes are equal to only 1.9 percent and 3.9 percent respectively of the mean projected total anthropogenic emissions of carbon according to the SRES-A2[1] scenario of the Intergovernmental Panel on Climate Change (IPCC). Carbon sequestration would peak in 2032–33, at that time reaching 4.4 and 8.9 percent respectively of the projected annual emission. Thirty years later the sequestration rate would have reduced by half as a new equilibrium is reached.

In conclusion, the study reported that improving the carbon sequestration potential of current agricultural soils is likely to contribute relatively little to solving the climate problem of the coming decades. However, the authors also pointed out that additional measures such as the large-scale restoration of degraded lands (see below), and adoption of agroforestry systems, could significantly increase the amount of carbon sequestered beyond the levels reported in their study, up to 5-15 percent of total global C emissions (Smith *et al*, 2008). Furthermore, they stressed that soil organic carbon is vital for sustaining soil health, agro-ecosystem functioning and increasing productivity; all issues of global significance that deserve attention, irrespective of any potential impact on climate change.

Putting biological nitrogen fixation to work for smallholder farmers

Nitrogen is severely depleted in many African soils, making it difficult for smallholder farmers to produce the

[1] The Special Report on Emissions Scenarios (SRES) is a report by the Intergovernmental Panel on Climate Change (IPCC). The A2 family of scenarios is characterised by a world of independently operating, self-reliant nations, continuously increasing population and regionally oriented economic development.