Soil Productivity Variables

Organic Matter

Soil organic matter is important to soil productivity because it: 1) contributes to the development of soil aggregates, which enhance root development and reduce the energy needed to work the soil; 1) increases the air- and water-holding capacity of the soil, which is necessary for plant growth and helps to reduce erosion; 3] releases essential plant nutrients as it decays; 4) holds nutrients from fertilizer in storage until the plants need them; and 5) enhances the abundance and distribution of vital soil biota. The importance of these functions varies greatly from one soil type to another.

The best soils for plant production possess substantial water-holding and ion-exchange capacities, good physical structure, and thriving populations of bacteria, fungi, and invertebrates. These attributes are highly correlated with soil organic matter content derived from plant remains and microbial synthesis. Good soil structure depends on aggregation of colloidal clay minerals held together by organic molecules. These organic molecules are being consumed continually by microbes and other invertebrates, so maintaining soil organic matter requires a steady influx of plant biomass from root decay and aboveground organic residues (Jenny, 1980).

Effects on Productivity

Increased soil organic matter commonly improves water infiltration, decreases evaporation, fosters more extensive and deeper root systems which may make more moisture available to crops, and improves the efficiency of water use by the crop.

Major benefits to soil fertility are derived from soil organic matter largely through its effect on aggregation of soil particles. Increased particle aggregation lowers soil bulk density, consequently improving tilth, increasing soil percolation and aeration characteristics, and improving soil drainage, microbial activity, and temperatures. Fine-grained organic matter and soil clay minerals form soil colloids, which play major roles in supplying nutrients to plants. Some soil colloids have the ability to hold abundant plant nutrients on their surfaces where the nutrients are easily exchangeable with hydrogen ions produced by plant roots.

The main natural source of nitrogen for plant growth is soil organic matter. Mineral soils ordinarily contain about 400 to 6,000 lb per acre of nitrogen in the plow layer and somewhat lesser amounts in subsoils. However, most of the nitrogen is in soil organic matter and is unavaiable to plants until it is converted into ammonia and nitrates by micro-organisms (Allison, 1973).

Soil organic matter may contain from 15 to 80 percent of the total soil phosphorus, an important plant nutrient. Micro-organisms use inorganic phosphorus and synthesize organic phosphorus, subsequently providing an important link in the soil/phosphorus plant chain. Like nitrogen, there are active and inactive forms of phosphorus in soil organic matter. The active substances chiefly are residues that have not yet been transformed by microbial processes. A substantial amount of organic phosphorus released during the plants' growing season comes from decomposition of this soil organic matter. The literature contains numerous statements that the addition of farmyard manure and green manures will increase the availability of soil phosphorus to plants; however, experimental evidence to support such statements is scarce (Allison, 1973).

Soil organic matter helps control the supply of potassium for plant growth. Potassium is adsorbed on organic colloids and is present in organic residues and living micro-organisms (Mulder, 1950). As these reservoirs of available potassium are depleted, they are replenished both by potassium released from inorganic compounds and from added organic residues. Under many conditions, the organic residues are the important factor in maintaining the soil's plant-available potassium.

Even though required in only small amounts, the micronutrients sulfur, calcium, magnesium, iron, copper, manganese, zinc, boron, and molybdenum also are essential for general plant growth. Here, too, soil organic matter plays a major role in assuring that these trace elements remain available for plant uptake.

Maintenance and Loss of Soil Organic Matter

Farming practices affect the organic matter content of soil. Where the land is plowed, soil organic matter decreases through oxidation. Keeping freshly broken virgin land bare for long periods markedly decreases soil organic matter, The decrease occurs mostly in the first 25 years after the soil is broken; after that a new, but lower, steady state of organic matter content is reached.

Under cultivation, much of the vegetation produced is removed, water and wind erosion are accelerated, and frequent cultivations favor oxidation of organic matter, The reduction of soil organic matter content can be reduced significantly by adopting cropping systems that reduce the frequency and degree of tillage and keep the soil protected by vegetation as much of the time as possible. Field experiments at Mandan, N. Dak., showed that the loss of nitrogen during the first 33 years of cropping was 34 percent for continuous corn while the loss with continuous small grains was 14 percent (Allison and Sterling, 1949). Where grass sods are maintained, even in regions of heavy rainfall, there is little loss of nitrogen or organic matter,

The smaller the crop and the more completely it is removed from the soil, the more rapidly the soil humus will decrease, and conversely, the larger the crop and the more of it that is returned to the soil, the higher the level of organic matter that can be maintained. Nevertheless, the level in any tilled soil usually will be considerably below that of the original virgin soil.

