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Soil Nitrogen and Organic Matter

A vast amount of knowledge concerning soil nitrogen and organic matter has been accumulated. Most of this knowledge has come from research in temperate environments. However, the fundamental principles established in research in temperate regions have application in tropical regions. There are numerous reasons to conclude that tropical regions differ from temperate regions largely in climatic environment, but the fundamental biological principles formulated in temperate regions apply equally well in tropical regions when adequate consideration is given for changes in environmental factors. The purpose of this chapter is to review the fundamental principles that should guide research on soil nitrogen and organic matter in tropical regions and to emphasize measurements that are required in order to manage tropical cropping systems efficiently.

NITROGEN SUPPLY CAPABILITIES OF SOILS

Nitrogen Supply Processes

Natural nitrogen supply processes have provided the nitrogen for crop production since the beginning of time. However, seldom have

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they provided an abundance of nitrogen for long and sustained periods of crop production on the same land areas. Moreover, natural supply processes at their best have seldom provided enough plant available nitrogen to achieve the level of food and fiber production needed to meet the demands of present-day crop production. The natural supply processes include (1) mineralization of nitrogen from soil organic matter and from crop residues and the reverse process of immobilization in the decomposition of plant and animal debris and soil organic matter; (2) fixation of nitrogen from the atmosphere, largely through biological processes; (3) addition of nitrogen added through rain and other forms of precipitation.

Soil Organic Nitrogen

The nitrogen in soil organic matter has been and is yet an important source of nitrogen for crop production. However, soil nitrogen is not inexhaustible; it must decline in quantity in the soil in order to supply net amounts of nitrogen to crops grown on the land. Consideration of several factors associated with formation and decomposition of soil organic nitrogen will illustrate its importance and also its limitations as a source of nitrogen for crop production.

Nitrogen in the soil is largely in organic form. The organic nitrogen is an integral part of the soil organic matter system. Changes in organic matter are always accompanied by parallel changes in organic nitrogen. Organic matter is a temporary product—a stage in a natural cycle of elements. Each increment of organic matter originated as a particle of plant or animal residue, and it remains in the soil while it passes through the several slow biological changes that eventually convert it to carbon dioxide, water, ammonium, and other mineral elements. The soil supply of organic matter is replenished by periodic additions of fresh plant or animal residues.

Under all nonsterile soil conditions, nitrogen is added to the organic supply in the soil annually through crop residues (immobilization). Also (through biological decomposition, organic nitrogen in the soil is continuously converted to the inorganic form (mineralization). Under any sustained system of crop and soil management, these two processes tend to approach each other in magnitude so that mineralization balances immobilization (Bartholomew and Kirkham, 1960). When this balance is attained, the system is considered to be in equilibrium.

Soil areas differ markedly in the equilibrium level of soil nitrogen

attained after long periods of constant soil management. The equilibrium system is best illustrated by reference to the general mathematical expression used to describe soil nitrogen changes with time (Woodruff, 1950).

$$(dN/dt = A - rN) \tag{1}$$

is the primary differential equation that states that the rate of change in soil nitrogen is positively related to the rate of addition and inversely related to the rate of decomposition. N in the equation is soil nitrogen content. A is constant and is the annual rate of addition. The rate of decomposition, r, is a given fraction of the organic nitrogen in the soil. Upon integration, the expression in Eq. (2) results.

$$N = \frac{A}{r} - \frac{Ae^{-rt}}{r} + No\, e^{-rt} \tag{2}$$

The function e^{-rt} varies from 1 to 0 as rt varies from 0 to some very large number. Therefore, after a long time ($t \infty$), the last two components in the equation approach zero and the equation becomes

$$N = A/r \tag{3}$$

and

$$rN = A \tag{4}$$

This means [Eq. (4)] that addition is equal to decomposition. Equation (3) shows that the amount of nitrogen in the soil at final equilibrium is influenced by both the rate of addition and the rate of decomposition.

The implications and consequences of equilibrium situations in soil organic nitrogen need to be emphasized. At equilibrium, the amount added to the supply of organic nitrogen is essentially balanced by a like amount of decomposition. The total quantity of nitrogen in the soil remains unchanged. Consequently, the net amount that can be and is supplied to a crop is zero. Under these conditions, there must be as much organic nitrogen returned to the soil from crop residues as is liberated from decomposition. A critical examination of equilibrium situations reveals that when a part of the crop is harvested and removed from the land, equilibrium in organic matter can exist only if the nitrogen and organic matter inputs are

supplemented from sources apart from the land area in question. Fallow areas and permanent pastures most nearly provide conditions where equilibrium situations could exist without fertility input from outside sources. Also, at very low levels of soil nitrogen, rainwater and nonsymbiotic nitrogen fixation may furnish enough additional nitrogen to permit low levels of removal by crops for long and sustained minimum production.

