1058

however, application rates of subsequent irrigations can be greatly reduced.

Because soil surface structure is kept porous when using PAM, infiltration rates are generally higher with PAM-treated water on fine to medium-textured soils (clays and loams). Farmers can use PAM to improve infiltration precision and uniformity in surface and sprinkler irrigation systems and reduce runoff and runon problems. In many settings, the infiltration management potential is a greater incentive than erosion control to adopt PAM use.

Environmental restrictions. Soil amendment registrations, environmental regulations, and USDA-NRCS guidelines restrict erosion-control PAMs to anionic forms containing <0.05% unreacted acrylamide monomer (AMD). Neutral or cationic PAMs can harm certain microorganisms or aquatic species. Cationic PAMs adhere to hemoglobin-bearing fish gills, causing suffocation. Anionics are safe at (and well beyond) the prescribed erosion-controlling concentration. Acrylamide monomer, a neurotoxin, poses no health or environmental risk at the rates and concentrations specified, and it is removed rapidly from the environment (hours to days) by microorganisms. High-purity anionic PAMs are used in municipal water treatment, food processing and packaging, pharmaceutics, and animal feeds. Erosion control represents 1-2% of PAMs or related polymers used annually in the United States for paper manufacture, mining, and sewage treatment.

Environmental benefits. The environmental benefits of PAM-based erosion prevention are well documented. PAM reduces nitrogen and phosphorus (eutrophying nutrients), biological oxygen demand (BOD), and several herbicides and pesticides by 60-80% in runoff water. Since 1998, 10-20 million tons of sediment, thousands of tons of nutrients, and hundreds of tons of herbicides and pesticides per year have been prevented from entering riparian (wildlife-supporting) waters. Recent research has shown large reductions in weed seed and microorganism loads in PAM-treated runoff. Sequestration of weed seed and microbes reduces the spread of weeds and crop diseases within and among fields, reducing their impact on crop production and lowering the need for herbicides and pesticides. Because fecal coliforms and other human hygiene-impacting microorganisms enter surface water from manure-treated fields, microbe sequestration via PAM also reduces organism-related human health threats.

Extension of PAM technology to rain-fed agriculture is difficult and may not prove economical or effective on a wide scale for various physical, chemical, and logistical reasons. However, PAM use for construction site, road cut, and mine site erosion control and for accelerating water clarification in runoff retention ponds has increased rapidly. PAM and other organic and synthetic polymer-based erosion-control and water quality-protection technologies will likely continue to improve and be implemented in the future.

For background information *see* EROSION ; IRRIGATION (AGRICULTURE); POLYACRYLONITRILE RESINS; SOIL CONSERVATION; WATER POLLUTION in the McGraw-Hill Encyclopedia of Science & Technology.

R. E. Sojka; D. L. Bjorneberg

Bibliography. F. W. Barvenik, Polyacrylamide characteristics related to soil applications, *Soil Sci.*, 158:235-243, 1994; D. L. Bjorneberg et al., Unique aspects of modeling irrigation-induced soil erosion, *Int. J. Sediment. Res.*, 15:245-242, 2000; W. J. Orts, R. E. Sojka, and G. M. Glenn, Biopolymer additives to reduce soil erosion-induced soil losses during irrigation, *Ind. Crops Prod.*, 11:19-29, 2000; F. J. Pierce and W. W. Frye (eds.), *Advances in Soil and Water Conservation*, Ann Arbor Press, Chelsea, MI, 1998; R. E. Sojka et al., Irrigating with polyacrylamide (PAM): Nine years and a million acres of experience, in R. G. Evans et al. (eds.), *National Irrigation Symposium: Proceedings of the 4th Decennial Symposium*, American Society of Agricultural Engineers, St. Joseph, MI, 2000; U.S. Department of Agriculture, *Natural Resources Conservation Service Conservation Practice Standard: Anionic Polyacrylamide (PAM) Erosion Control, Code 450*, Washington, DC, July 2000.

