The ABC of TURF CULTURE

BY
O. J. NOER

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. of .
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AN INTRODUCTION

By John Morley, President

National Association of Greenkeepers of America.

The author of this valuable book on turf culture has contributed the most beneficial information to greenkeepers in the history of literature.

I know Mr. Noer personally, and a great many greenkeepers know him personally. He has lived among us a great deal, and much of his knowledge and experience has been gained through practical knowledge of our problems.

As President of the National Association of Greenkeepers, I have no hesitancy in recommending this book to the greenkeepers and Green committee chairmen of this country. Mr. Noer with his background of education and his intimate contact with our every-day problems of growing fine turf, has advanced facts and theories which are fundamentally sound.

I sincerely believe the golfing fraternity owes Mr. Noer a debt of gratitude for his work in preparing this material for publication and I recommend it to the serious attention not only of golf club officials, but to park and cemetery superintendents who have turf and soil problems to deal with.

O. J. NOER

Graduate of University of Wisconsin, Division of Soils, and America's most noted turf expert.

CHAPTER I

Factors Affecting Turf Growth

Turf culture is affected by the same factors that control the growth of all plants. The excellent turf on fairways and greens of certain golf courses is not a matter of chance, but the result of intelligent management on the part of a painstaking greenkeeper, and the club possessing such a greenkeeper is indeed fortunate.

An understanding of the basic principles of plant growth, coupled with ability to apply these principles to local conditions, simplify the problem of maintaining greens and fairways in good good playing condition.

The growth of plants is dependent upon the following factors:

1—Suitable air temperatures.

2—Ample supply of water.

3—Sufficient light.

4—A fertile soil.

5—Protection of the turf from injury.

It is impossible to alter some of these factors, but others can be so modified as to improve the conditions for plant growth.

Air Temperatures Vary Greatly

The air temperatures at which different plants grow best vary greatly. Most of the best turf grasses prefer a moist cool climate, so it is generally difficult to maintain good turf where high average temperatures are the rule. In some sections the months of July and August are hot and dry, and under such conditions turf suffers badly.

While climate cannot be modified, varieties of grasses suited to local climatic conditions should be selected. Obviously, grasses adapted to cool climates are not generally suitable for use in warm climates, and modifying cultural and fertilizer practices does not adapt them to the new environment.

How Plants Use Water

Water constituting from sixty to ninety per cent of the weight of growing grass, imparts rigidity to the plant structure and plays an important role in plant growth. The plant obtains its water from the soil, through its root system.

Most of the water taken into the plant is evaporated from the leaf surfaces, and as a result a stream of water passes through the plant. The evaporation helps control the temperature of the plant, just as the evaporation of perspiration aids in controlling our body temperature. Naturally greatest evaporation occurs during hot weather, but even so the temperature of plant surfaces is often ten degrees higher than that of the surrounding atmosphere.

Turf often wilts during hot, dry weather, because water is evaporated from the leaf surfaces more rapidly than it can be taken up by the root system. The plants' demand for water is considerable, some varieties evaporating as much as five thousand barrels of water per acre during a single growing season.

Turf grasses are among the first to suffer during periods of scant rainfall. Root systems are proportional to the amount of top growth, and since the turf is kept short by constant cutting the root system is confined to a relatively thin layer of surface soil. During periods of drought the water of this thin soil layer is quickly exhausted and the turf soon suffers. It is folly to expect good turf, particularly on soils of low water holding capacity, without providing water during periods of low rainfall.