Cropping Practices and Changes in Organic Matter

In virgin soils, some kind of an equilibrium situation must have been attained or closely approached with respect to soil organic matter. When cultivation of the virgin soils was begun, this equilibrium was disturbed. Either the rate of addition of soil organic nitrogen or the rate of decomposition or both were so altered that a new equilibrium level was approached. In most instances, this new level of organic matter was lower than that in the virgin soils.

Available Nitrogen in Relation to Supply Processes

Soil organic nitrogen must decline in quantity in order to supply net amounts of nitrogen for crops grown on the soil. This is still happening in some areas of the world. There is no simple method for determining the extent to which soil areas have attained organic matter and organic nitrogen equilibrium. Soil test procedures largely reflect total mineralization or total organic nitrogen. The time that the soil has been under constant cultivation is the best guide. Some long-time soil and crop management experiments in temperate regions show that a new equilibrium in nitrogen and soil organic matter is closely approached in 60 to 100 years of constant management. In some tropical and semitropical areas, the time to attain organic matter and nitrogen equilibrium may be much shorter.

During periods of virgin or noncultivated conditions, certain soils tend to build up soil organic matter and soil nitrogen. Some soils accumulate as much as 10,000 kg/ha of nitrogen under virgin conditions. During the first years of cultivation, these same soils may supply as much as 400 kg/ha of available nitrogen per year (Schreiner and Brown, 1938). As cultivation continues and the organic nitrogen declines, the quantity of nitrogen becoming available each year declines. After long periods of cultivation, the soil organic matter becomes exhausted as a major source of available nitrogen, and, unless

legumes are grown, the annual available nitrogen from natural supply processes becomes chiefly that from rainwater and from nonsymbiotic nitrogen fixation.

Current Situation

Many of the major land areas of the tropics have now been cropped for extended periods, and the organic matter stored under virgin conditions has been dissipated. Where little or no nitrogen fertilizer has been used, yields of major crops largely reflect the magnitudes of the natural nitrogen supply processes from rainwater and nonsymbiotic nitrogen fixation.

Yields of corn in the order of 600 to 1,200 kg/ha and of wheat of 400 to 800 kg/ha require supplies of available nitrogen only a little larger than could be expected from rain and from nonsymbiotic fixation. Moreover, such yields do not remove more than 15 kg/ha of nitrogen from the land in the harvested grain products. Such yields, therefore, could be sustained for long periods under primitive conditions of agriculture with the use of only small amounts of fertilizer and without the culture of leguminous plants. In many important food-producing areas of the tropics, these yield levels prevail, and the lack of available nitrogen is the chief limiting factor in production of crops. To increase yields in these same areas will require the use of nitrogen fertilizer or leguminous crops as well as other production inputs.

Large areas of land in tropical regions have not been cleared and cultivated within the known history of the land. Some of these areas—for example, the inland regions of Brazil—are expected to be cleared and cultivated in the near future. After clearing and cultivation, the soil would be expected to furnish some substantial amounts of nitrogen to the crops grown. The amounts furnished, the rate of anticipated decline in soil nitrogen, and the time required for a close approach to nitrogen and organic matter equilibrium are important research topics.

BIOLOGICAL NITROGEN FIXATION

Nitrogen Fixation by Biological Agents

Biological nitrogen fixation processes have been responsible for providing most of the large quantities of nitrogen currently used by and

tied up in plants and animals and in the decomposed residues found in soil (soil organic matter). Moreover, biological fixation processes still supply the major part of the nitrogen for crop production in world agriculture.

The chief process is symbiotic nitrogen fixation, in which a host plant (mainly leguminosae) and bacteria function in symbiosis in the nitrogen fixation processes. Numerous host plants function in this way, and a large number are employed in crop husbandry. The symbiotic process of nitrogen fixation may supply a part or all of the nitrogen used by the host plant for growth. As a result of the growth of the host plant, which has functioned in nitrogen fixation, other crop plants that are associated with or that follow the host in a crop sequence may benefit by being supplied with some increased quantity of nitrogen. An understanding of some aspects of the fixation process provides a basis for determining what may be expected of the host plant and the benefit that may accrue to the associated crops.

