AP42 Section:	9.2.1
Background Ch	2
Reference:	14
Title:	W. V. Bartholomew and F. E. Clark (eds.), *Soil Nitrogen*, American Society of Agronomy, Madison, WI, 1965.

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Sect. 2
14

SOIL NITROGEN

Edited by
W. V. BARTHOLOMEW
North Carolina State University
Raleigh, North Carolina
and
FRANCIS E. CLARK
Agricultural Research Service, USDA
Fort Collins, Colorado

Published by the
AMERICAN SOCIETY OF AGRONOMY

Number 10 in the series
AGRONOMY

American Society of Agronomy, Inc., Publisher
Madison, Wisconsin, USA
1965

correct for a particular set of conditions. For this reason the author is not presenting the usual nitrogen cycle, but a more involved diagram (*Fig. 1*) *showing soil nitrogen* income and outgo. This diagram is not meant to be strictly accurate and complete to the last detail, but does show the major changes in soil nitrogen, most of which have been discussed in previous chapters.

Fig. 1, as constructed, shows the sources of nitrogen that gain entrance into the soil, the transformations that occur, and the fate of the end products. It will be observed that all sources of soil nitrogen are, figuratively speaking, thrown into the hopper (the soil) where the end products are ground out by the soil micropopulation. Strictly chemical reactions, where enzymes are not involved, are limited in number.

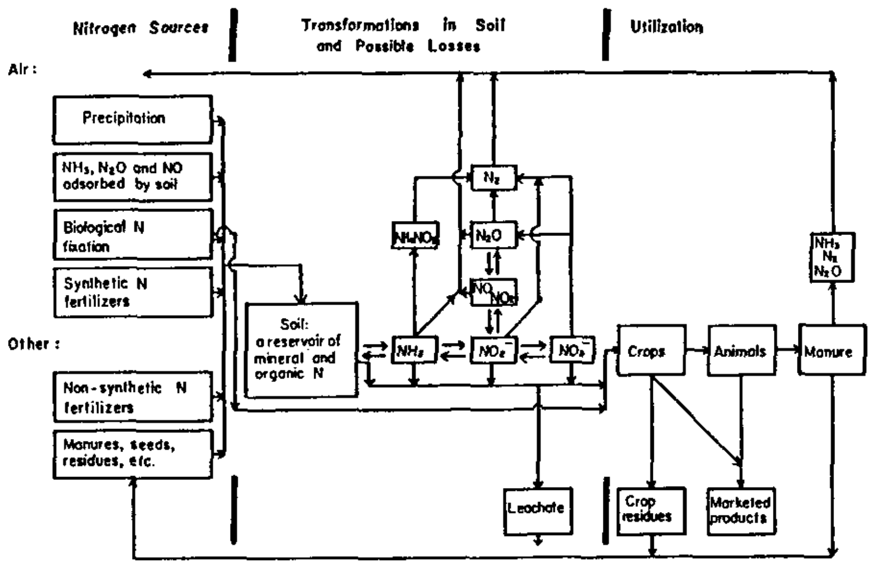

Fig. 1. Soil nitrogen sources and transformations and fate of the end products.

III. SOURCES OF CROP NITROGEN

A. Natural Sources of Combined Nitrogen

1. SOIL ORGANIC MATTER

The chief source of nitrogen for crops is commonly soil organic matter, which is in large part a residual product from previous additions of crop residues. So long as the nitrogen remains in this form, it is comparatively safe from loss except through erosion. Normally, however, the soil organic matter is slowly being converted into ammonia and then into nitrites and nitrates, and in these forms it is subject to the same losses as nitrogen derived from outside sources. Under laboratory or greenhouse conditions, in the absence of a crop or leaching, as much as 5 to 10% of soil nitrogen may accumulate as nitrate during a period of six months (Allison and Sterling, 1949). Under humid conditions in the Temperate Zone it has been shown repeatedly (Salter and Green, 1933; and Woodruff, 1949) that a crop such as corn removes about 2 to 3% of the soil nitrogen in the plowed layer during one growing season. A small grain crop removes about half this amount, whereas a nonlegume sod crop removes even less. So far as soil nitrogen balance is concerned, such removal of nitrogen presents no major problems that are not well understood. The normal error of soil sampling and analysis, plus variable values for leaching and gaseous losses, however, make it impossible to measure such annual losses accurately. Crop *analysis gives only a partial* answer.

2. CROP RESIDUES AND ANIMAL MANURES

The nitrogen returned to the *soil in the form of crop residues* under good farm management practices commonly constitutes a considerable portion of the total nitrogen removed in the crop. Including the root residues not removed, this nitrogen may, in the case of a small grain *crop, for example*, amount to 20% or more of the total nitrogen originally assimilated by the crop. The quantity varies widely, of course, with type of crop, climatic conditions, yields, and nitrogen level at which the crop is grown. If the crop residue contains less than about 1% nitrogen, this nitrogen will tend to remain tied up in organic form for several days or weeks, and may even immobilize any available soil nitrogen present. If the residue contains 2% or more of nitrogen, some ammonia may be lost to the *atmosphere during the initial* stages of decomposition unless the material is incorporated into the soil before decay starts.