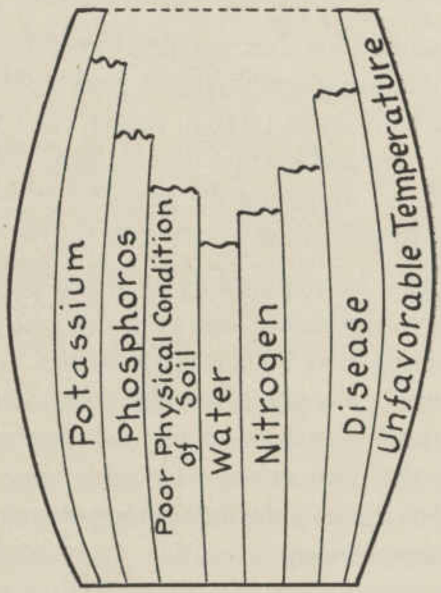
Leaves Manufacture Food

In the presence of sufficient light, the leaf of a grass plant becomes a manufacturing establishment, and builds a class of substances called carbohydrates (starch, sugars, etc.) from the simple raw materials, water and carbon dioxide gas. Light makes this synthesis possible by supplying the needed energy, just as steam furnishes energy to propel the locomotive.

Carbohydrates are required by all living parts of the plant, and since they are only manufactured in the green portion of the plant, it is essential that sufficient quantities are produced to supply other parts of the plant, notably the root system. When manufacture exceeds the demand, the excess of carbohydrate is stored to supply the plant in time of need. Since manufacture is largely confined to the leaf, the importance of maintaining an adequate leaf surface is evident.

Close clipping of fairways and greens late in the fall seriously restricts the leaf surface, and may result in depleting the carbohydrate reserves. This leaves the turf in such a weakened condition that severe winter-killing on greens, and a slow initial growth of the turf in the spring often results. If turf is permitted to make a longer growth in the late fall, possibly carbohydrate reserves can be built up sufficiently to insure an adequate supply for use in the early spring. A more extensive root system also accompanies longer top growth, and this increases the storage capacity of the roots for carbohydrates.

In the case of new fairway seedings probably a more vigorous turf will be obtained by encouraging a good leaf growth to



Just as capacity of barrel is limited by shortest stave, so turf growth may be limited by one or more unfavorable factors. Eliminating one unfavorable factor may produce marked improvement, but until all are corrected maximum growth is not possible. Adapted from Whitson.

promote rapid carbohydrate production, thus supplying the young expanding roots with sufficient carbohydrate to establish an extensive root system. This does not mean that young turf should be allowed to grow too long before initial cutting, for long delayed cutting results in a coarse tufted turf. Frequent clipping is essential to the development of side shoots, a prerequisite to the formation of dense uniform turf.

Fertile vs. Infertile Soil

The soil is a manufacturing plant where the plant food elements it contains are converted into forms which the plant can utilize, and it is the business of the plant grower to make conditions favorable so the factory can produce sufficient food to satisfy the growing plant.

That soils differ in their capacity to produce plant growth is generally recognized, but some of the factors which distinguish a fertile from an infertile soil are often overlooked. The soil not only acts as a support to which the plant anchors itself by means of the root system, but also contains sufficient air to satisfy the root system's demand for oxygen, and furnishes the plant with moisture and the mineral plant food elements.

A fertile soil contains about fifty per cent solid material, twenty-five per cent moisture, and twenty-five per cent air (pore space). The solid portion consists mainly of small particles of minerals derived from the disintegration of rocks, and some organic matter derived from the decay of plant and animal residues.

Of the ten chemical elements required by plants to make normal growth, seven are obtained from the soil. These plant food elements enter the plant through the roots, and are available only when present in the soil water in the form of soluble compounds. Practically all soils contain sufficient supplies of four of these elements, but are often deficient in one or more of the elements, nitrogen, phosphorus and potassium, sometimes referred to as ammonia, phosphoric acid and potash.

While the soil water does not, at any one time, contain sufficient plant food to satisfy the entire demand of the plant, a fertile soil is one which contains these materials in forms which enable rapid solution when the plant makes heavy demands.