The amount of nitrogen fixed per acre per year under field soil conditions has been estimated by several investigators. It is presumed that in most instances the estimates are based largely on the quantities of total nitrogen taken up and immobilized in the plant tissue. Total nitrogen contained in leguminous crops ranges from a few kilograms per hectare in poor stands of legumes to as much as 500 kg/ha in large yields of soybeans and several cuttings of alfalfa.

An important aspect of biological nitrogen fixation is that the fixation processes are growth related. In both symbiotic and nonsymbiotic fixation, nitrogen is fixed and used only as it is needed for growth of the bacteria, the host plant, or both. The fixation process does not result in indiscriminate nitrogen fixation in which an excess of fixed nitrogen is transported to the exterior of the bacterial cell in nonsymbiotic fixation or to the outside of the host plant in symbiotic fixation. Fixation is growth bound, and the fixation processes are in some way regulated by growth processes and by needs for nitrogen.

Another important factor in biological nitrogen fixation is that in both symbiotic and nonsymbiotic processes fixation is inhibited by the presence of available inorganic nitrogen. When mineral nitrogen is in the system and available for use by the bacteria and the host plant, the inorganic nitrogen is absorbed and used first, and the fixation processes function only to supply the nitrogen deficit. In other words, available nitrogen substitutes for and replaces the fixation

processes (Allos and Bartholomew, 1959). A very small but sustained concentration of mineral nitrogen in the soil solution will completely inhibit fixation.

Fixation may be inhibited without inhibiting nodulation. Nodules on host plants do not necessarily indicate that extensive fixation is occurring or has occurred. When small but sustained amounts of available nitrogen are supplied to leguminous plants, infection processes of the roots may be normal and nodules may be formed, but very little, if any, nitrogen may be fixed. Higher concentrations of available nitrogen prevent the formation of nodules (Vincent, 1965).

Influence of Nitrogen Fertilization on Legumes

In considering the nitrogen nutrition of some leguminous crops, it should not be forgotten that legumes may respond in growth and yield to the presence of a favorable quantity of mineral soil nitrogen (Thornton, 1948). Greenhouse tests have demonstrated such responses (Allos and Bartholomew, 1959). Moreover, maximum yields of soybeans have most often been produced where high quantities of nitrogen fertilizers have been applied. Nitrogen fertilizer management for the production of legumes is largely an unknown field. About all that has been done so far is to try application practices that have been successful for nonleguminous crops. Some serious studies should be undertaken on nitrogen fertilization of legumes in the tropics, especially those that are important food crops.

Influence of Legumes on Associated Crops

The influence of legumes on associated crops or on crops that follow the legume is difficult to assess. During the active growing period of leguminous plants, very little nitrogen escapes and becomes available to associated crops. It is only when the legume matures or when environmental conditions induce parts of the plant to die that the nitrogen contained in the tissue of the legume begins to become available through microbial decomposition. Perennial legumes begin to exert a major influence on associated plants after the season of establishment, and annual legumes, at maturity or thereafter during decomposition of top and root residues.

An evaluation of meadow and catch crops has been made by Shrader *et al.* (1966), in terms of nitrogen supplied by the legumes to

crops that followed. The crop immediately following the legume obtained a rather large quantity of available nitrogen from the legume that preceded it. Their data indicate that a crop that followed a good legume crop in the rotation benefited to the extent of better than 110 kg/ha of nitrogen. The benefit to the second crop following the legume was one third to one half that obtained by the first crop.

The increase in available nitrogen in the soil immediately following the growth of the legumes is due in large part to the legume residues returned to the soil and to the release of nitrogen upon decomposition of the residues. The increase also reflects some increment in total nitrogen in the soil in the legume rotation plots over that in continuous corn plots.

Green manure and cover crops vary markedly in the quantities of nitrogen they supply to a crop that follows. All of the nitrogen in the green manure is not available to the following crop. The proportion of the nitrogen in the legume crop that becomes available is closely related to the percentage of nitrogen in the residue returned to the soil (Bartholomew, 1965). In general, green manure crops have furnished growth responses in crops that followed that were equivalent to those obtained from the addition of from 10 to 60 kg/ha of nitrogen. The amount of nitrogen supplied is not large in terms of fertilizer equivalents. The economics of the practice need to be critically considered before green manures are recommended as a source of nitrogen to crops that follow.