Where animal manures are supplied to the soil, they may be expected to behave much as do crop residues except that the chances for loss as ammonia during handling, especially from the liquid portion, are much greater (Linhard, 1954). If the fresh liquid and solids are immediately incorporated into the soil, there is little reason to expect appreciable loss of ammonia. Data summarized by *Salter and Schollenberger* (1939) show that on the average 74% of the nitrogen in the feed of cows is found in fresh manure. Under practical conditions it is doubtful if more than a third of this excreted nitrogen actually enters the soil, and the value may *be much less.*

3. PRECIPITATION AND IRRIGATION

The quantity of nitrogen that is added to soil in rain and snow, as am*monia and nitrate*, is shown in Table 1. These data, assembled by Miller (1905), were obtained at locations all over the world. In addition to these two forms of nitrogen, there is also some organic nitrogen in rainwater in the forms of bacterial cells and dust. According to Miller, *this amounts* to 1.35 pounds per acre annually at Rothamsted, England, and 0.45 pound in New Zealand where the total inorganic nitrogen in the rain is very low.

Table 1 shows variations between 1.6 and 19.9 pounds of inorganic nitrogen *per acre per year in the rainfall at the 28 locations*; the average value is 7.8 pounds. Ammonia nitrogen, on the average, constitutes 69% of the total and the values fall within the range of 60 to 80% for 20 of

Table 1. Nitrogen as ammonia and nitric acid in rain.

Location	Rainfall, in.	N, lb. per acre per annum			% of total	
		NH_3	N_2O_5	Total	NH_3	N_2O_5
Rothamsted	27.3	2.71	1.13	3.84	70.6	29.4
Copenhagen	22.0	9.27	2.21	11.48	80.8	19.2
Gembiox	27.2	7.07	2.14	9.21	76.8	23.2
Montsouris	21.5	10.37	3.22	13.59	76.3	23.7
Dahme	17.1	5.50	1.16	6.66	82.6	17.4
Insterburg	25.7	3.90	2.25	6.15	63.1	36.9
Kuschen	14.8	1.63	0.55	2.18	75.0	25.0
Proskau	17.8	12.94	6.97	19.91	65.0	35.0
Regenwalde	22.7	10.69	3.28	13.97	77.0	23.0
Florence	38.3	8.70	3.09	11.79	73.8	26.2
Vallombrosa	59.9	8.36	3.46	11.82	70.7	29.3
Scandicci	29.2	4.06	1.76	5.82	69.8	30.2
Catania	18.4	1.36	0.67	2.03	66.9	33.1
St. Michele, Tirol	43.9	11.83	5.76	17.59	67.3	32.7
Libwerd, Bohemia	24.4	7.18	3.37	10.55	68.1	31.9
Peček, Bohemia	19.3	5.53	2.19	7.72	71.6	28.4
Ploty	17.5	3.38	0.24	3.62	93.3	6.7
Tokyo	57.4	1.77	1.11	2.88	61.6	38.4
New Zealand	29.7	0.50	1.13	1.63	30.7	69.3
Kansas	29.4	2.62	1.03	3.64	71.8	28.2
Mississippi	44.1	2.35	0.74	3.09	76.0	24.0
Averages	28.9	5.80	2.26	8.06	72.0	28.0
		Tropical Rain Areas				
Calcutta	46.0	1.79	1.20	2.99	59.7	40.3
Ceylon	82.1	3.65	1.28	4.93	72.0	28.0
East Java	47.0	1.13	0.71	1.84	61.5	38.5
Mauritius	70.0	6.81	6.34	13.15	51.8	48.2
Barbados	64.0	1.22	3.88	5.10	23.9	76.1
Venezuela	40.0	14.03	5.20	19.23	72.8	27.2
British Guiana	102.4	1.17	1.82	2.99	39.1	60.9
Averages	64.5	4.26	2.92	7.18	59.3	40.7
Avg, all locations	27.8	5.41	2.42	7.84	69.1	30.9

the 28 locations. There is little relationship between total rainfall and the total amount of nitrogen brought down annually. The results for tropical soils are more variable than for other regions but the averages are similar. The ammonia is derived both from the burning of coal and other organic materials, and from the soil. A few writers have also emphasized the sea as an important source, but this seems doubtful. Electric discharges in the air probably account for most of the nitrates in rainwater but some oxides of nitrogen are also released from the soil. Little or no nitrite is found in rainwater since this form of nitrogen is readily oxidized to nitrate by oxygen of the air.

More recent data than those tabulated by Miller are given by Schreiner and Brown (1938). At seven locations in the Temperate Zone the inorganic nitrogen in the rain averaged 6.1 pounds per acre annually, 75.8% being in the ammonia form. These results agree very closely with the earlier data where less accurate methods of analysis may have been used.

Irrigation waters may sometimes contain traces of nitrogen but, unless intentionally added, are usually too small to have much effect on the soil nitrogen balance sheet.