Bacteria in the Soil

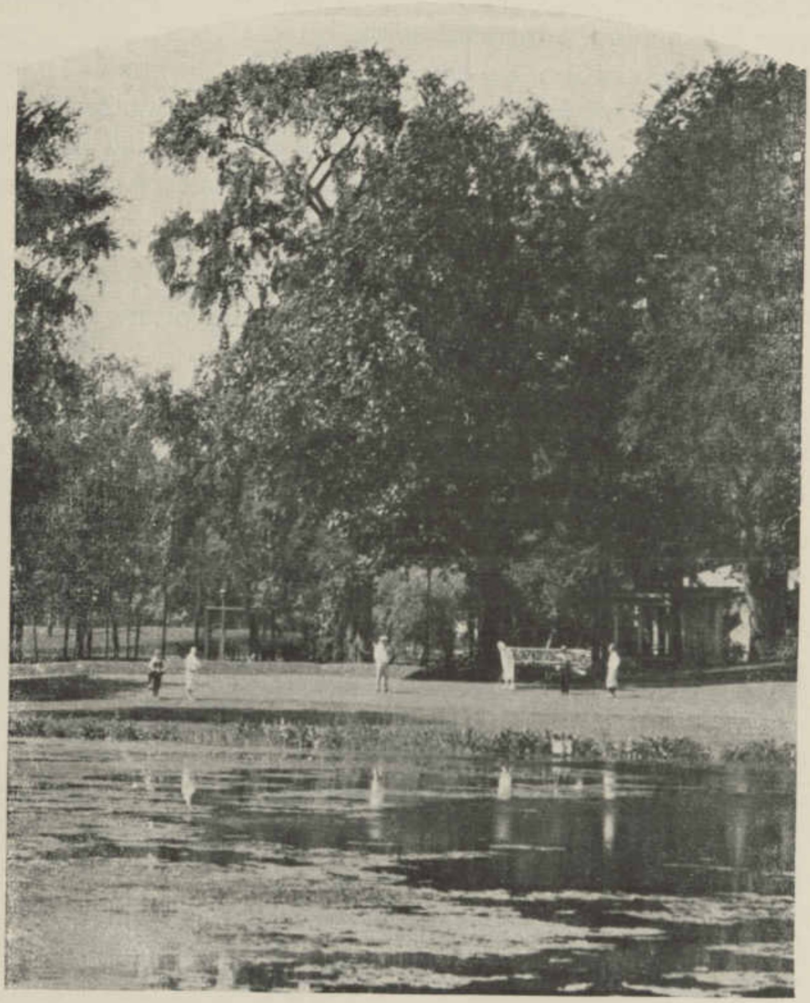
Fertile soils contain vast numbers of micro-organisms called bacteria. The numbers are so great that a thimbleful of soil contains millions of them. These micro-organisms are the scavengers of the soil, for they are responsible for the decay of plant and animal residues applied to the soil. During decay plant food materials are released in available form, and normal plant growth does not occur unless these organisms are present in the soil. When conditions are favorable they are tireless workers. These conditions are, an abundance of organic matter, proper temperatures for growth, a sufficient supply of moisture, and air within the soil for the most beneficial bacteria require oxygen.

Factors Adverse To Turf Growth

While the most important factors affecting plant growth have been discussed there are several others which deserve mention, although they are negative factors. Plants require protection from injury and on established turf this resolves itself into protection from mechanical injury and the ravages of insect pests and plant diseases such as brown patch, etc. The presence of toxic substance in the soil occasionally prevents plant growth.

It is evident that normal plant growth depends upon a variety of factors. This may be illustrated by the use of a barrel whose staves are of unequal length. Just as the capacity of the barrel to hold water is limited by the length of the shortest stave, so plant production may be limited or prevented by one deficient plant food element, or a single unfavorable condition. If the shortest stave of the barrel is lengthened, then the next shortest stave determines the capacity of the barrel to hold water. So with plant production, the elimination of one unfavorable factor increases plant production up to the point where another unfavorable factor may limit growth. It is only when all limiting factors are eliminated that maximum and normal plant growth results.

Since soil conditions and plant feeding are the factors most easily modified these will engage our attention in future chapters.



The Water Hole at Congress Lake Club, Canton, Ohio.

CHAPTER II

Effect of Size and Arrangement of Soil Particles on Turf Growth

The soil as already indicated consists of mineral particles derived from the waste of rocks, humus resulting from the decay of plant and animal residues, and spaces between the individual soil particles which contain air and water. The size of the individual soil particles, and the way in which they are arranged greatly affect the producing power of the soil.