Place of Legumes in Modern Agriculture

It would be well at this point in the discussion to appraise the potential and the value of leguminous culture and of biological nitrogen fixation in modern agriculture. Where legumes are valuable as forage or food, they will continue to be important in modern agriculture. Their culture may not be justified, however, when a major purpose is only to supply nitrogen to associated crops. First, the cost of nitrogen supplied by leguminous crops, in terms of labor and land use, is often much too high to compete with fertilizer except where fertilizer is expensive and difficult to get. Second, leguminous crops cannot supply enough nitrogen to meet the needs of modern high-yielding crops. A perennial legume crop, after two or more years of

growth, may furnish from 50 to 150 kg/ha of nitrogen to a nonlegume crop that follows. Green manure crops and annual legumes may provide from 10 to 70 kg/ha. In some areas of the tropics and under some circumstances, these sources of nitrogen may be the most effective for a fair crop yield. However, the nitrogen for high and efficient yields will probably need to be supplied in substantial part from fertilizer. The natural supply processes—soil organic nitrogen and biological fixation—supply some nitrogen for crop production but do not appear capable, in light of present knowledge, of providing the nitrogen requirements for high production. However, further research on this subject in tropical environments may challenge current concepts.

Fixation by Free-Living Microorganisms

In nonsymbiotic nitrogen fixation by free-living bacteria in the soil, a limiting condition is food energy for the growth of the organism. For example, 10 mg of nitrogen fixed per gram of organic food decomposed is near the maximum efficiency obtained by young, fast-growing, heterotrophic nitrogen-fixing bacteria (*Azotobacter*). Assuming maximum efficiency in the use of food energy and the absence of available nitrogen—two conditions that seldom occur in a soil system—for 10 kg of nitrogen fixed per hectare, the nitrogen-fixing bacteria would have consumed 1,000 kg of energy food. In the case of nitrogen fixing algae, the energy would come from light. The evidence strongly suggests very little nonsymbiotic nitrogen fixation in most soils.

In Brazil, a favorable environment for nonsymbiotic nitrogen fixation is under study (Dobereiner, 1961, 1968). *Azotobacter paspali* thrives in the root zones of sugarcane and some species of *Paspalum*. The plants, through the root system, may provide sufficient energy to result in significant fixation. A pseudosymbiotic association appears feasible. The importance of this to agriculture warrants further study. However, if the known principles that influence nitrogen fixation apply to the nonsymbiotic and pseudosymbiotic associations, only fair to moderate yields of the particular crops could be expected from nitrogen fixation. To obtain the higher yields required for modern economic agriculture would necessitate the addition of nitrogen fertilizer.

NITROGEN MOVEMENT IN RELATION TO CLIMATIC FACTORS

Loss Processes

A problem of major concern in the tropics is the apparent poor use made by plants of available soil nitrogen. Well-documented evidence from a number of sources indicates that plant recovery of available soil nitrogen ranges on the average between 50 and 60 percent (Rogers, 1961; Viets, 1960). The other 40 to 50 percent somehow escapes from the soil system. It could be lost by leaching, or it could escape by volatilization. Moreover, experimentation indicates that native soil nitrogen coming from mineralization of soil organic matter has not been used more efficiently by crops than has added fertilizer nitrogen.

The chief loss process has been considered to be removal of the available nitrogen from the root zone by water, usually referred to as leaching. Under high rainfall conditions and in friable well-drained soils, leaching may be quite rapid (Charreau, 1961; Roose and Godefroy, 1968). Under low rainfall conditions, as at the beginning or end of the dry season, leaching may be negligible, and other factors may make the nitrogen unavailable.

Denitrification and other volatile loss processes do occur in soil and account for some of the inefficiency in the use of nitrogen by crop plants. However, except for some unusual soil conditions, volatile loss processes do not appear to account for all of the nitrogen escaping use by crop plants. Reasonable estimates of denitrification are from 5 to 15 percent of the available nitrogen in the course of a single cropping season (Allison, 1966; Bartholomew, 1964).

Loss of ammonia nitrogen by volatilization has been a major loss process in some situations, e.g., where ammonia-yielding fertilizers have been applied to the surfaces of sandy soils. When the rate or method of addition results in a local or general concentration of ammonia too great for effective adsorption by the soil, some volatilization is inevitable.

Influence of Soil Water on Nitrogen Absorption

Soil water appears to be the most important single factor influencing or controlling nitrogen uptake and use by crop plants in field situations. This hypothesis derives from a critical evaluation of a large body of indirect evidence.

Soil water is directly involved in the transportation and absorption of nitrate nitrogen by plants. Also, it is involved in leaching, the chief mechanism of loss from the soil system. It is involved indirectly in denitrification. Soil water also influences the incidence and activity of roots in some soil horizons.

