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Editorial

Soils and world food security

The growing threat of food insecurity (Brown, 2008; Anon., 2008a,b,c; FAO, 2006, 2007a,b,c), rapidly engulfing poor and under-privileged population across the globe (FAO, 2007a,b,c; Anon., 2008a,b,c), necessitates a critical appraisal of agronomic strategies needed to enhance and sustain productivity while mitigating climate change, improving biodiversity, restoring quality of soil and water resources, and improving the environment (Lal, 2004, 2006a,b; Sanchez, 2002). The required increase in global average cereal yields is estimated from 2.64 Mg/ha in 2000 to 3.60 Mg/ha (+36%) by 2025 and 4.30 Mg/ha (+63%) by 2050 without major dietary change versus 4.40 Mg/ha (+67%) by 2025 and 6.0 Mg/ha (+127%) by 2050 with changing dietary preferences in emerging economies (Wild, 2003). Further, the challenge of food insecurity will be exacerbated by the projected climate change (Cline, 2007), and the attendant risks of soil degradation and desertification (Cline, 2007; Sugden et al., 2004; Kaiser, 2004; Oldeman, 1994; Diamond, 2005). However, the necessary increase in food production must be based on agricultural intensification of cropland already under cultivation. The new land that can be brought under cultivation exists either in ecologically sensitive ecoregions (e.g., tropical rainforest) or on agriculturally marginal soils (e.g., too steep, too shallow, too dry or too cold). Therefore, the strategy is to enhance soil productivity per unit area, time and energy-based input from existing croplands.

The first Green Revolution of the 1960s and 1970s, which saved hundreds of millions from starvation especially in South Asia, occurred through the “seed-based” technology. It comprised of growing input responsive dwarf varieties of wheat and rice on irrigated soils with heavy input of chemical fertilizers. Irrigated land area in the world increased from 100 Mha in 1950 to 275 Mha in 2000, of which the most increase occurred in Asia (FAO, 2005; Postel, 1999). Similarly, global fertilizer consumption increased from 30 million t (Mt) in 1960 to 140 Mt in 2000, with drastic increase in Asia (IFDC, 2004). However, the first Green Revolution by-passed sub-Saharan Africa (SSA) because soils were degraded and fertilizers and irrigation were not available. Irrigated land area in Africa increased from 3.5 Mha in 1960 to only 6.9 Mha in 2000 (FAO, 2005; Postel, 1999) of which most increase occurred in Sudan, South Africa and Madagascar rather than in the West African Sahel. Similarly, the fertilizer use in SSA increased from 0.16 Mt in 1960 to only 1.4 Mt in 2002 (IFDC, 2004). Consequently, crop yields are low and highly variable. For example, the grain yield of millet in Niger is <400 kg/ha with the harvest index of merely 20%.

The seed-based approach exacerbated the problem of soil and environmental degradation by: (i) simplification of cropping systems (e.g., rice-wheat system) without reliance on legume-based rotations, (ii) excessive use of irrigation, (iii) unbalanced use of fertilizers comprising mostly of heavily-subsidized N with little input of P, K and micro-nutrients and (iv) crop residues removal for fodder and uncontrolled grazing without the benefits of mulch farming (Fig. 1a and b), and the excessive use of plow-based tillage The problem of soil degradation was exacerbated by the use of dung for household fuel rather than manure (Fig. 1c), and use of topsoil for brick making to meet the needs of urbanization (Fig. 1d). Consequently, soil degradation manifests itself in diverse forms including: (i) depletion of soil organic matter (SOM), (ii) nutrient imbalance, (iii) accelerated soil erosion (Fig. 1e), (iv), waterlogging and salinity in canal irrigated areas (Fig. 1f), and excessive withdrawal of water in regions with tube well irrigation, (v) degradation of soil structure leading to crusting and compaction, and (vi) decline in soil's water and nutrient retention capacities with reduction in use efficiency of fertilizers and water. The problem of soil degradation is more severe in developing countries of Asia and Africa, where resource-poor (<$2/day) and small-size land holders (<2 ha) can neither afford the use of chemical fertilizers and other input nor are they sure of their effectiveness. Consequently, the agrarian stagnation has perpetuated the food crisis while exacerbating the already severe problem of soil degradation and desertification in developing countries. As much as 81% of the 749 Mha of land areas globally affected by moderate to strong/extreme form of erosion by water occurs in developing countries. Similarly, 75% of the 280 Mha affected by wind erosion, 89% of 240 Mha affected by chemical degradation, and 53% of 83 Mha affected by physical degradation occur in developing countries of Asia, Africa, South America and Central America (Oldeman, 1994). There is a close interaction between soil degradation and climate. The greatest effects of degradation on climate are expected in the West African Sahel, where substantial reduction in precipitation has already been observed over the degraded/desertified areas (Clark et al., 2001).