The amount of air space, the water holding capacity, and the rate at which plant food elements are made available, not only depend upon the size, but also the arrangement of the individual soil particles.

Size of Soil Particles Determine Texture

Texture refers to the size of the individual soil grains. Sands, loams and clay soils are spoken of as coarse, medium or fine textured depending upon the predominating particles. Many soil properties, such as water holding capacity, workability, and power to supply the plant with essential mineral food elements depend ultimately upon texture. For practical purposes the individual soil particles are arbitrarily grouped into classes based on size. The limits of the different groups are determined by the relative value of the various sized particles in affecting the physical properties and crop producing power of the soil. Seven groups are recognized, namely—fine gravel; coarse, medium, fine and very fine sand; silt and clay. The relative size of the particles of these seven different groups is illustrated below. Actually the various particles are 1/800 the size represented. The number of fine particles in a given volume is very great. In one gram (453.69 grams equal 1 pound) there are the approximately following number of individual particles for the classes indicated.

Clay	45,000,000,000
Silt	65,000,000
Very fine sand	2,000,000
Coarse sand	2,000

With these enormous differences is there any wonder that differences of texture exert such an enormous effect upon the properties of the soil. Sand and clay are most important, so some of their distinctive properties deserve special attention. Humus exerts a marked effect on soil structure but will be dealt with in a later chapter.

Sand

Sand consists mainly of grains of quartz, although other minerals are also present, especially in the fine grained sands. Due to the abundance of quartz, sands are generally low in plant food constituents. Considered in the mass the chief characteristic of sand is its lack of coherence, or ability to retain its form especially when dry. Soils containing large amounts of sand have a low water holding capacity, and are not well adapted to turf for reasons which will be considered under soil moisture.