Four major premises relative to nitrate absorption by plants and loss from a soil by leaching are worthy of critical consideration. These are as follows:

Nitrate nitrogen absorption by crop plants from soil is closely related to water absorption and to water availability.

Nitrate nitrogen absorption by plant roots is negligible in soil zones where moisture conditions are low or are adverse for ion diffusion and plant uptake of water.

Root penetration into and root proliferation in the several horizontal layers that make up the solum vary markedly among soils and among plant species and varieties.

Nitrate moves with water, and an understanding of water movement and availability in soil largely explains nitrate movement and availability to particular crop plants.

If these premises are correct, they not only would provide explanations for much of the poor efficiency of nitrogen use by crop plants but also would point the way to formulating management practices to alleviate nitrogen losses by leaching.

In solution culture experiments in the absence of soil, it has been shown that the plant can take up nitrate more rapidly than it takes up water (Minotti *et al.*, 1968). In soil systems, however, nitrate nitrogen must be carried or moved in some way by or through the soil solution to the root boundary. This transport process is by and through water (Ohlrogge, 1969; Olsen and Kemper, 1968), and the chief limiting factor in nitrogen absorption is transport to the root surface.

In these situations, the nitrogen uptake by the plant from nitrate sources would appear to be passive (Jensen, 1962), in that it is dependent on water transport or the movement through water films. Another well-known feature of soil water is that not all of it is available to plants. Of the water held at field capacity, not more than 60 percent, and often less than that, is available to crop plants. Water held at moisture tensions above the wilting point can contain nitrate but would tend to prevent its movement to the roots of crops. If ni-

trate nitrogen absorption by the crop plant is dependent on water to transport it to the roots either through mass flow or by diffusion, then in soil systems where water is stored in the soil for subsequent crop growth, not more than 60 percent of the nitrogen could be absorbed by the crop. The water would have to be replenished and recharged a number of times in order to permit a large proportion of the soluble soil nitrate to be moved to the plant roots.

In field situations the moisture conditions would be different from those in solution culture experiments. In the field, incoming water from the surface, in part, may displace the old soil water to deeper depths. Incoming water also may only wet the surface of the soil and have little influence on the soil water in the lower parts of the root zone. Often the water supply for a crop comes largely from the top few inches of soil. In such situations, any nitrate nitrogen in the lower parts of the root zone would not be available for absorption.

Under conditions of high rainfall, the incoming moisture may rapidly leach most of the nitrate nitrogen from the confines of the root zone. Normal precipitation results in water entering the top layers of soil. Net movement of water downward through the top few centimeters of soil may be quite extensive. As a result of water absorption by plant roots and subsequent transpiration through the leaves into the atmosphere, net downward movement of water becomes progressively less through progressively deeper layers of soil. When a plant removes water from the subsoil, some upward movement of water must occur. When subsoil layers get dry during crop growth, there must be some depth position in the root zone where the net vertical movement of water is zero.

Water movement patterns vary markedly among soils, cropping practices, and climatic regions. Also, water movement at a single site may vary considerably from season to season. Because nitrate nitrogen is carried and moved by water, the water movement pattern in a soil may have a marked influence on plant absorption and on how fast and when nitrogen is moved down in the soil to positions beyond the reach of crop plants.

CROP NEEDS FOR NITROGEN

Nitrogen needs for some widely grown crops have been investigated and are quite well understood. However, for many crops peculiar to tropical regions, the total nitrogen requirements for particular levels of production are not known.

TABLE 1 Nitrogen Used and Needed by Selected Crops

Crop	Yield Level (tons/ha)	Nitrogen, kg/ha: In Grain	In Tops and Roots (Crop Residues)	Needed to Produce Yield Shown in Column 2
Corn	10-12.5	150-190	112-150	300-390
Corn	1	11	10	28
Rice	6-10	82-141	46-86	200-360
Wheat	5	140	78	300
Wheat	600[a]	12	6	27
Soybeans	4	245	115	–
Peanuts	3.5	128	205	–

[a] kg/ha.

Data on nitrogen use and needs for some cereal and leguminous crops give some indication of the total quantity of nitrogen that may be needed to achieve high crop production (Table 1). Such quantities can be compared to the magnitudes of the natural supply processes.

The actual use of nitrogen by the crop may be much lower than the total quantity of soluble nitrogen that may be required in the soil or may be applied as fertilizer in order to produce the crop. Use efficiency is often low and is one of the problems needing investigation in the efficient production of tropical crops.