Research on Changes in Soil Organic Matter

Changes in the amount of organic matter in soils occur relatively slowly. Research of several years' duration is required for properly documenting the effect of cropping systems, soil treatments, and other management practices on the soil organic matter. Few such studies have been initiated in recent years, in part because many agronomists and soil scientists feel that the effects of many management practices on soil organic matter are reasonably predictable. Another reason is that funding for long-term research generally is not as available as for shorter term research.

Data on the effects of management practices on soil organic matter come mostly from studies initiated years ago, many of which now have been discontinued. However, some long-term studies still are under way, notably the Morrow Plots in Illinois and Sanborn field in Missouri. European studies include those of Rothamsted Experimental Station in England, and those at Grignon, France.

Information Needs

Improved data and understanding in a number of areas will assist in determining the long-term impacts of new and old technologies on soil productivity, Further information is needed on how soil organic matter affects soil productivity under various cultural practices and climatic conditions, and on how cultural practices affect organic matter, Improved data are needed on optimum levels of soil organic matter for specific sites, specific crops, and specific cropping systems. As the cost of commercial fertilizers increases, new data on the interrelationships of soil organic matter and commercial fertilizers will become increasingly important, Similarly, by enhancing soil tilth, organic matter ultimately may help reduce the amount of fossil fuel used during plowing, planting, and other such field activities.

As organic wastes, some containing high levels of toxic heavy metals, are introduced into agricultural practices, further understanding of how soil organic matter holds or releases these toxic substances will become increasingly important.

Biota

Most soils are inhabited by a diversity of life forms. The soil biota include numerous microbes, a wide variety of invertebrate animals, and a few vertebrates. Most soil biota are microscopic or, at the largest, tiny to the naked eye. Some larger soil invertebrates such as earthworms, ants, other soil insects, and land snails and slugs are also important. Small mammals are the dominant vertebrate animals found below ground, but some amphibians, reptiles, and even a few birds live at least a part of their lives within soils.

Soil organisms often modify and enhance the soil by their activities. They are vital to the formation and maintenance of the natural soil system and perform functions essential for plant growth. Before the widespread availability of commercial fertilizers, nutrients recycled by the biota were recognized as a major component of land productivity and so soil ecology ranked high among the agricultural sciences. In recent decades, however, there has been much less emphasis on soil biology.

Scientists generally are not alarmed about the possibility of pesticide use causing severe harm to soil ecology in the near future, Insecticides and herbicides in use are tested for their impact on soil biota, Inhibition of some biological processes and suppression of particular groups of biota occur, but generally the gross effect of each pesticide application seems neither great nor long-lived. Pesticides do cause changes in soil insect and earthworm populations, but the impact of these changes on long-term land productivity is not known.

Frequent applications of toxic chemicals probably are changing the composition of soil biota communities, favoring species that can adapt to the new chemical environment. However, methods are not well-enough developed to make practical differentiation among microbe species in the field, and soil invertabrates have been studied so little that many are still unknown. Thus, the cumulative effects of agricultural technologies on productivity will not be measured until advances are made in the science of soil biology.

Micro-organisms

Soil micro-organisms include bacteria, fungi, actinomycetes, and protozoa. A critical function they perform is to generate nutrients essential for plant growth. Micro-organisms are either the sole or chief natural means for converting unavailable forms of nitrogen, sulfur, phosphorus, and other elements in soil into products that plants use. Thus, the rate at which micro-organisms convert organic nitrogen and other nutrients to inorganic products determines the rate of plant growth. Hence any action deleterious to microbial processes critical to plant nutrition would have adverse consequences.

Soil micro-organisms also modify soil structure by forming humus that binds minute soil particles into larger aggregates. These larger structures are beneficial because they promote root development, improve soil aeration, and lead to improved soil moisture.

Microscopic forms of life are responsible for decomposing organic matter and releasing elements not used directly as plant nutrients. Some of these elements may be converted to gaseous form, as in the case of carbon and nitrogen. By such conversions, micro-organisms in part regulate the chemistry of the atmosphere and the Earth's surface. Microbial decay of plant remains is useful because some crop residues contain naturally occurring toxic substances that at high concentrations are deleterious to plants (Alexander, 1980).