Soil quality

Soil—the thin, unconsolidated, vertically differentiated portion of the Earth's surface—is ubiquitous and often ignored despite its many important environmental and life-sustaining functions. Soil is necessary for the production of food, feed, and fiber products, and supports buildings, roads, and playing fields. Soil helps to safely dispose of and process biological and industrial wastes, and it purifies and filters water that may enter drinking water supplies. Usually, soil performs more than one of these roles simultaneously.

Soil is in large but finite supply. It varies greatly in chemical and physical properties both in short distances and regionally. Some soil components cannot be easily renewed within a human time frame; thus the condition of soil in agriculture and the environment is an issue of global concern. For these reasons, an effort has been made to distinguish among the many kinds of soils and identify those best suited for specific uses. The concept of soil quality stems from the desire to evaluate soils, match appropriate management and uses for each soil, and measure changes in soil properties.

Concept. The concept of soil quality has been controversial among soil scientists because it is subjective, as well as being management- and climate-dependent. The concept has not been thoroughly tested by the scientific community, but it has been institutionalized by some government agencies despite the scientific discord surrounding it. In contrast, concepts of air and water quality are well accepted. It may seem reasonable to include soil quality as a basic natural resource. However, air and water quality are based on standard pure states against which all qualities can be measured. No ideal or "pure" soil state exists or can be measured for all possible uses, or for the many different combinations of soil types, climates, and management strategies.

In the United States, soil quality includes soil fertility, potential productivity, resource sustainability, and environmental quality. Most assessments attempted to date have been linked mainly to microbial diversity or crop yield. In Canada and Europe, contaminant levels and their effects are the primary factors determining soil quality. Most farmers and agricultural scientists who have embraced the concept of soil quality have associated it primarily with crop productivity. Some expand this to include specific indicators, such as soil surface condition, organic matter content, or microbial respiration. Critics of the concept note that, despite the best of intentions, such paradigms fail to resolve the contradiction that some soil properties associated positively with productivity have negative impacts on environmental quality.

The Soil Science Society of America Ad Hoc Committee on Soil Quality proposed that soil quality is "the capacity of a specific kind of soil to function, within natural or managed ecosystem boundaries, to sustain plant and animal productivity, maintain or enhance water and air quality, and support human health and habitation." This definition requires that the following soil functions be evaluated simultaneously to describe soil quality: (1) sustaining biological activity, diversity, and productivity; (2) regulating and partitioning water and solute flow; (3) filtering, buffering, degrading, immobilizing, and detoxifying organic and inorganic materials, including industrial and municipal by-products and atmospheric deposition; (4) storing and cycling nutrients and other elements within the Earth's biosphere; and (5) providing support of socioeconomic structures and protection for archeological treasures associated with human habitation.

Quantification of the Ad Hoc Committee's general definition is difficult because no single conserving or degrading process or property determines soil quality. Soil has both dynamic and static properties that vary spatially. In addition, soils perform various functions, often simultaneously, for which quantitative relationships between measured values and predicted responses are lacking.

M. J. Singer and S. A. Ewing have reviewed other definitions of soil quality. The existence of multiple definitions suggests that the soil quality concept is evolving. All soil quality definitions have some similarities: high-quality soils are productive and biologically active; they support plant productivity and human and animal health; and they serve in various capacities in unmanaged ecosystems. In particular, high-quality soils are those that adequately regulate water, nutrient, and energy flow through the environment, while providing buffers against undesirable environmental changes. An integrated vision of soil quality has been offered in definitions, but its characterization and indexing have focused on limited individual aspects of the definition without attempting to integrate the conflicting functions.

Measurement. To proceed from definition to quantitative measure, a minimum data set of characteristics representing soil quality must be selected and quantified. A minimum data set may include the presence of specific biological, chemical, or physical soil characteristics; optimum levels of specific characteristics that benefit soil productivity or other important soil functions; or the absence of a property that is detrimental to these functions.