NITROGEN AVAILABILITY AND ITS MEASUREMENT

Availability

Availability of a nutrient implies a condition that permits its use by a plant. This connotes that the nutrient is in the proper chemical form for plant absorption, that it is located where it is accessible for uptake, and that the local environment is conducive to plant use. However, we have only a meager understanding of the conditions that must obtain in the soil to satisfy the requirements for availability. Consequently, no precise methods for evaluation have been found. Plant uptake, therefore, has been used, and it still remains the best measure of an "available" situation. Conventional methods of measuring nitrogen availability do not necessarily indicate how much can be absorbed by the plant. Soil test methods for nitrogen generally re-

flect a quantity of mineral nitrogen in the soil or a potential to supply mineral nitrogen during a cropping season.

The quantity or proportion of the soluble nitrogen (chiefly ammonium and nitrate) that can be absorbed by the crop is dependent on or is influenced by several important local site factors. These are

Rooting habits of the crop

Volatile loss processes and the local environmental factors that influence these loss processes

Vertical movement of nitrate nitrogen and in some instances the complete removal of the nitrate by leaching

The moisture status in that part of the root zone where the nitrogen resides

The presence or absence of crop residues, which may immobilize nitrogen

Evaluation of Available Nitrogen in Soil

Crop needs for nitrogen fertilizers depend on the total crop requirement for nitrogen and the proportion of this total that can be supplied by natural processes. Both factors should be appraised in soil fertility evaluation programs. Test methods measure or reflect soluble soil nitrogen. Calibration of test methods with crop response to nitrogen applications should indicate crop needs.

A number of kinds of test procedures have been used to indicate availability of nitrogen in soil. Some are chemical extraction methods and reflect the total nitrogen in soil. Some are biological and measure mineralization. All are arbitrary and to be useful must be calibrated with plant use and plant needs.

Test procedures have had varying degrees of usefulness and success in soil fertility evaluation programs. Under specified soil and cropping conditions, the calibration relationships for some methods have been very good. However, no methods have been used widely for diverse soil and cropping conditions.

In general, test methods for nitrogen are expensive in terms of analytical time and equipment. This fact suggests the need for a critical appraisal of the usefulness of nitrogen test methods in soil fertility evaluation programs. Such an appraisal should include consideration of (1) the type or types of tests that could be used and the unit costs of making the tests; (2) the kind and extent of field calibration research needed to make the test meaningful; (3) the kinds and

values of the crops to be grown; (4) the general level of nitrogen in the soil and the cropping history of the area; and (5) other procedures for getting equally useful information about nitrogen fertilizer needs and crop response to fertilizer. For all cropping systems, a critical appraisal should be made of the precision in fertilizer recommendations that can be achieved by use of a test method and the relationship of this precision to the needs of the crop for nitrogen fertilizer.

Immobilization and Mineralization

The processes of immobilization (fix) and mineralization (release) often exert a very marked influence on nitrogen availability in soil (Bartholomew, 1965). Moreover, these transformation processes complicate the use and interpretation of a number of soil fertility analysis procedures for evaluating soil supplies of and crop needs for nitrogen. Practical appraisals of the influence of these processes generally take into account the influence of past cropping practices.

Nitrogen in organic form remains associated with crop residues during the decomposition process. The quantities remaining as organic nitrogen and the periods of immobilization and mineralization have been extensively studied (Bartholomew, 1965). Some important aspects of these transformation processes need to be emphasized. First, ordinary crop residues are rather similar in their capacity to immobilize nitrogen and will retain from 9 to 13 kg of organic nitrogen per ton of original residue when decomposition occurs under aerobic conditions. If the residue originally contains less nitrogen than needed by the microorganisms for decomposition, inorganic nitrogen is absorbed from the soil and immobilized by the organisms. If the residue contains more than is needed by the microbes, the excess nitrogen is mineralized and appears as inorganic nitrogen in the soil.

The major tie-up and release processes come early in the decomposition processes. In soil they are essentially complete within the first 2 to 4 weeks of decomposition. Low nitrogen residues, which immobilize extra nitrogen from the soil, tend to retain the total immobilized nitrogen for two or more seasons without any appreciable release. High nitrogen residues tend to release small amounts of nitrogen after the first initial decomposition surge. Small but measurable amounts of nitrogen become available from high nitrogen residues during the second and subsequent seasons of decomposition.