Further, soil micro-organisms are responsible for decomposing a wide array of synthetic chemicals deliberately or inadvertently released into agricultural soils and water, including pesticides, industrial wastes, and air pollutants. Micro-organisms convert many chemicals to inorganic products. The breakdown process may lead to detoxification of toxic chemicals, the formation of short- or long-lived toxicants, or the synthesis of nontoxic products, Scientists have investigated only a few of the multitude of chemicals to determine what breakdown products are formed when micro-organisms encounter chemicals in natural systems (Alexander, 1981).

Some data are available on micro-organisms and their effects on soil chemistry, but numerous and considerable voids exist in the data base. The processes most frequently studied are the decomposition of soil organic matter, nitrogen mineralization, vitrification, the decomposition of added organic materials, and nitrogen fixation.

Most of the major technological innovations that might affect the microbiology of agricultural and rangeland soils have been evaluated for their impacts on microbiology, at least in part. Thus, the likely impact of a particular type of technological change or agricultural operation on soil microbiology can be predicted, but only in relatively gross, qualitative terms. The studies generally have not been conducted in a fashion that would allow extrapolation from the particular in~'estimation to conditions prevailing elsewhere. Thus, generalizations cannot be made on the quantitative responses of microbial populations in different soil types, different climatic regions, and areas that have different types of vegetation [Alexander, 1980).

Essentially no models have been devised to predict how agricultural technologies will affect the aggregate of microbial activities that are important to crop production and rangeland management. Specific interactions among micro-organisms, and between microbial predators and their prey, are not known. Thus, practical methods do not exist for scientific advisors, farmers, and policy makers to predict the impact of existing or alternative technologies on microbial plant production or soil fertility (Alexander, 1980).

Because policy makers, public interest groups, and sometimes Federal agencies have been acting largely with inadequate information, the impacts on microbial activities may sometimes be overdramatized, whereas in other instances a significant problem may be wholly ignored. In addition, this lack of data on microbial populations and activities means that the risks, costs, or profits that farmers incur by applying new agricultural technologies are largely unknown (Alexander, 1980).

Sell Invertebrates and Vertebrates

Soil invertebrates include such animals as earthworms, slugs, land snails, ants, and other insects. These animals carry out the early stages of the physical and chemical decomposition of all types of organic debris in or on the soil. Most soil invertebrates also act as carriers of microbial propagules (e.g., seeds, spores] and so they inoculate the organic matter as it is passed through their bodies, The final stages of biochemical decomposition are also accomplished by microbes, thus recycling nutrients, forming humus, and fostering soil particle aggregation (Dindal, 1980).

Historically, most research on the biology and ecology of soil invertebrates has been carried out in Europe and Russia. Although there were occasional American publications on soil organisms before the late 1960's, it was not until then that a major research thrust was initiated in this country. Even today, few U.S. colleges and universities offer courses in soil biology. Consequently, much of the understanding of the general functions of soil invertebrates comes from the works of foreign scientists. This is exemplified by the recent International Colloquium of Soil Zoology held in Syracuse in 1979, "Soil Biology as Related to Land-Use Practices. " Of the 96 papers presented, 20 dealt with effects of agriculture on soil fauna, and only one of these 20 papers described work conducted in the United States (Dindal, *1980).*

This dearth of research in the United States can be explained by several factors: 1) agricultural practices in the United States have not been developed to take advantage of soil organisms; 2) a lack of funding and of an organization with "lead agency" status to oversee research in this area; 3) a lack of employment opportunities in this field of research; 4) a lack of cooperation between Federal agencies and soil invertebrate ecologists; and 5) the lack of research is partially a result of the nature of the research itself (i. e., procedures may be extremely rigorous, tedious, and time-consuming).

Research on soil invertebrates generally encounters one or more of the following problems. First, to get useful data on how changes in soil invertebrate ecology occur, many (generally 10 or more per site) small samples per year must be taken from treated and control areas. Second, few croplands have been sampled for soil fauna because the soil is regularly disturbed by plowing, planting, cultivation, and harvests, thus hindering needed control. Third, the sheer numbers of soil organisms per sample can become overwhelming to assess. For example, a soil sample 5 cm in diameter by 3 cm deep in a central Ohio field may have a range of 30 to 1,000 individual microarthropods in it (Dindal, Felts, and Norton, 1975).

