# Ushering Soil Science into the 21st Century

by Rattan Lal

The knowledge of soil properties and processes, rudimentary and basic as it was, has been used ever since the transition from foraging to farming/cultivation by the farmers who domesticated cereals (wheat, barley, and rye) 10,000 to 13,000 years ago in the Fertile Crescent of the Middle East (from modern day Israel through Syria and Turkey to Iraq), squash about 10,000 years ago and peanuts and cotton 8,000 to 6,500 years ago on the western slopes of Andes in northern Peru, corn and squash in Mexico about 9,000 years ago, along with several crops by the farmers in other centers of origin for agriculture such as the Indus Valley, Yangtze Valley, southern India, and New Guinea. The traditional knowledge (e.g., shifting cultivation, manuring, and plowing) was extremely relevant when the population was small and the demands on soil resources were low. With bigger challenges in the 21st century of increasing production and improving the environment, using modern cutting-edge science and interdisciplinary knowledge to understand and manage soil properties and processes is more important now than ever before. With regards to the resource-poor farmers in the developing countries of sub-Saharan Africa and Asia, use of modern technology (with high productive potential and efficient use of input) is essential to promoting gender and social equity, narrowing the economic divide, eliminating hunger, and improving the environment.

Three examples among numerous modern technologies that are scale neutral—applicable to both large-scale commercial agriculturists and small-scale resource-poor farmers—are nanotechnology, biotechnology, and information technology, or knowledge management. Specific application of these technologies to improving the productivity of resource-poor small-land holders of Africa and Asia are schematically presented in Fig. 1.

## Nanotechnology

There are numerous nanoenhanced products and nanobased tools and methods with immediate application to addressing the issues pertaining to low use efficiency of inputs (e.g., fertilizers, irrigation water, and pesticides) and recurring drought/high-soil-temperature stress in the tropics. These include nanoenhanced products such as nanofertilizers and nanopesticides with a nanobased smart delivery system (use of halloysite) to provide nutrients at the desired site, time, and rate to optimize productivity. Using such nanoscale formulations of agricultural chemicals can enhance the use efficiency of input and minimize losses into the environment. Nanoporous materials (e.g., hydrogels and zeolites) can store water in the soil during the rains and release slowly during the dry season, minimizing the adverse effects of drought stress. Similarly, nanoporous membranes are available to minimize loss of $H_2O$ from soil and to moderate soil temperature. Nanomaterials are efficient sorbents of pollutants and can reduce eutrophication of natural waters, and nanofilters are available to remove agricultural and natural chemicals (As) from water. Nanocrystals of magnetite (<12 mm) can bind up to 100 times as much As as the larger Fe particles. Nanosensors can be used to improve predictability of edaphic environments by remote sensing, using nanoscale mass spectrometers, atomic force microscopes, and other modern devices. With remote sensing of edaphic conditions, automatic release of targeted input (nanoscale precision farming) can effectively and efficiently alleviate soil-related constraints.

## Biotechnology

Similar to nanotechnology, biotechnology also has numerous applications to understanding and managing pedospheric properties and processes. Relevant examples of such applications include:

1. enhancing carbon (C) sequestration in terrestrial ecosystems (soils, trees, and wetlands) by