4. ADSORPTION OF NH_3, N_2O, AND NO FROM AIR

In the early years of agricultural chemistry, during and after the time of Liebig, the possibility of direct adsorption by soils of ammonia, and possibly of oxides of nitrogen, from the air was considered. Although a few workers, cited by Miller (1905), reported adsorption of as much as 11 to 42 pounds of ammonia nitrogen per acre annually, the values found by most workers were small and hence little importance was attached to this source of nitrogen for crops. Hall and Miller (1911) reviewed some of these results and reported new data which show that only about 1 to 2 pounds of nitrogen per acre are adsorbed annually by dilute sulfuric acid kept in shallow glazed earthenware dishes.

In more recent years there has been some revival of interest in the subject and a limited amount of new data has been reported. One reason for the new interest is that occasionally a research worker has observed that the nitrogen content of a cropped soil did not decrease as fast as expected, and accretions of nitrogen through biological nitrogen fixation did not seem to be an adequate explanation.

Ingham (1939, 1940, 1950) was one who did not accept the conclusions of the earlier workers and advanced the theory that "a well-tilled soil is able to absorb from the air in 12 months sufficient nitrogen in the form of ammonia to supply the needs of a crop like maize." Seventy determinations reported by him of the ammonia content of air in South Africa show a mean value of about 1 ppm by weight. Many earlier analyses (Hall and Miller, 1911) had shown only 0.01 to 0.02 ppm of ammonia-nitrogen in city air, and even less in country air. When Ingham exposed slightly acidulated water to the air, 1.3 mg of ammonia-nitrogen per square foot of surface was absorbed in seven days. This corresponds to 6.5 pounds per acre per year. In other experiments Ingham (1940) exposed dishes of 1 N H_2SO_4 to air for 24-hour periods and obtained ammonia-uptake values of 6.1 to 45.3 pounds per acre per year, with an average value of 19.4 pounds. The highest values seemed to be correlated with high wind velocities.

Ingham (1950) also suspended washed, dry cellulosic materials in the air, and at weekly intervals determined the ammonia and nitrate contents. The mean weekly values reported are shown in Table 2. He concluded that cellulosic and related plant materials, such as are found in plant residues and humus, can likewise adsorb considerable nitrogen from the air.

In experiments involving the absorption of ammonia by a weak acid, too little attention has been given to the fact that during such absorption there is formed a monomolecular layer of ammonium hydroxide or ammonium salt. This tends to block further absorption until it is removed by surface agitation or otherwise. Bubbling air, containing ammonia, through an acid may, therefore, give absorption values much higher than would be obtained by exposure to the air without solution agitation. These facts would seem to indicate that a well-drained and aerated moist soil can take up ammonia from the air much more readily than can an undisturbed acidic solution because of the greater surface area, and also

Table 2. Ammonia and nitrate adsorbed from the air in 7 days by air-dry cellulosic materials.

Cellulosic material	Mean adsorption values, *ppm		
	NH_4-N	NO_3-N	Total N
Filter paper, washed with H_2O	31	9	40
" " " " 0.01 HCl	113	13	126
" " " " 0.01 Na_2CO_3	9	13	22
Dried grass, washed with H_2O	11	7	18
Jute fiber, " " "	84	19	103
Sisal fiber, " " "	51	20	71
Wood fiber, " " "	24	16	40

* All values are based on the weights of the cellulosic materials.

because any ammonia adsorbed in soil would normally be removed rather rapidly by bacteria, especially by *Nitrosomonas,* or by higher plants. Because of the conflicting evidence, it would seem well worthwhile for an effort to be made to obtain better ammonia adsorption data even though there is little reason to expect that new evidence would appreciably modify the view now generally held that such adsorption is of minor agricultural importance.

Some evidence indicating that soils adsorb little ammonia from the air is supplied by the Rothamsted Broadbalk continuous wheat plots (Allison, 1955; Russell and Watson, 1940) that have received no outside nitrogen since 1843. On plots 3 and 5, which received no nitrogen fertilizer, the known nitrogen gains and losses are in close balance. If it be assumed that an appreciable quantity of ammonia was adsorbed from the air, it must also be assumed that a comparable quantity was lost in gaseous forms. The Rothamsted drainage experiment (Russell and Richards, 1920) constitutes further evidence of this type. Doubtless a study of other long-time fertility experiments would supply somewhat similar data, for it is extremely rare for carefully controlled experiments to show net gains that would suggest the possibility of appreciable ammonia adsorption from the air. It is also obvious that if Ingham's ideas are correct it would be very difficult to account for the extreme need for nitrogen fertilizers, now so evident in many field soils all over the world.

B. Biological Nitrogen Fixation

Before the use of commercial fertilizers became so common, biological nitrogen fixation accounted for nearly all of the new nitrogen, other than that in rainwater, that reached the soil. Even this rainwater nitrogen, as already pointed out, is only in small part newly fixed nitrogen. In biological nitrogen fixation the active agents are microorganisms that either live in symbiosis with certain species of higher plants or nonsymbiotically in soils, water, or on vegetation.