The massive number of organisms in a soil sample increases the problems of sorting, counting, identifying, and determining the ecological roles of these creatures within a reasonable time, and demands extreme patience and technical knowledge. To complicate such research further, between 5 and 25 percent of the microarthropods alone found on most new study sites will be species never before described taxonomically. Further, the available taxonomic keys to identify soil biota are European or Russian and do not apply adequately to many U.S. fauna. Life history details of these new forms also are unknown, thus demanding further time-consuming laboratory and field consideration (Dindal, 1980]. Finally, soil invertebrates and vertebrates exist as part of a microcommunity within the soil. The structure and function of this community, too, must be assessed.

Despite the lack of quantitative data on the impact of agricultural technology on invertebrates in most U.S. soils, some qualitative information exists. The situation is not the same for soil vertebrates, which include such animals as moles, gophers, mice, other burrowing mammals, and some reptiles and amphibians. Even though some people worry that agricultural technologies may harm beneficial soil invertebrates, the activities of soil vertebrates are commonly and narrowly viewed as negative—e.g., making burrows in which farm machinery can become entrapped, or consuming valuable grain or forage. Some studies of soil vertebrates suggest that they may also have beneficial impacts, such as breaking up hardpan a foot or more below the surface, thus improving drainage and increasing rooting depth (Ross, et al., 1968). Unfortunately, such ecology studies typically are conducted on virgin land and are difficult to relate to agricultural productivity,

Soil animals play an integral, if limited, part in humus formation. Their chief contribution to land productivity lies in the degree that microbial activity is enhanced by their activities. Together, soil fauna and microbiota play an indispensable role in soil formation, soil profile modification, nutrient release, and the mixing of organic and inorganic materials. Holistic field studies of invertebrate-soil, vertebrate-plant productivity associations are practically nonexistent. Until such studies have been undertaken on different soils under various agricultural conditions, scientists and farmers will lack the information needed to design and implement farming systems that can make optimum use of scarce resources.

Soil Chemistry

Each agricultural crop, whether plant or animal, that is removed from the land carries with it some soil nutrients. This nutrient loss is in addition to the losses from soil erosion, leaching, denitrification, and volatilization of certain elements. If the nutrient supply is not replenished, the soil's fertility will decrease.

Commercial fertilizer helps maintain the supply of soil nutrients needed for continued agricultural production. Most people are aware that large amounts of commercial fertilizers are applied to U.S. lands each year, but are less aware of the soil nutrients that are taken from the land in the form of agricultural products. For example, 30 lb of phosphorus are removed with 50 bushels of wheat (3,000 lb) (Shacklette, 1977). Similarly, Hawaii exports 2,200 tons of potassium each year in its pineapple crop alone. Losses of nitrogen and sulfur follow the same general trend as those of phosphorus and potassium. Even well-maintained organic farms that carefully collect and return the farm's unused crop residues and animal wastes to the soil can only reduce but not eliminate nutrient losses.

Natural weathering produces new soil and releases additional nutrients, but the process is exceedingly slow and thus unable to keep pace with modern agriculture's needs. Whether soil nutrient replacement is accomplished by addition of natural or commercial fertilizers is an individual's choice, but agriculture has to replace what it has taken from the soil if it expects to accomplish long-term, sustainable crop production.

Judicious use of fertilizers is the key. Additions that are too low result in nutrient deficiencies in the soil and lower crop yields. Where fertilizers are applied too heavily, chemical excesses in the soil, runoff, and ground water not only are unnecessary capital expenses but also detriments to other parts of the natural resource base.

Most of America's croplands are fertilized so that the exchangeable concentration of nutrients remains at a level that will sustain high yields. Normally, fertilization requires frequent [usually annual) input of nutrients. The cost of fertilizing is spiraling because its production is highly energy intensive, especially nitrogen fertilizers. In fact, of the on-farm energy expenditures for food production in *1977, 36* percent was for fertilizer (Pimentel, et al., 1973; Olson, 1977). Thus, the on-farm production costs of food can be expected to continue to rise with the cost of energy as long as present energy-intensive fertilizer technology is used.