After the first early surges in decomposition, crop residues tend to

continue decaying slowly, losing chiefly carbon dioxide and water but retaining nitrogen. Consequently, with progressive decomposition, the percentage of nitrogen increases in the residue material and the carbon-to-nitrogen ratio decreases. In arable soils, environmental factors, chiefly weather, influence the nitrogen tie-up and release processes principally by influencing the rate of decomposition of the crop residues but do not significantly alter the amount of nitrogen retained or released by residues at particular stages of decomposition.

Many observed cropping and soil management practices exert part or all of their influence upon the soil or the crop through some modification or control of the tie-up and release of nitrogen. The marked influence that one crop may have on a crop that follows is often largely due to the influence of the crop residue on the nitrogen supply from the soil.

The amounts and kinds of residues left on the land and the manner in which the residues are managed determine the rate and extent of nitrogen tie-up and release. Although residue yields vary with season, with soil, and with crop variety, the residue yields tend to be closely related to the level of production of the particular crop. High production of a crop results in high yields of residue.

The practical handling of crop residues, including plowing versus subsurface tillage, and the time of year when tillage operations are carried out may alter the nitrogen supply. Residues left on the surface decompose more slowly than those plowed under. This slow decomposition, along with the fact that surface residues are in contact with less soil material, results in a much slower tie-up of nitrogen from low-nitrogen residues and a slower release of nitrogen from high-nitrogen residues than when residues are incorporated in the soil by tillage. Surface mulches also modify soil temperatures and moisture contents, which in turn influence tie-up and release of nitrogen in crop residues and soil organic matter.

Plowing-under low nitrogen residues well in advance of planting a crop is always likely to result in more soil nitrogen being available to the next crop than plowing just prior to planting. The chief reasons are, first, that weeds and other plants that absorb soil nitrogen are killed, leaving available nitrogen to accumulate in the soil; and, second, that the nitrogen tie-up processes of decomposition will have been satisfied long before planting, so that nitrogen made available from the soil will be available to the crop and not reabsorbed by the residue during early stages of decomposition. Plowing-under legumi-

nous residues too far in advance of planting a subsequent crop may provide opportunity for nitrogen loss by denitrification or by leaching.

Cultivation of the soil has been reported to stimulate microbial activity and to result in increased nitrogen becoming available from the soil. The validity of this principle has never been adequately investigated. It may or may not be correct. Factors other than just disturbing and aerating the soil, in most instances, can explain most of the benefits of cultivation. Changes in soil temperature or in soil moisture brought about by cultivation may account for the effects of cultivation.

The carryover effect of nitrogen fertilization into the second season after application may be explained in part by the amount and composition of crop residues left on and in the soil and in part by inorganic nitrogen remaining in the root zone. Even though increasing the rate of applying nitrogen fertilizer to nonlegumes increases the amount of residue returned to the soil, the higher nitrogen contents of the residues induced by high rates of nitrogen fertilization would tend to offset the effect of the amount of residue in total nitrogen immobilization.

Volatile loss processes and the impact of water on nitrogen availability and use were discussed in a preceding section. The incidence and activity of plant roots in the several horizontal layers of soil have a marked influence on nitrogen absorption. Some of the factors that influence root growth are discussed in other sections.

MANAGEMENT OF CROP RESIDUES

Crop residues should be considered apart from soil organic matter. They can have several important influences on soil. Also, they are much more subject to management than is soil organic matter. Crop residues function in the following ways in and on soil:

As a protective cover on the soil surface, crop residues prevent the deterioration of soil structure that may result from high-intensity rain. Such a function can be used to reduce erosion of surface soil and to increase infiltration of water into the topsoil.

Crop residues insulate the soil surface against rapid changes in temperature. Soils partially covered with a layer of crop residues tend to increase in temperature less rapidly than bare soil. This may be due

in part to the color of the residue and reflection of the incident energy rays and in part to moisture changes in the topsoil induced by the residue layer. Residue covers also reduce heat loss from soil.

Crop residues supply and regulate the supplies of mineral nutrients in soil. Upon decomposition, the mineral elements contained in the crop residues may be released and may become available (potassium is a special case in that most or all of plant potassium is water soluble and decomposition processes are not necessary for release). In the initial decomposition processes, all of the mineral elements are not released. The quantities released initially, or in the early stages of decomposition, are related (1) to the percentage of the nutrient in the residue and (2) to the susceptibility of the residue to decomposition. The most important influence of decomposition often is reflected in the nitrogen tie-up and release.

Crop residues often harbor diseases and insect pests. The management of residues, therefore, can have a marked influence on soil sanitation and on the incidence of diseases and pest damage to crops that follow the addition of the residue.