1. SYMBIOTIC NITROGEN FIXATION

The quantity of nitrogen fixed by an acre of legumes in a year varies widely from only a few pounds to 200 to 300, or occasionally even more (Henzell and Norris, 1962). The quantity fixed is determined by many

factors, such as plant species, density of plant stand, weed competition, climatic conditions, effectiveness of the bacterial strain, pH, and nutrient status (Andrew, 1962), especially the amount of nitrogen made available from the soil. From the standpoint of total nitrogen contributed annually to the nation as a whole, the frequency with which a legume is grown in a rotation must also be considered. The portion of the total cultivated area that is in legumes is commonly not more than a fifth to a tenth.

The growth of a legume in a cropping system greatly complicates the calculation of an accurate nitrogen balance, since there is no practical way of knowing accurately how much nitrogen is fixed by a legume crop growing in the open in a normal soil. Usually the fixation varies inversely with the level of available nitrogen in the soil, and hence the nitrogen content of the crop may bear little relation to fixation.

Considerable research by Bond (1958) and others has shown that at least eight genera of nonleguminous shrubs and trees have root nodules and fix comparatively large quantities of atmospheric nitrogen. Norris (1962) gives a summary of our knowledge of these symbionts, as well as of leaf symbionts and lichens that appear to be involved in nitrogen fixation. In most cases little is known about the microorganisms involved. Since these nitrogen-fixing plants are found chiefly in waste places or forests, the nitrogen that they fix is usually not a factor in ordinary cropping systems.

2. NONSYMBIOTIC NITROGEN FIXATION

In 1895 Winogradsky isolated the anaerobic nitrogen-fixing bacterium, *Clostridium pasteurianum,* and in 1901 Beijerinck isolated two species of *Azotobacter.* The intensive studies that followed resulted in the isolation of other species of the two genera that fixed nitrogen. Many claims were made that other free-living organisms possessed this property but most of these early claims were not substantiated by later work. In 1928 Drewes (1928) isolated in pure culture two genera of blue-green algae, namely *Anabaena* and *Nostoc,* and showed that they could use free nitrogen gas. In subsequent years many other nitrogen-fixing blue-green algae and clostridia have been isolated and described (Norris, 1962). In more recent years *Beijerinckia,* which resembles *Azotobacter,* and certain hydrogen bacteria have also been added to the list of nitrogen fixers. Tracer techniques have shown that many organisms can fix small amounts of nitrogen.

How much nitrogen do these free-living organisms contribute to agricultural crops annually? This question has been asked repeatedly over the years. In a symposium at the meeting of the American Society of Agronomy in 1924, Löhnis (1925) estimated that nonsymbiotic bacteria may fix an average of 10 to 40 pounds of nitrogen per acre annually. His estimate for the cultivated soils of the United States was 10 pounds, and for the soils of Germany 20 to 25 pounds per acre. In contrast, Lipman (1925), who spoke at the same symposium, stated that "we are, unfortunately, quite in the dark as to the amounts of nitrogen fixed by nonsymbiotic bacteria." A few years later Lipman and Conybeare (1936) gave an estimated value of 6 pounds of nitrogen per acre per year fixed in the har-

Jenny (1928, 1929, 1930, 1931) restricted his sampling to soils with similar texture, slope, and exposure, and having a common pool of plant species. Later, Jenny and Raychaudhuri (1960), working with Indian soils, were obliged to use samples having variable textures; this factor was controlled by adjusting the nitrogen values to uniform texture by using moisture retention data. In forest soils, horizontal gradients in nitrogen occur, and the nitrogen content varies with exposure. These variables were standardized by Harradine and Jenny (1958) to the extent that the samples were taken at a uniform distance from a tree trunk (6 feet) and at the same exposure.

According to Jenny (1930), the order of importance of the soil-forming factors in determining the nitrogen contents of loamy soils within the United States as a whole is as follows: climate > vegetation > topography = parent material > age.

The concept developed by Jenny, namely, that each factor can be treated as an independent variable, has been criticized on the grounds that an alteration of any one factor produces changes in remaining factors. Leeper (1938) pointed out that while the theory takes into account the influence of temperature on the rate of decomposition of organic matter by microorganisms and the influence of rainfall on the synthesis of plant material, no consideration is given to the effect of *both* temperature and moisture on *both* synthesis and destruction. Despite these shortcomings, Jenny's studies have contributed substantially to our understanding of the factors influencing the nitrogen content of the soil, and they have provided a better appreciation of the problems involved in maintaining nitrogen reserves on land placed under cultivation.

Tyurin (quoted by Kononova, 1961) expressed the limiting value of humus accumulation (S) by the equation

$$S = (1 - a)A/x \qquad [1]$$

where a is the decomposition coefficient of plant residues, x is the decomposition coefficient of humus, and A is the amount of plant residues added to the soil annually.