Commercial Fertilizers

Commercial fertilizers generally are synthesized or manufactured through various industrial processes and contain one or more of the essential plant nutrients (Fertilizer Institute, 1976). These include important soluble compounds of nitrogen, phosphorus, and potassium. Limestone, gypsum, dolomite, greensand (glauconite), rock phosphate, and granite are common rocks that when ground to a fine particle size also can be added to cropland soils to provide calcium, magnesium, potassium, and phosphorus. These finely ground, less soluble natural materials usually are not included in the category "commercial fertilizers. " They were the basic inorganic soil nutrient inputs prior to industrial synthesis of commercial fertilizers. Because conlmercial fertilizers are synthesized, highly soluble, and concentrated, some people are concerned that such fertilizers may have certain long-term adverse impacts on soils, the soil biota, water supplies, and other parts of the natural resource base. The following discussion briefly examines the impacts of the common commercial fertilizers on land product i\'-ity.

NITROGEN FERTILIZER

The nitrogen fertilizers used today are acid-forming. This can be a benefit or a potential problem depending on the specific soil. In naturally alkaline soils, acid-forming fertilizers can increase productivity. However, in naturally acid soils, fertilizers can increase the soil's acidity and reduce crop yields unless lime is applied to neutralize the acidity. Thus, depending on soil properties and management, the residual acidity formed could be a problem, but one that is easily managed.

The rate of application of fertilizer nitrogen to croplands can influence the amount of nitrate leaving fields via subsurface waters or drain tiles, When the percentage of the applied nitrogen used by the crop decreases, the amount available for leaching increases. Fertilizer use on cultivated crops can increase the nit rogen loss from soils, but how this effects nitrogen concentration in streams is still unclear.

Nitrogen can be lost through surface runoff, too. Most of the nitrogen removed by surface runoff is organic nitrogen associated with sediment. Even though it is possible to lose significant fertilizer nitrogen in surface runoff if heavy rains immediately follow application, this accounts for only a small proportion of nitrogen lost from soils or of the fertilizer nitrogen applied (Mengel, 1980). Nevertheless, spring measurements of nitrate in surface waters in Illinois showed that at least 55 to 60 percent originated from fertilizer nitrogen (Kohl, et al., 1971).

The amounts of fertilizer nitrogen either lost to, or found in transit to, ground water are quite variable. In general, in the Southeastern United States nitrate enrichment of shallow ground water does occur, though no enrichment of deep ground water is known. Denitrification of nitrate in shallow ground water also has been noted. In the Midwest, significant amounts of nitrogen can be found below the root zone (Mengel, 1980).

The problem of leaching nitrates from fertilizer to ground water is greater in irrigated areas. Nitrogen fertilizer use on irrigated sandy soils shows a high correlation with nitrate-contaminated aquifers (Spalding, et al., 1978; Reeves and Miller, 1978).

PHOSPHORUS AND POTASSIUM

Unlike nitrogen, which has a relatively short residual activity in soils, phosphorus tends to accumulate in soils in relatively insoluble inorganic forms. Thus, phosphorus fertilization leads to increased soil phosphorus levels over time. In many intensively managed soils, particularly where high-value crops such as vegetables are grown, phosphorus levels have become quite high. The questions then asked are: at what level is soil phosphorus high enough that no additional phosphorus is needed and how long can soil reserves adequately supply plant needs? Fertilization emphasis thus shifts to maintaining soil phosphorus at a level adequate for optimum crop growth.

Phosphorus buildup is of practical significance. Soil test reports indicate that soil phosphorus levels are increasing in some States, and in many instances have become adequate to supply the phosphorus needed for crop production with only small additions (Mengel, 1980). Only a very small amount of fertilizer phosphorus is lost from soils if erosion is controlled. However, even these small amounts can be significant and can accelerate surface water eutrophication. Phosphorus loss can be minimized through proper erosion control.

Although some phosphorus is lost by movement into ground waters through leaching, the amounts generally are insignificant from both agronomic and water-quality standpoints. However, significant phosphorus may enter ground water where the water table is high or approaches the plow layer. Similarly, flooding may provide anaerobic conditions in soils, and in such cases phosphorus concentrations can be fairly large in effluent from tile drains and can be a ground water pollutant.