For agriculture, the goal is to measure properties that lead to a relatively simple and accurate soil ranking based on potential plant production without soil degradation. Presumably, optimal ranges of soil properties exist for meeting the quality criteria of productivity with acceptable levels of soil and environmental degradation.

Examples of dynamic soil characteristics are the size, membership, distribution, and activity of a soil's microbiological community; the soil composition, pH, and nutrient ion concentrations; and the exchangeable cation population. Soils respond quickly to changes in conditions such as water content. As a result, the optimal timing, frequency, and distribution of soil measurements vary with the property being measured.

Soil properties that change quickly present a problem because many measurements are needed to know the average value and to determine if changes in the average indicate improvement or degradation of soil quality. Unfortunately, the average quantified value of a rapidly changing property may not accurately represent the soil condition at any given time. Conversely, properties that change very slowly are insensitive measures of short-term changes in soil quality.

Some important soil characteristics are slowly renewable. Organic matter, most nutrients, and some physical properties may be renewed through careful long-term management. Certain chemical properties (pH, salinity, and nitrogen, phosphorus, and potassium content) may be altered to a more satisfactory range for agriculture within a growing season or two, while removal of unwanted chemicals may take much longer.

Physical and chemical factors. Physical factors, such as effective rooting depth, porosity or pore size distribution, bulk density, hydraulic conductivity, soil strength, and particle size distribution, are potential soil quality indicators. Other physical properties, such as structure, texture, and profile characteristics, affect management practices in agriculture but are only indirectly related to plant productivity and require large efforts to specifically correlate with crop performance. Water potential, oxygen diffusion rate, temperature, and mechanical resistance directly affect plant growth, and may be better indicators of the physical quality of a soil for production, but are difficult to measure. Nutrient availability depends on soil physical and chemical processes, and chemical characteristics. At low and high pH, for example, some nutrients are unavailable to plants and some toxic elements become more available.

Biological factors. The focus of many soil quality definitions is soil biology. Soil supports a diverse population of organisms, ranging in size from viruses to large mammals. Members of these populations usually interact positively with plants and other system components. However, some soil organisms, such as nematodes and bacterial and fungal pathogens, reduce plant productivity. Many proposed soil quality definitions focus on presence of beneficial rather than absence of detrimental organisms, although both are critically important. Various measures of microbial community viability have been suggested as measures or indices of soil quality. Community-level studies consider species diversity and frequency of occurrence of species. Scientists emphasizing the use of biological factors as indicators of soil quality often equate soil quality with relatively dynamic properties, such as microbial biomass, microbial respiration, organic matter mineralization, and organic matter content. They suggest that keystone species, taxonomic diversity at the group level, and species richness of several dominant groups of invertebrates can be used as part of a soil quality definition.

Future. Complex and evolving, the concept of soil quality brings together soil science, philosophy, politics, and policy. No single soil property represents soil quality. Soil scientists have not agreed on a single set of soil properties that can universally assess soil quality. Disagreement continues as to whether the concept is scientifically valid. It is unlikely that scientific agreement will be found to satisfy all points of view. Regardless of acceptance of the concept, or its definition, or the suite of soil variables chosen to define and quantify soil quality, soil scientists agree that it is critical to human sustainability that soils be carefully managed to provide for human health and welfare, while minimizing soil and environmental degradation.

For background information *see* AGRICULTURE; CONSERVATION OF RESOURCES; SOIL; SOIL CONSERVATION; SOIL ECOLOGY; SOIL FERTILITY in the McGraw-Hill Encyclopedia of Science & Technology.