The second Green Revolution, needed to feed the global population of 6.7 billion in 2008 and projected to be 9.2 billion by 2050, must be based on sustainable management of soil and water resources. The projected increase in population will occur, where the soil resources are most scarce and severely degraded. Increase in population between 2008 and 2050 will be from 827 millions (M) to 1761 M (+113%) for SSA, 364 M to 595 M (+63%) for Middle East and North Africa, 35 M to 49 M (+41%) for Oceania, 579 M to 769 M (+33%) for Latin America and Caribbean, 342 M to 445 M (+30%) for North America, and 3872 M to 4909 M (+27%) for Asia. In comparison, the world population will increase

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Fig. 1. Soil degradation in South Asia and Sub-Saharan Africa, where food insecurity is the major concern, is caused by (a and b) complete removal of crop residues for cattle feed and other purposes in India and elsewhere (c), use of animal dung for household fuel rather than manure and (d) indiscriminate use of top soil for brick making such as in Haryana, India, where soil to 1-m depth is removed from 0.5% to 0.75% of the crop land every year. The problem is exacerbated by (a) soil erosion such as under corn grown on the plowed fields in western Nigeria (Fig. 1e), and (b) salt build up on canal irrigated fields such as in Punjab and Pakistan (Fig. 1f).

from 6750 M in 2008 to 9191 M (+36%) in 2050, and that of Europe will decrease from 731 M in 2008 to 664 M (−9%) in 2050 (U.N., 2006). In SSA and South Asia, with predominantly resource-poor farmers, the focus is to increase the minimum assured crop yields during the bad years (to avoid starvation) than to improve the maximum attainable yield during good years. In this regard, increasing the average yield may not necessarily avoid starvation during the bad years. Therefore, the strategy is to restore quality and productivity of degraded soils and ecosystems by: (i) enhancing SOM pool, (ii) improving soil structure, (iii) conserving water in the root zone, (iv) creating positive C and nutrient budgets, (v) strengthening nutrient cycling processes, and (vi) improving soil biology (e.g., earthworm activity). Being a slow process, and the fact that the reversal in soil degradation trends may occur at a decadal scale, the technological challenges are often underestimated.

Technological innovation for sustainable management of soil and water resources (Table 1) include: (i) no-till farming based on use of crop residue mulch and cover crops for conserving soil and water and enhancing SOM through addition of biochar and other amendments (Fig. 2a and b), (ii) water harvesting and recycling in conjunction with efficient irrigation methods and growing appropriate species/varieties that can tolerate drought stress (Fig. 2c), (iii) including leguminous cover crops in the rotation cycle (Fig. 2d), (iv) using agroforestry where appropriate (Fig. 2e), (v) adopting integrated nutrient management options based on use of compost and manure, biological nitrogen fixation, use of biosolids, and nano-enhanced fertilizer sources with slow release formula-

Table 1
Technological options for bringing Green Revolution to Sub-Saharan Africa and elsewhere through soil and water management

Problems and issues	Proven technologies	Strategies and approaches
1. Soil erosion and degradation	No-till farming, mulching, cover cropping in conjunction with contour farming, terracing and simple engineering structures	Farming carbon, trading credits of C sequestered in soils/biota, providing no-till seeders and herbicides
2. Drought stress	Water harvesting and recycling, mulch farming, improving irrigation efficiency using drip and furrow irrigation	Providing technical support in installing farm ponds, and efficient irrigation systems
3. Nutrient depletion and low soil fertility	Nutrient cycling, manuring, biological nitrogen fixation, biosolids, judicious use of fertilizers, zeolites as slow release fertilizers, nanoenhanced materials, and biochar-based amendments	Providing clean cooking fuel to the rural households so that animal manure and crop residues can be used as soil amendments, making fertilizers available to farming community through developing local sources of fertilizer
4. None or slow adoption of proven technologies	Involving farmers in the decision process, participatory approach	Improving land tenure, and addressing gender and social equity, micro finance for purchasing inputs
5. Lack of resources for adopting recommended management practices	Enhancing farm income, growing high value crops, trading soil C credits	Paying farmers for ecosystem/environmental services