Like phosphorus, potassium from fertilizers can accumulate in soils over time. Soils in humid areas of the United States are inherently low in potassium, so yields can be enhanced by potassium application. Many soils in the more arid regions contain adequate potassium levels, and potassium fertilization can actually decrease yields (Rehm, et al., 1979). Thus, care is needed to ensure that potassium is applied only on soils with low natural potassium levels. Potassium fertilizer does not appear to be a potential source of pollution for either surface or ground water.

COMMERCIAL FERTILIZER EFFECTS ON SOIL INVERTEBRATES ON MICRO-ORGANISMS

Although little-studied, fertilizers seem to have considerable effects on soil invertebrates through alterations of plant species diversity and composition (Morris, 1978). Field studies of fertilizer-caused changes in the diversity of invertebrate populations show that the impacts diminish in successively higher levels in the food chain (Hurd and Wolf, 1974), Similarly, the population of microarthropods in several test plots treated with commercial fertilizers or with manure showed a small population increase with the commercial fertilizer and a large one with manure (Wallwork, 1976). Combinations of commercial and organic fertilizers may produce the most beneficial effects.

The activities of soil micro-organisms, and the impact of commercial fertilizers on them, have been studied extensively in other countries, but less in the United States. *Convincing data for a long-term detriment caused by synthetic fertilizers do not exist,* Although individual studies do in fact show temporary inhibitions of microbial activity, the suppressions do not appear to be long term or to affect significantly the microbial processes important to soil fertility, This does not mean that detrimental effects do not occur, however. It may be that the science of soil biology is not able to detect the effects, The commercial fertilizer anhydrous ammonia is a special case because of the high concentrations that normally are applied to a narrow region of the soil. It is toxic to specific microbial processes for a short period after application. However, the ammonia is converted in several days or weeks to the nontoxic product nitrate so that it is not certain whether the inhibition has long-term significance (Alexander, 1980).

Pesticides

Pesticides are chemicals used primarily to combat pests that affect food and fiber production or cause a public health hazard. They are broadly classified on the basis of the kinds of pests they control—namely, insecticides, herbicides, fungicides, nemat icicles, rodent icicles, and miticides. Also, chemicals used for defoliation, desiccation, soil fumigation, and plant-growth regulation also are classified as pest icicles (Hark in, et al., 1980).

Most pesticides are organic chemicals. Some are manmade and some are of natural origin, Many contain chlorine, nitrogen, sulfur, or phosphorus which serve to determine the toxicological impacts of the compounds.

The U.S. consumption of pesticides represents 45 percent of total world USe. Approximately 36,000 pesticide labels are now registered with the U.S. Environmental Protection Agency (EPA), although only a few' substances are used extensively. The agricultural sector is the major user of pesticides and the amounts used are increasing at a more rapid rate than use by homeowners, industry, institutions, and Government.

During the past decade a significant shift occurred in the agricultural use of insecticides with an increase in the use of organophosphorus and carbamate compounds and a decline in the use of organochlorine compounds. The decline in organochlorine insecticides will continue as a result of Government restrictions on their use because of their adverse environmental impacts.

Mankind has benefited markedly from the use of pesticides, notably in terms of high production of food and fiber at relatively low cost and in improved public health. The demand for pesticides is expected to continue to increase because there are few feasible alternatives for pest control. Integrated pest management, if widely practiced, could reduce pesticide use on croplands [U.S. Congress, OTA, *1979).*

Since the early 1960's when environrnental awareness became acute, increasing concern has been expressed over the potential hazards associated with pesticide use and their long-term impacts. Pesticides are potential pollutants of food, drinking water, and fish and wildlife habitats. The impacts of pesticide use on the environment are determined by the environmental transport of the chemicals, their persistence, degradation, and dissipation in the environment, and the hazards associated with pesticides and the products created when they are decomposed or metabolized.

PESTICIDE EFFECTS ON GROUND WATER, SURFACE WATER, AND PRECIPITATION

The presence of pesticide residues in surface runoff is well documented, and numerous short-term environmental impacts are noted such as fishkills, contamination of mollusks, etc. (Ehrlich, et al., 1977), Longer term impacts that could affect overall land productivity include the effect of pesticides carried by surface water into marsh and estuarine ecosystems that provide the breeding grounds for many animal species, including many which are economically important (Heckman, 1982). Pesticide pollution of ground water has been documented (see ground water section). The problem seems to be most severe for shallow ground water and sites having sandy, permeable soils.