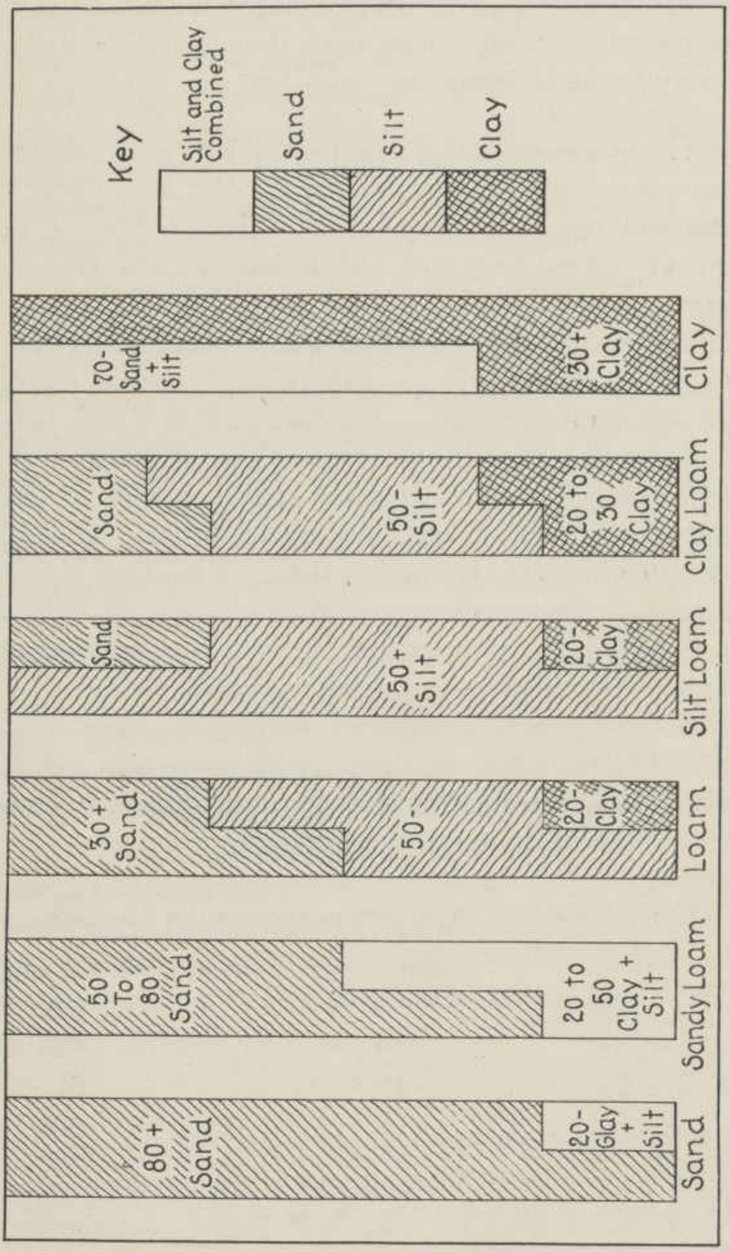
Clay

The finest soil particles constitute the group clay, a material possessing unusual properties, which are most apparent when clay is puddled, or worked when wet. In puddled clay the individual particles are so closely packed that even thin layers prevent the passage of water. Moist clay is plastic and can be worked into shapes which it still retains upon drying, and the mass becomes very hard and tenacious.

If a small amount of clay is rubbed up into water, the water becomes clouded and even after long standing the minute clay particles still remain in suspension. The addition of small amounts of certain substances such as lime, gypum, etc., cause the fine suspended particles to clot or form larger aggregates which rapidly settle to the bottom of the container. This power of clay to clot or form larger aggregates occurs in the soil mass and plays a very important part in the management of soils high in clay. When the clay is in the state of aggregation the soil behaves as though it were composed of coarser particles. Just as the potter works clay to break the aggregates into the ultimate particles to make the clay more plastic, so working clay soils when too wet destroy the aggregates and make the soil more clayey than before. The soil then becomes more impervious to the passage of water and air, and dries into hard, tenacious lumps. To make it more tractable is difficult and requires time. It is accomplished by the action of weather, such as freezing and thawing, alternate wetting and drying, the incorporation of organic matter, and the action of lime is particularly effective.

Relative Size of Grains of Different Classes

	Millimeters	Limits	Inches
1. Fine Gravel	.1-2	....	.039-.078
2. Coarse Sand	.5-1	....	.019-.039
3. Medium Sand	.25-.5	....	.01 -.019
4. Fine Sand	.1-.25	....	.004-.01
5. Very Fine Sand	.05-.1	....	.002-.004
6. Silt	.005-.05	....	.0002-.002
7. Clay	Less than .005		Less than .0002



Graphic Representation of Soil Classes Based on Texture.

Soils Grouped Into Classes Based on Texture

The fact that soils consist of a mixture of different sized particles is generally recognized. Yet a soil may contain a large proportion of particles of uniform size. Thus a sandy soil contains a large proportion of sand, and the larger the proportion the coarser the sand. A clay soil contains a large proportion, but not necessarily a larger proportion of clay than material of any other size, because a given amount of clay has a larger effect upon the properties of the soil than the same amount of coarser sand particles. For practical purposes, soils are grouped into the following classes based on texture.

Sands (Usually Poor Turf Soils)

Contain 20% or less of silt and clay; 80% or more of sand. A sand may be coarse, medium, fine, or very fine depending upon the predominance of the different groups of sand particles.

Loams (Generally Good Turf Soils)

Sandy loam contains 20 to 50% clay and silt; 50 to 80% sand.

Loam contains 20% or less of clay; 50% or less of silt; balance sand.

Silt loam contains 20% or less of clay; 50% or more of silt; balance sand.

Clay loam contains 20 to 30% clay; 50% or less of silt; balance sand.

Clay, over 30% clay; balance silt and sand.

With a little experience it is easy to place a soil in its proper class right in the field. Texture is judged by rubbing the soil between the thumb and finger and with practice one soon becomes expert in judging the size of the soil grains.

The best soils for golf courses are undoubtedly the sandy loam, loam and silt loams. Sands are not well suited to turf, and although good turf can be obtained on the clay loam and clay soils, these soils require very careful management.