Residues on the surface of the soil impede and often restrict certain cultural practices. For this reason, as well as to control diseases and pests, residues are often burned. Residues on the surface decompose more slowly under many environmental circumstances than residues buried by plowing or other cultural practices. Large yields of residues are generally a much greater problem for tillage operations than are small yields.

A widespread conventional practice in tropical and subtropical areas is to burn crop residues during or near the beginning of a dry season. This practice cleans the land surface of coarse residues and permits new forage to emerge in grazing areas or eliminates tillage impediments on cultivated land. Although the literature concerned with burning is extensive, there remain a number of unanswered questions relative to the value of the practice as a practical means of handling crop residues. These questions need to be resolved.

Residues may also be of major concern in areas where multiple cropping is practiced. Fresh crop residues often pose tillage and cultivation problems when a second crop is planted immediately after the harvest of a first crop. When two or three crops are grown in the course of a single year, the accumulation of residues from high yields of crops could very well induce a number of operational and management problems.

REFERENCES

Allison, F. E. 1966. The fate of nitrogen applied to soils. Adv. Agron. 18:219-258.

Allos, H. F., and W. V. Bartholomew. 1959. Replacement of symbiotic fixation by available nitrogen. Soil Sci. 87:61-66.

Bartholomew, W. V. 1964. Nitrogen loss processes a recapitulation Soil Sci. Soc. N.C. Proc. 7:78-81.

Bartholomew, W. V. 1965. Mineralization and immobilization of nitrogen in the decomposition of plant and animal residues, p. 285-306. *In* W. V. Bartholomew and F. E. Clark [ed.], Soil nitrogen. Agronomy Monograph No. 10. American Society of Agronomy, Madison, Wis.

Bartholomew, W. V., and D. Kirkham. 1960. Mathematical descriptions and interpretations of culture induced soil nitrogen changes. Trans. 7th Int. Cong. Soil Sci. 2:471-477. Madison, Wis.

Charreau, C. 1961. Dynamique de l'eau dans deux sols du Sénégal. Agron. Trop. 16:504-561.

Döbereiner, J. 1961. Nitrogen-fixing bacteria of the genus *Beijerinckia* Derx in the rhizosphere of sugar cane. Plant Soil 14:211-217.

Döbereiner, J. 1968. Non-symbiotic nitrogen fixation in tropical soils. Pesqui. Agropecu. Bras. 3:1-6.

Jensen, G. 1962. Active and passive components in ion uptake processes; experiments with intact and excised tomato root systems. Physiol. Plant. 15:363-368.

Minotti, P. L., D. C. Williams, and W. A. Jackson. 1968. Nitrate uptake and reduction as affected by calcium and potassium. Soil Sci. Soc. Am. Proc. 32:692-698.

Ohlrogge, A. J. 1969. Sidedress corn with nitrogen. Agr. Nitrogen News 1969 (May-June): 22-23, 26, 28.

Olsen, S. R., and W. D. Kemper. 1968. Movement of nutrients to plant roots. Adv. Agron. 20:92-151.

Rogers, T. H. 1961. Recovery of applied nitrogen by crops. Assoc. South Agr. Workers Proc. 58th Annu. Conv. 86-87 (Abstract).

Roose, E., and J. Goc'efroy. 1968. Lessivage des éléments fertilisants en bananerais. Fruits 2:580-584.

Schreiner, O., and B. E. Brown. 1938. Soil nitrogen, p. 361-376. *In* Soils and men. The yearbook of agriculture. U.S. Department of Agriculture. U. S. Government Printing Office, Washington, D.C.

Shrader, W. D., W. A. Fuller, and F. B. Cady. 1966. Estimation of a common nitrogen response function for corn (*Zea mays*) in different crop rotations. Agron. J. 58:397-401.

Thornton, G. D. 1948. Greenhouse studies of nitrogen fertilization of soybeans and lespedeza using isotopic nitrogen. Soils Fert. 11:130. (Abstract).

Viets, F. G. 1960. Recovery of fertilizer nitrogen in irrigated and dryland soil of the Western United States. Trans. 7th Int. Cong. Soil Sci. 2:486-493. Madison, Wis.

Vincent, J. M. 1965. Environmental factors in the fixation of nitrogen by the legume, p. 384-435. *In* W. V. Bartholomew and F. E. Clark [ed.], Soil nitrogen. Monograph No. 10. American Society of Agronomy, Madison, Wis.

Woodruff, C. M. 1950. Estimating the nitrogen delivery of soil from the organic matter determination as reflected by Sanborn field. Soil Sci. Soc. Am. Proc. 14:208-212.