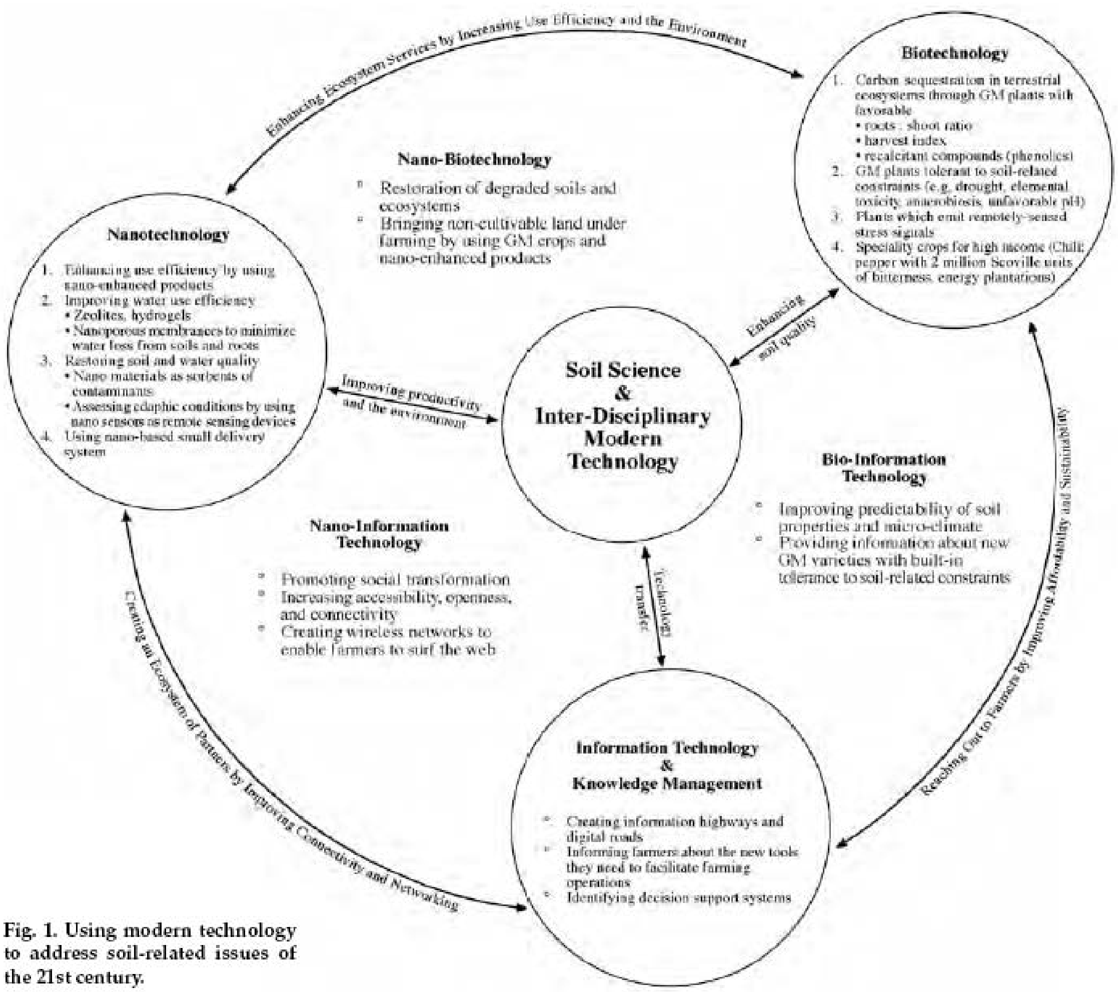


**Fig. 1. Using modern technology to address soil-related issues of the 21st century.**

using genetically modified plants characterized by favorable root/shoot ratio and harvest index with high biomass production and deep root systems containing recalcitrant compounds (e.g., phenolics);

2. expanding the land base by bringing new land under production, which was hitherto not cultivable, by growing specifically improved crops/cultivars and restoring degraded ecosystems through bioremediation of contaminated soils;
3. growing efficient plants with high N fixation capacity, built-in resistance to drought (aerobic rice), anerobiosis, nutrient/elemental imbalance, unfavorable soil pH/reaction, etc.; and
4. developing plants that emit stress signals that can be remotely sensed and treated with targeted inputs to alleviate the stress prior to severe adverse effects on production.

### Information Technology

Creating information highways and digital roads are essential to reaching out to farmers, especially those in remote areas of Africa, Asia, the Andean region, and the Caribbean. The strategy is to enhance accessibility, connectivity, openness, and networking in order to increase affordability and sustainability. Use of solar-powered and hand-held computers along with wireless networking can enable farmers to surf the web, learn about onset of monsoons or incidence of soil-borne and other pathogens, and receive information about new crops and cropping systems as well as the soil inputs needed to optimize production. The goal is to provide farmers with the tools they need to increase production, alleviate poverty, and improve standard of living.

Ever since the dawn of settled agriculture about 13,000 years ago, it has been difficult to assess soil's contribution to human society in material or monetary terms. However, the strong link between soil and human society will become even stronger during the 21st century and beyond. For both issues, food security and environment improvement, the answer lies in soil. That is why the motto of the modern civilization must be "In soil we trust."

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