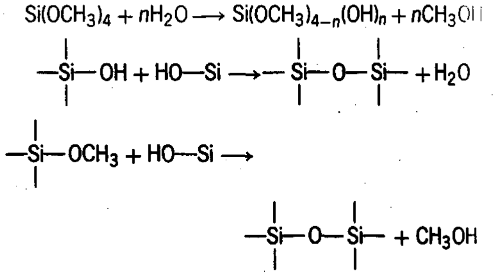
M. J. Singer; R. E. Sojka

Bibliography. J. W. Doran et al. (eds.), Defining Soil Quality for a Sustainable Environment. *SSSA Spec. Publ.*, no. 35, Soil Science Society of America, Madison, WI, 1994; D. L. Karlen et al., Soil quality: A concept, definition, and framework for evaluation, *Soil Sci. Soc. Amer. J.*, 61:4-10, 1997; M. J. Singer and S. A. Ewing, Soil quality, in M. E. Sumner (ed.), *Handbook of Soil Science*, CRC Press, Boca Raton, FL, 2000; R. E. Sojka and D. R. Upchurch, Reservations regarding the soil quality concept, *Soil Sci. Soc. Amer. J.*, 63:1039-1054, 1999.

Sol-gel sensors

The use of sol-gel chemistry as a means to prepare inorganic and organic-inorganic composite materials has blossomed in recent years. The fundamentally intriguing chemistry, coupled with the ease with which these materials can be made, modified, and processed, has attracted the interest of a variety of scientists.

Sol-gel processing. Sol-gel processing involves the preparation of glasslike materials through the hydrolysis and condensation of metal alkoxides. Two of the most studied alkoxysilanes used for fabricating silicate materials are tetramethoxysilane (TMOS) and tetraethoxysilane (TEOS). In a typical procedure, TMOS is mixed with water in the presence of a mutual solvent such as methanol and a catalyst such as an acid (for example, hydrochloric acid), a base (such as ammonium hydroxide), or a nucleophile (such as fluoride). During sol-gel transformation the viscosity of the solution increases as the sol (a colloidal suspension of small particles) becomes interconnected to form a rigid porous network—the gel. Gelation can take place on the order of seconds to months, depending on the sol-gel processing conditions (type and concentration of catalyst, alkoxide precursors, silicon-to-water ratio, temperature). A simplified scheme for the hydrolysis [reaction (1)] and condensation [reaction (2) and/or (3)] of TMOS is shown.



$$Si(OCH_3)_4 + nH_2O \longrightarrow Si(OCH_3)_{4-n}(OH)_n + nCH_3OH \quad (1)$$

$$-\overset{|}{\underset{|}{Si}}-OH + HO-\overset{|}{\underset{|}{Si}}- \longrightarrow -\overset{|}{\underset{|}{Si}}-O-\overset{|}{\underset{|}{Si}}- + H_2O \quad (2)$$

$$-\overset{|}{\underset{|}{Si}}-OCH_3 + HO-Si \longrightarrow -\overset{|}{\underset{|}{Si}}-O-\overset{|}{\underset{|}{Si}}- + CH_3OH \quad (3)$$

Sol-gel processing provides the ability to make materials in various forms. For example, the silica sol can be spin-cast or dip-coated on a suitable substrate (such as a glass slide, electrode surface, or silicon wafer) to form a thin film. Alternatively, it can be poured into a suitable container such as a cuvette to form a block monolith. The block monolith can be crushed and sieved to form small particles that can be packed into tubes. Another unique feature of sol-gel processing is the ease with which the chemical properties of the material can be manipulated. For example, organoalkoxysilanes (R—Si(OR′)$_3$, where R = CH_3, C_6H_5, $CH_2CH_2CH_2NH_2$, and so on) can be cohydrolyzed and condensed with TMOS to form organic-inorganic hybrid materials. Finally, because the sol-gel processing conditions are relatively mild, various molecules can be introduced into the porous silicate matrix by simply adding them to the sol prior to its gelation (see **illus.**). Relative to many organic polymer matrices, sol-gel-derived glasses

McGRAW-HILL YEARBOOK OF
Science & Technology

2002