How Soil Texture Can Be Modified

The only feasible method of modifying soil texture is by adding to it material of different texture. Obviously the huge expense generally prohibits such practice on fairways, but it is entirely practical in the preparation of soils for greens. The presence of only 30 per cent clay is sufficient to classify a soil as a clay, whereas a soil does not fall in the sand class until sand particles constitute 80 per cent of the whole. Hence, relatively small amounts of clay effectively change the sands, but large amounts of sand are required to materially modify the properties of a heavy clay soil. For green purposes soils of intermediate texture, the sandy loams, and loams are best. These require minimum additions of sand or humus to make suitable topdressing mixtures. The addition of too much humus makes the topdressing too spongy and may encourage worms. If the clay content is too high the soil consolidates, and the surface of the green becomes hard. On such surfaces it is almost impossible to hold the ball.

Texture is not easily modified after turf is even partially established. Applications of sand or clay do not mix with the underlying soil and thus may do positive damage. Changes must be effected by gradually building a soil of good texture by frequent application of suitable topdressing mixture.

It is important to provide surface soil of the proper texture prior to planting or seeding. Failure to do so, may retard or prevent rapid formation of dense heavy turf. It is almost useless to attempt turf improvement by fertilization or other means unless soil conditions are suitable.

Soil Structure Depends Upon Arrangement of Soil Particles

While texture is of great importance, the arrangement of the individual soil grains is also important. Texture refers to the size of the particles, but the arrangement of the grains determines soil structure. The structural condition influences the circulation of air and water in the soil both of which are necessary to the normal development of turf. In clean sand each individual particle is a unit by itself and has but a chance arrangement in relation to the surrounding grains. Highly fertile soils have a marked structure. The individual grains are bunched, and more or less rigidly bound into groups, granules or crumbs. This arrangement is essential in soils of fine texture (clay loam, etc.). Granulation or formation of crumb structure enables these soils to function as though more or less coarse grained.

Spaces Between Soil Particles

Collectively the spaces existing between soil particles are known as the pore space. Theoretically, in a soil made up of equal sized spheres in contact with one another, the amount of pore space depends solely on the arrangement of the spheres. Thus a cubic foot of marbles contains as much pore space as one of small shot with the same arrangement of spheres.

Ideal Arrangement of Spherical Soil Particles

1. Columnar order, 47.64% pore space.
2. Oblique order, 25.95% pore space.
3. Compound spheres in Oblique order, 74.05% pore space.
4. Three sizes of spheres with closest packing, about 5% pore space.

If small spheres exist within larger ones, the pore space is materially increased. This is the condition in granulated soils. Where there are spheres of several sizes, and the smaller ones occupy spaces between the larger ones the pore space is materially reduced. This is the condition in puddled soils. By working clay soils when too wet the small particles are forced into the spaces between the larger grains. Some ideal arrangements are illustrated in the accompanying cut.

These ideal arrangements do not exist in the soil. The soil grains are irregular in shape and uneven in size. In fine textured soils the smaller particles are so light that they do not settle so closely together in proportion to their size as do the sands. The relation between texture and total amount of pore space for some soils under field conditions is as follows:

	Percent of Pore Space
Clean Sand	33.50
Fine Sand	44.00
Sandy Loam	50.00
Silt Loam	53.00
Clay	56.00

Not only the total amount of pore space, but the diameter of the individual pores is of importance. Together they determine the capacity of soil to retain and move water and air, as well as facilitate the extension of plant roots.

Soils Contain Enormous Amount of Internal Surfaces

The amount of surface exposed by the soil particles is of great importance, because it is from these surfaces that the plant roots obtain water and mineral food elements. The water held by a well drained soil exists as a film covering the surface of the particles, and the amount held is dependent upon the surface exposed. The mineral plant food elements are dissolved at the soil surfaces by the soil water, and other things being equal the amount of substance dissolved from a solid body is proportional to the surface exposed. The enormous extent of internal soil surface is not often appreciated. There are more than 10 square miles of surface exposed in the surface foot of an acre of coarse sandy soil, in a loam more than 60, and in the finest clay, the surface exposed may exceed 300 square miles. These differences are enormous, and partly account for the greater productive capacity of the loam and clay soils.