1. CLIMATE

Climate is the most important single factor which determines the array of plant species available at any given location, the quantity of plant material produced, and the intensity of microbial activity in the soil; consequently, this factor plays a prominent role in determining the nitrogen and organic matter levels in the soil. As was mentioned earlier, the level of nitrogen in soil parallels closely that of organic matter.

Considering climate in its entirety, a humid climate leads to forest associations and the development of podzolic-type soils (podzols, gray-brown podzolic, red-yellow podzolic); a semi-arid climate leads to grassland associations and the development of brunizem, chernozem, and chestnut soils. Chernozem and brunizem soils exceed all other well-aerated soils in nitrogen content; desert, semi-desert, and laterite soils have the lowest. Intermediate between these types are the chestnut, gray-brown podzolic, and red-yellow podzolic soils. Soils formed under restricted drainage (humic gley) do not follow a climatic pattern. In these soils, oxygen deficiency prevents complete destruction of organic residues by microorganisms over a wide temperature range.

The profile distributions of nitrogen in soils representative of the various great soil groups are given in Fig. 5.

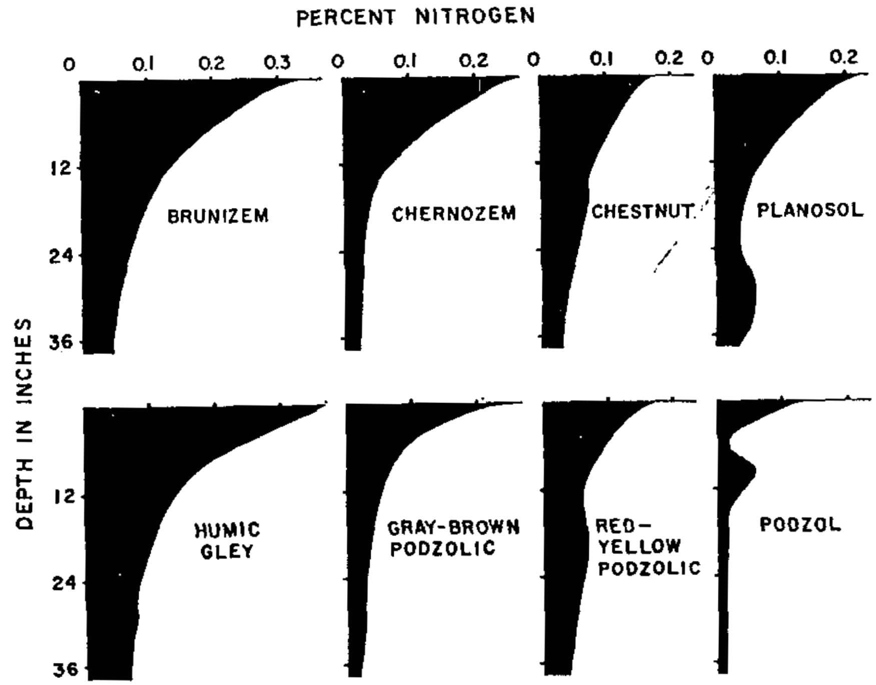

Fig. 5—Distribution of nitrogen in profiles representative of several great soil groups. The data for the chestnut was taken from Brown and Byers (1935), for the humic gley from Brown and Thorpe (1942), and for the podzol from Byers et al. (1935).

The effect of increasing rainfall on nitrogen levels in the soil is to cause greater plant growth, and, consequently, the production of larger quantities of raw material for synthesis of humic substances. For grassland soils, a definite correlation exists between the depth of the root system and the thickness of the grass cover with depth of penetration of nitrogen and organic matter, as illustrated in Fig. 6 for a west-to-east transect along the Great Plains region of the United States. The profile distribution of nitrogen in the chestnut and chernozem soils typical of the central and eastern parts of this area, respectively, and of the brunizem soils to the east of this region, is shown in Fig. 5.

Jenny and his co-workers (Jenny, 1928, 1929, 1930, 1931, 1950; Jenny et al., 1948; Jenny and Leonard, 1934; and Jenny and Raychaudhuri, 1960) made extensive studies of the importance of the components of climate (temperature and moisture) on nitrogen levels in soil. The influ-

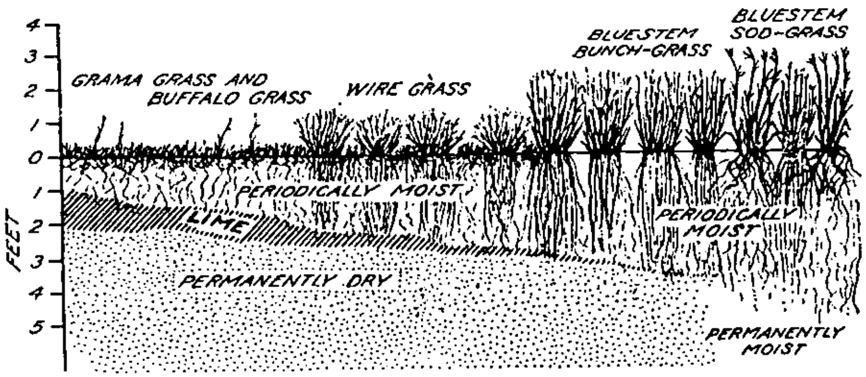

Fig. 6—Relationship between vegetative growth and moisture supply in the soils along a west to east transect of the Great Plains. (From Shantz, 1923).

ence of moisture was evaluated by use of the NS quotient of Meyers, which is the ratio of precipitation (in mm) to the absolute saturation deficit of the air (in mm of Hg).