Fig. 2. Sustainable soil and water management practices include: (a) using no-till farming with crop residue mulch for corn cultivation in western Nigeria, (b) retaining crop residue mulch to support good corn growth (as in the background) vs. poor growth with residue removal (as in the foreground) on a long-term experiment conducted at IITA, Ibadan, Nigeria, (c) water harvesting and recycling such as with micro catchments used for afforestation in Niger, (d) cover cropping with Mucune utilis and other legumes, (e) using agroforestry practices where appropriate such as growing wheat under poplar in Punjab, India, and (f) encouraging the activity and species diversity of soil biota (termites, earthworms) to ameliorate soil quality.

tion to improve soil fertility, and (vi) promoting activity of soil biota (Fig. 2f). Productivity-enhancing effects of these technologies are greatly accentuated when used in conjunction with improved germplasm.

The rate of adoption of proven technologies has been slow especially in SSA and SA. Even with five decades of basic research, the maximum adoption of no-till farming world wide is <100 Mha (~6% of cropland area), most of which is in the U.S., Brazil, Argentina, Australia and Canada (Derphsch, 2007). For improving adoption, farmers must be at the center of the planning and implementation process, and empowered to decide how the technology is adapted, delivered, and managed. In this regard the importance of land tenure and gender and social equality cannot be over-emphasized.

The problem of food-insecurity has been confounded by the emphasis on biofuels (Barbara, 2007; Nonhebel, 2005; Somerville, 2006; Service, 2007), while the policy makers are agonized to allocating resources for meeting the food or fuel needs. While using grains (corn, soybeans) for biofuel have caused drastic increases in food prices (Brown, 2008; Normile, 2008) and civil unrest (Anon., 2008a,b), removal of crop residues for biofuel production adversely affects soil quality. Crop residue removal depletes SOM pool, declines soil structure, increases risks of runoff and erosion, and exacerbates non-point source pollution and hypoxia of coastal waters (Wilhelm et al., 2004). Long-term experiments at IITA, Nigeria, showed that retention of crop residue mulch maintained maize grain yield at 6.0 t/ha compared with 2.5 t/ha when residue was removed (Juo et al., 1995). Similar to mulch, application of biochar as a soil amendment has also been shown to sustain soil fertility for centuries in the Amazon (Mann, 2002). Therefore, feed stock for cellulosic biofuel, must be produced by establishing energy plantations (e.g., switch grass, miscanthus, poplar, willow) on surplus land, agriculturally marginal soils and eroded/degraded soils rather than using crop residues.

Income of the resource-poor farmers can be enhanced by payments for ecosystem services (FAO, 2007a,b,c), such as trading credits of C sequestered in soils and trees. As much as 60% of ecosystem services have been either degraded or used unsustainably (MEA, 2005; Srinivasan et al., 2008), and must be restored. The potential of genetically modified (GM) crops to serve the needs of subsistence farmers of sub-Saharan Africa and South Asia remains unproven and unfulfilled (Kiers et al., 2008), because of the severe problem of soil degradation. Yet, world's hungry and poor cannot be deserted (Anon., 2008a,b,c). Enhancing SOM pool, equivalent to 1 t C/(ha year), can increase food production in developing countries, by additional 30–40 Mt/year (Lal, 2006a,b), while also mitigating the climate change.

There is a strong need for the paradigm shift to focus on soil-based strategies for increasing food production while restoring the natural resource base, improving the environment, and making agriculture an integral component of the solution to addressing the global issues of the 21st century. If soils are not restored, crops will fail even if rains do not; hunger will perpetuate even with emphasis on biotechnology and genetically modified crops; civil strife and political instability will plague the world even with sermons and mantras on human rights and democratic ideals; and humanity will suffer even with great scientific strides. The time to act is now. If not now, when? If not on restoring soils, what else? If not on improving the food security, what other human right deserves a higher priority?

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