The contamination of rainfall by pesticides has been documented for the organochlorinated compounds. Recent studies show that toxaphene can be carried long distances from its use site and deposited through rainfall elsewhere in concentrations high enough to damage fisheries. Transportation of the chemical seems to result from vaporization and subsequent adsorption on airborne particles (Bidleman, et al., 1979).

PESTICIDE EFFECTS ON SOIL INVERTEBRATES

The effects of pesticides on soil fauna is a highly complex issue and researchers have had difficulty making generalizations. Variables include: 1) the abundance of biocidal compounds from various chemical families, 2) great differences in persistence of pesticide compounds i n the environment, 3) the diversity of invertebrate organisms in different soil communities, 4) metabolic(: products of different organisms that ingest pesticides, 5) the many chemical and physical varicties of different agriculatural soil ecosystems, and 6) t h e psychological, cultural, and traditional agricultural practices of people who use pesticides (Dindal, 1980).

Where effects of pesticides have been observed and analyzed, the biotic responses are equally variable: 1) soil fauna may exhibit either a direct response to pesticides or more often an indirect sec -

ondary response; 2) only certain organisms are affected in a detrimental fashion, some populations actually increase; 3) certain pesticide residues accumulate in tissues of some soil organisms with no apparent ill effects; and 4) certain sensitive species are killed from acute or chronic exposure to biocides. In almost all cases, the structures and functions of soil communities are modified by pesticide use (Dindal, 1980).

Although much knowledge exists on the effects of individual pesticides, much more research is needed to determine the combined effects of many pesticides used on the same site,

EFFECTS ON SOIL MICROBES

Although pesticides are designed to control pest species, the extent of their selectivity for pests in some cases is not great and other organisms are injured, including soil micro-organisms,

Inhibitions of microbial activity are most pronounced from fungicides and fumigants and the suppression may remain for long periods. The impact may be so great that the natural balance among the resident soil microbial populations is upset and new organisms, such as plant disease vectors, become prominent. Moreover, certain nutrient cycles regulated by micro-organisms are inhibited by fungicides and fumigants in such a way that significant adverse effects on plant growth and nutrition become evident. The lack of widespread concern for these antimicrobial agents is not because of their lack of toxicity but rather because they are not as widely used as are the other two major classes of pesticides (Alexander, 1980),

Insecticides have received most attention in the past, These compounds may be applied directly to) soil for the control of soil-borne insects, or they may reach the soil from drifting sprays or when treated plant remains fall to the ground or are mixed with the soil during normal farming practices. Inhibition of some microbial processes or suppressions of individual populations of bacteria, fungi, or actinomycetes occur. On the other hand, the toxicity is generally not marked, and the beneficial effects of the insecticides in controlling insect pests argue for their use. U.S. regulatory agencies have not acted on the basis of possible long-term harm insecticides might have on microbial processes, but few instances of major suppressions of microbial activities in the field have been noted, so that a change in policy in regard to their use does not appear warranted (Alexander, 1980).

Herbicides are designed to control the growth of seed-bearing plants. The amount of herbicide used per unit of land area is small and the compounds are reasonably selective for target plants, so little or no inhibition of other soil processes has been noted. In some instances, herbicides alter microbial activities, but such changes probably are associated with suppression of target plant species which limits organic nutrients needed by the micro-organisms around its roots. These effects seem slight and have not warranted questioning the use to particular chemicals (Alexander, 1980). Herbicide use in no-till agriculture, however, is a matter of increasing concern because of the increased amounts applied.

The general consensus among soil microbiologists seems to be that a few of the registered pesticides affect microbial processes in the short term, but the influence is not sufficient to warrant banning the chemicals. Continual assessment of the effects of new pesticides on microbial processing as required by current EPA regulations is certainly worthwhile.

Effects of Toxic Wastes

The addition of toxic waste products to agricultural land can occur inadvertently when waste materials are applied as fertilizers, Some toxic substances such as heavy metals, polychlorinated biphenyls (PCBS), and other industrial chemicals can reach agricultural land through the atmosphere or surface water.

Collectively, such toxic wastes provide a wide spectrum of pressures on all living creatures. Some organic toxicants on or in the soil can be decomposed or at least modified by biological decomposes, but others cannot. Some of the compounds, however, are able to sublimate, volatilize, or disperse throughout the soil microenvironment. The cause-and-effect relationships between many of the priority pollutants and soil biota are yet to be investigated (Dindal, 1980).