Best Soils Have Granular Structure

The development of crumb structure is necessary in all soils except some of the sands. Water and air pass more freely, and it also permits of more ready penetration of the roots and root hairs. Without granulation the spaces between the particles are so small that the soil is almost impervious to both water and air. Thus if a coarse sandy soil disposes of its excess of water after a heavy rain in 2½ hours, by under drainage, the finest clay without granular structure requires about 3 months to free itself of the same amount of water in a like manner. When the fine soil particles are collected into larger aggregate grains, excess water is quickly disposed of by under drainage, and there is an opportunity for the roots to advance between the grains, and absorb the plant food and moisture contained in them. Each aggregate acts like a tiny sponge which maintains itself full of water highly charged with plant food materials to be sucked out by the root hairs as they advance alongside them.

On fairways it is rarely possible to modify soil texture by the addition of sand, humus or clay due to the huge expenditures necessary to effect material change, especially if turf is already established. Efforts must usually be confined to changes in soil structure. Development of granular structure on heavy soils produces marked improvement. Adequate drainage is the first essential. When these soils are saturated with water, the excess water tends to break down and detach the small particles existing in the compound granules. Thorough drainage removes this superfluous water, and as the water films surrounding the particles contract the small particles are gathered into clusters, and lightly cemented by the action of humus or the salts dissolved in the soil water. Feeding the turf will then promote greater growth and produce improvement by extension of the roots, and augmentation of the humus supply when the older roots die. Surface applications of manure do not add much humus to the surface soil layer.

When new fairways are to be established on fine textured soils extreme care should be used in the preparation of the seed bed. Plowing should be done when the moisture condition is such as to prevent the formation of clods. If plowed a season in advance of seeding the alternate freezing and thawing, during the winter improves granulation. If it is possible to grow a green manure crop and plow it under, the resulting humus will materially improve soil structure.

Ideal soil conditions are most likely to occur in loam soils. These soils have some particles large enough to function separately, and others of medium size to form centers around which the smaller particles may cluster to form granules or crumbs. Thus there are a few large pore spaces which facilitate drainage, and numberless small openings in which water is retained.

Turf Improves Soil Structure

Practical men appreciate the importance of maintaining soils in good physical condition. When seeds begin to grow there is no direct connection between the seed and soil. The small amount of plant food contained in the seed is soon expended in the development of a root system. If the seed is placed in conditions unfavorable for free development of the first roots it may succumb. A mellow seed bed, with many pores allows the roots to grow unhindered, and tends to place absorbing surfaces in direct contact with the soil grains. It is particularly mportant to have a mellow seed bed for turf seedings. The young grass seedling must forage for itself as soon as growth begins because of the exceedingly small amount of food contained in the very small grass seed. After the soil is once covered with grass, the turf aids in improving soil structure. As the roots grow and decay, the soil particles are wedged apart in some places and crowded together in others. The grains are finally cemented together into larger aggregates and the open mellow structure characteristic of virgin soils results.

A view of Number 18 at Forest Hills, Tampa, Fla.

CHAPTER III

The Part Water Plays in the Growth of Turf

Turf in common with all other plants requires water and is among the first to suffer during periods of drought, due to its shallow root system. There are periods during every season when turf suffers for want of water. Soil is the reservoir from which water is obtained, and since soils differ in their water holding capacity and ability to supply water a clear understanding of the relationships between plant, water and soil are essential.