A distinguishing feature of the nitrogen-temperature function reported by Jenny was that the relationship conformed to van't Hoff's temperature rule. Thus, the nitrogen content of the soil decreased 2 to 3 times for each fall of 10°C in mean annual temperature, and the reaction was defined adequately by the formula:

$$N = a/(1 + Ce^{-kt}) \qquad [2]$$

where N is the total nitrogen content of the soil, t is the temperature, e is the base of the natural logarithm, and a, C, and k are constants.

The relationship between mean annual temperature and the nitrogen content of the soils in the semi-humid region of central United States is illustrated in Fig. 7. Jenny (1928, 1930) found that the nitrogen contents

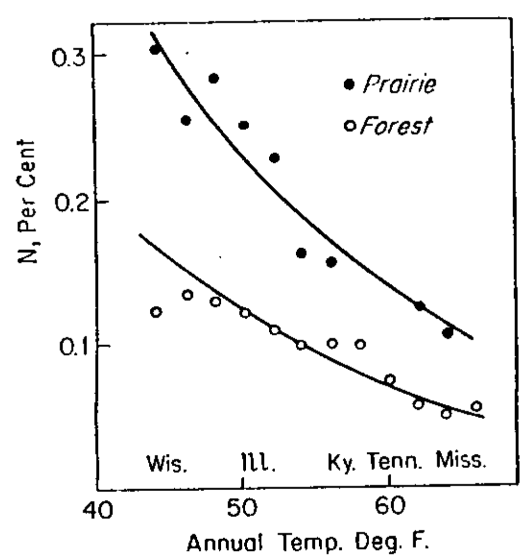

Fig. 7—Nitrogen content of soils in the semi-humid region of the United States, as influenced by temperature (From Jenny, 1941. Used by permission, McGraw-Hill Book Co.)

of the soils along a north to south transect of this region conformed to the equation:

$$N = 1.55/(1 + e^{0.065(t-18.5)}) \qquad [3]$$

The expression for the nitrogen content of the soils along a similar transect for the semi-arid region was:

$$N = 1.70/(1 + e^{0.045(t-1.5)}) \qquad [4]$$

With the mean annual temperature held constant, Jenny (1928, 1930) found that the nitrogen content of the soils in central United States increased logarithmically with increasing moisture, as evaluated by the NS quotient. Fig. 8 gives the nitrogen contents of the soils along a west to

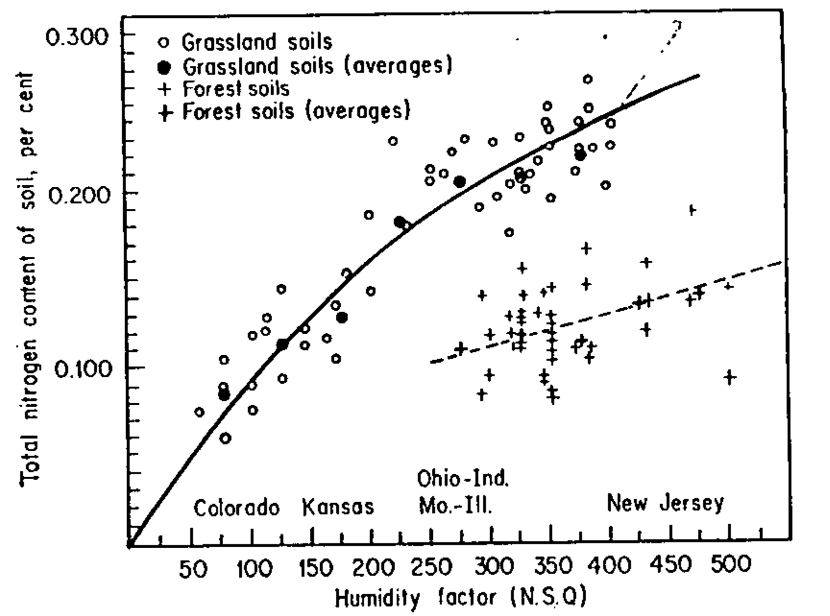

Fig. 8—Soil nitrogen-rainfall relation along the annual isotherm of 11°C in the United States. (From Jenny, 1941. Used by permission, McGraw-Hill Book Co.)

east transect of the United States from the Rocky Mountains to the Atlantic coast (isotherm of 11°C). The nitrogen content of Australian soils has been found to correlate well with the NS quotient (Leeper, 1938).