Heavy metals, from whatever source, can threaten soil biotic systems. Research in Holland shows that earthworm growth and reproductive capacity can be reduced by copper and worms were eradicated from soils having copper accumulations over 80 parts per million (Rhee, 1969), Interestingly, other preliminary studies show that other heavy metals may accumulate to high levels in earthworms without being lethal (Dindal, 1980).

Much is known about the toxicity of cadmium, zinc, copper, nickel, lead, mercury, and certain other elements, individually and in combination, on several major soil microbial processes, including decomposition of litter and soil organic matter, certain steps in the nitrogen cycle, and enzymatic activities. Moreover, a variety of individual microbial groups has been tested showing that heavy metals indeed inhibit microbial processes at low concentrations. The extent of the toxicity depends on the particularly heavy metal, its concentration, soil type, soil pH, and the individual microbial process or group (Alexander, 1980).

impacts of Soil Chemistry Changes on Human and Animal Nutrition

A persistent rumor holds that modern food is not as good as it used to be. But whether this is true is not known. The chemical makeup of plants varies with: I) the chemical and physical makeup of the soil on which the plant is grown, and 2) climatological factors. Nutrient deficiencies in soil tend to restrict growth and yield of plants so that the plants that survive and produce well enough to harvest show little, if any, nutrient deficiency.

Until recently no systematic work had been undertaken to determine if variation in cultural techniques—e. g., organic v. conventional farming methods—affects the nutritional content of crops. Therefore, there are little data to shed light on this question.

However, reasoning a priori, it is possible to make the following statements:

1. The bulk of the-crops grown in this country are grains. Variations in soil and weather conditions are most likely to affect the nonseed part of the plant; therefore, it is unlikely that the nutritional content of grain products eaten by humans is changed by cultural techniques.
2, Most of the grain raised in the United States is fed to animals which subsequently nourish humans. Generally, the makeup of mammalian muscle and milk and avian eggs are genetically determined; therefore, the probability of any nutritional difference in a plant being passed on to humans through animal products is small. Mammalian liver is the one animal product whose nutritional content could be affected significantly by diet.
3. It is impossible to determine the extent to which U.S. soil is more or less able to produce nutritious crops than when it was virgin because of several factors: the lack, until recently, of sufficiently sensitive assay procedures to detect such differences accurately and reproducibly, especially with regard to the vitamins and trace elements; the lack of available virgin soil to conduct a comparison study; the disappearance of many of the crop varieties eaten by our ancestors; and changes in weather and increases in air pollution.

The question of whether cultural techniques cause the levels of either naturally or adventitiously occurring compounds to vary is difficult, though answerable. Tests for sensory qualities have been developed to a level of sufficient accuracy to allow for meaningful comparisons. The levels of naturally occurring toxins in plants, as well as harmful contaminants such as heavy metals, pesticides, or chlorinated hydrocarbons, now can be detected, measured, and discriminated among with accuracy. However, no data base comparing agricultural techniques with the presence of these factors exists.

Summary

There are no economically feasible substitutes for the significant agricultural productivity functions of organic matter and soil biota, so their maintenance in croplands and rangelands is critical. Soil organic matter can be regenerated in degraded soils by using various agricultural practices. By doing so, general soil structure, soil nutrient-holding capacity, and the soil's resistance to erosion can be improved.

Soil clay minerals also have a nutrient-holding capacity, but once these fine-grained materials are lost to erosion, they cannot be regenerated quickly by known agricultural methods. Generally, the soil clays play a less dominant role in maintaining good soil structure than does soil organic matter. Consequently, maintaining soil organic matter in productive soils and regenerating it in degraded soils probably is one of the most economically efficient ways of sustaining the land's agricultural productivity.

Soil invertebrates and micro-organisms assist in breaking down plant remains, which produces new organic compounds that promote good soil structure and converts soil nutrients to forms usable by plants. The microbes are also necessary to break down pesticides and *other* toxic chemicals. Without the soil biota, the organic matter from plant residues and manure would be of little use.

Commercial and natural fertilizers must be added to most soils to sustain present and projected levels of crop production. Commercial fertilizers are becoming increasingly costly, so maximum benefit of their application is being sought and this depends in part on improved knowledge of the dynamics of soil organic matter and soil biota.

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Appendix C References

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