Using nitrogen-climate functions developed in the United States as the basis, Jenny et al. (1948) found that the soils of Colombia had unusually high nitrogen contents. Later, Jenny (1950) attributed this finding to the more favorable climatic conditions in the tropics for plant growth, and to the presence of species of Leguminosae in the equatorial forests of Colombia. Hawaiian (Dean, 1938) and Puerto Rican (Smith et al., 1951) soils also appear to have higher nitrogen contents than would be predicted from climatic functions developed for the soils of continental United States.

Enders (1943a, b) concluded that the best soil conditions for the synthesis and preservation of humic substances having high nitrogen contents were frequent and abrupt changes in such factors as humidity and temperature; consequently, soils formed in harsh continental climates should have higher nitrogen contents. Harmsen (1951) used this same theory to explain the greater synthesis of humic substances in grassland soils as compared to arable land, claiming that in the former the combination of organic substrates in the surface soil and frequent and sharp fluctuations in temperature, moisture, and irradiation led to a better synthesis of humic substances. According to Harmsen (1951) the extreme surface of the soil (upper few millimeters) is the site of the synthesis of humic substances and the fixation of nitrogen.

Senstius (1958) concluded that the increase in soil organic matter (consequently, nitrogen) with decreasing temperature in an aerobic environment occurs because, at lower temperatures, the activities of microorganisms decrease more than does the photosynthetic process of higher plants. He emphasized that the life activities of higher plants start out at lower temperatures than do those of microorganisms (0°C vs. 5°C), and that the optimum is lower (25°C vs. 30°C): therefore, temperatures below about 25°C should favor the production and preservation of humic substances. The influence of temperature on the accumulation of organic matter (as proposed by Senstius, 1958) is illustrated diagrammatically in Fig. 9. The diagram shows that, under aerobic conditions, organic matter fails to accumulate at high temperatures, whereas, under anaerobic conditions, accumulations are possible over the entire temperature range.

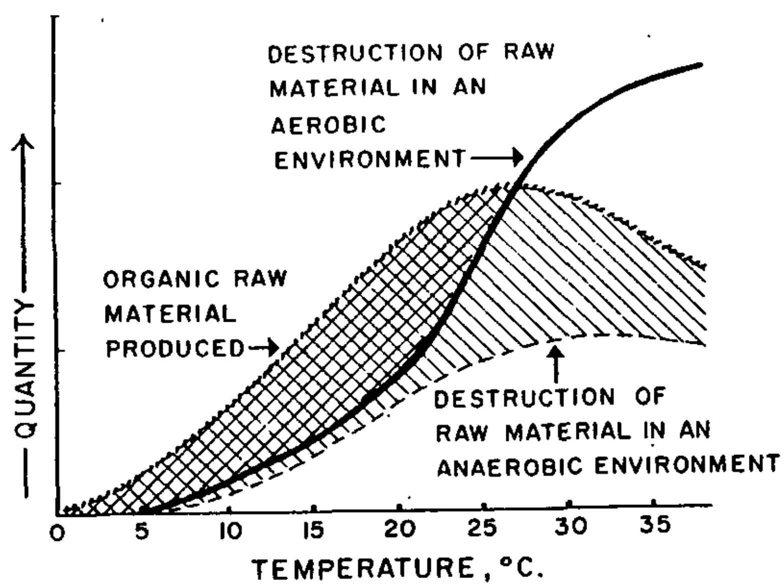

Fig. 9—Influence of temperature on organic raw material production through photosynthesis and organic matter destruction by microorganisms. The shaded areas depict humus accumulations. (Adapted from Senstius, 1958).

Waksman and Gerretsen (1931) found that, in the temperature range of from 5 to 30°C, the lower the temperature the lower the rate of decomposition of organic residues and the higher the nitrogen content. Some interesting results obtained by Jensen (1936, 1939) indicated that the rate of decomposition of organic matter increased with increasing temperature, while, on the other hand, the abundance of microorganisms decreased. According to Jensen (1939), the increase in soil humus with decreasing temperature cannot be explained entirely by the retarding influence of temperature on biological processes (according to van't Hoff's law), but also to the fact that, with decreasing temperature, larger proportions of the transformed organic matter are converted into microbial tissues.

Jenny and Raychaudhuri (1960) compared the nitrogen contents of some Indian soils with those of California, Texas, and the Atlantic Coast region of the United States. When the sites studied had comparable mean annual temperatures and precipitations, the Indian soils were decidedly superior in nitrogen. On the other hand, the Indian soils contained less nitrogen than the tropical soils of Central and South America.

2. *TYPE OF VEGETATION*

According to Jenny (1941), the vegetation factor of soil formation is concerned with the pool of plant species available to a given location, not the quantity of vegetative growth produced; the latter is considered to be controlled by the other soil-forming factors, especially climate.

Soils developed under plants with extensive root systems generally have higher nitrogen (and organic matter) contents, other factors being equal, than those developed under plants with restricted root systems. Under forest-type vegetation, where most of the plant debris is added to the soil in the form of fallen leaves, light-colored soils (for example, gray-brown podzolic) are formed which contain relatively low amounts of nitrogen. Under grass vegetation, where considerable debris is added in root excretions and as sloughed off roots, dark-colored soils (for example, brunizem) are formed which contain relatively high amounts of nitrogen. In commenting on the unusually high nitrogen values obtained by Smith et al. (1951) for some tropical soils of Puerto Rico, Joffe (1955) suggested that the human factor was partly responsible, namely, through cultivation of plants having sod characteristics.

The reason for the high nitrogen content of grassland soils, as compared to forest soils, has been the subject of considerable conjecture. It is common knowledge that the nitrogen (and organic matter) level of most soils cannot be maintained, or increased, without putting them into grass sods; consequently, the conditions in grassland soils are considered favorable for the retention of all available nitrogen as humic substances. Harmsen (1951) concluded that the accumulation of nitrogen and organic matter in grassland soil cannot be explained entirely by the higher amounts of plant residues produced, because luxuriously growing crops, together with high applications of organic matter in the form of manures, composts, or green manures cannot avert completely

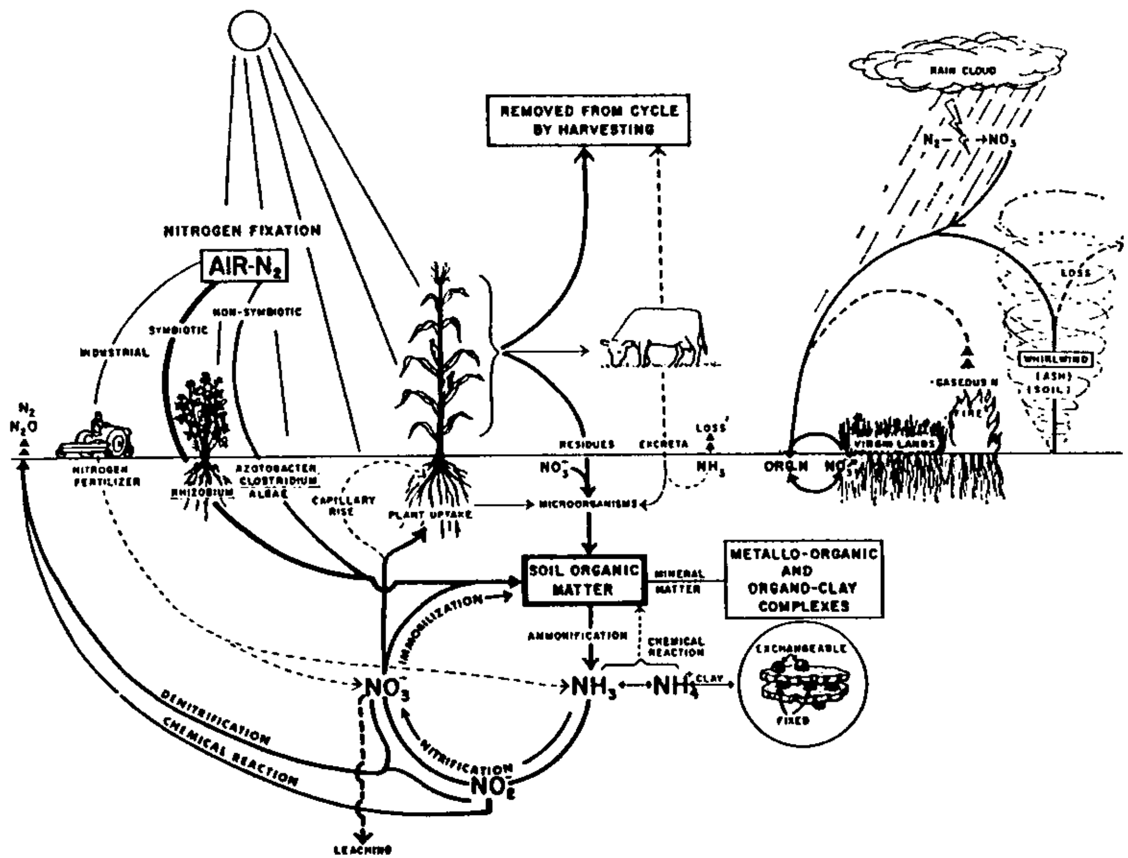

Fig. 1—The nitrogen cycle in soil. (From Stevenson, 1964. Used by permission, Reinhold Publishing Corp.)

which mineral nitrogen becomes immobilized during decay of carbonaceous residues. The formation of mineral complexes protects nitrogenous constituents against attack by microorganisms. The positively charged ammonium ion (NH_4^+) undergoes substitution reactions with metal cations on the exchange complex and can be fixed by clay minerals.

A solution to the problem of providing adequate nitrogen for crops is contingent upon a thorough knowledge of all aspects of the nitrogen cycle, including an understanding of the factors affecting nitrogen accumulation and distribution. The process of nitrogen accretion in relation to geochemistry and the soil-plant environment will be considered in this chapter. Subsequent chapters will be concerned with the other facets of the nitrogen cycle shown in Fig. 1.