Functions of Water

In amount water is the main constituent of grass, comprising 60 to 80 per cent of the green weight. Water serves the growing plant in a number of ways. It gives the plant rigidity. When the supply becomes limited plants first wilt and may finally succumb. In the leaf it serves as a direct food, being broken up and its elements utilized in the manufacture of starch and sugar. It serves as the vehicle for the carriage of the mineral elements of the soil and the gaseous substances of the air to the places where they are utilized by the plant. Water is also constantly evaporated from the leaf surfaces. This evaporation tends to control the temperature of the plant and enables it to better withstand intense heat. The effect is the same as the cooling effect of evaporating perspiration. During hot periods plants often wilt during the middle of the day when water is not absorbed rapidly enough by the roots to compensate for these losses at the leaf surfaces. Towards evening evaporation is checked by the cooler air temperatures and the wilted condition disappears. Very much more water is evaporated from the leaves than is used directly as food. Investigations show that from 200 to 500 pounds of water are evaporated for every pound of dry matter produced. The amount varies and is affected by a variety of conditions such as air temperature, amount of water in the soil, etc. It is probably safe to say that 5,000 barrels of water are evaporated during the production of $1\frac{1}{2}$ tons of dry grass. This amount of grass is often produced on each acre of fairway. Is it any wonder that insufficient water so often limits turf growth on fairways?

Amount and Kinds of Water in the Soil

The amount of water contained in the soil depends upon a number of factors. Obviously it is profoundly affected by the extent and frequency of rains or artificial additions by sprinkling or irrigation. The physical condition of the soil, especially the size of the individual particles and the amount of organic matter or humus, exerts a marked effect. During dry weather turf on sands suffers first and dries out long before turf on heavier soils. This is due to the great difference in the retentive capacity of the two soils. It is doubtful if sand can ever be made to support good turf in areas of limited rainfall unless its physical condition is modified, or provision is made to apply much needed water. Naturally the rate and amount of water lost from the soil also affects the soil supply

Three kinds of water exist in the soil, namely, hygroscopic, gravitational, and capillary. It is from the capillary water that plants satisfy their requirements. Hygroscopic water is the moisture which condenses on the surface of dry soil when exposed to the air, and is held so firmly that plants cannot use it. In amount it rarely exceeds a few per cent, and naturally soils made up of very fine particles contain most because such soils expose the largest surface. Gravitational water is the water which is free to move under the influence of gravity and passes down through the soil when conditions permit. If this free water remains in the surface soil it fills the spaces between the individual particles which should contain air to supply the turf roots with needed oxygen. Excess water also inhibits the development of beneficial soil organisms, and prevents the soil from warming rapidly in the spring. Where natural drainage is poor supplementary drainage must be provided to insure rapid removal of gravitational water. This is the first essential in turf culture because other treatments such as fertilization will never produce maximum benefits until adequate drainage is provided. Capillary or film water is the water held around the individual soil particles as a film, and is the most important from the standpoint of turf culture. The water surface on the outside of the film acts as an elastic covering or skin, and is responsible for the movement of capillary water. When water is removed by the plant root or evaporation, the stretched film pulls water from adjacent areas until the strains are again equalized.

The size of the individual soil particles exerts the greatest effect upon the amount of film water a soil can retain. Soils made up of small particles hold the most because they contain extensive internal surfaces. Loam and clay soils retain from two to three times as much film water as sands. Structure or the arrangement of the soil particles also exerts a marked influence. Loosening the structure of sandy soil often lowers its moisture holding capacity. The individual particles are so far apart that the formation of a continuous film is prevented. An open or granular structure, that is grouping of the very fine clay particles into larger particles, increases the supply. Water is held around the individual particles of the granules and also surrounds the compound granule. Thus such grouping increases the surface exposed.

Organic matter affects the soil capacity for moisture in several ways. Humus has a large capacity for moisture but it also acts as a weak cement, and aids in producing the desirable grouping already mentioned.

Plants cannot use all the capillary water held in the soil supply. Water is taken most readily by the roots when the films are thick. As the thickness of the film is reduced it becomes increasingly difficult for the plants to obtain water, and before all the capillary water is removed the plant begins to wilt. Light showers following a dry period may produce marked benefits on sandy soils and be wholly ineffective on the heavy soils. This is due to the small surface area in the sands, so less water is required to produce thick films than on the clay soils, with their extensive surfaces. More copious watering is needed on the heavy soils for this reason. The relationship between texture, capillary water and available water is illustrated in the following table:

	Per cent Capillary Water in Soil	Per cent Water in Soil When Plants Wilt	Per cent Available Water
Sand	8	3	5
Silt Loam	25	15	10
Clay Loam	40	23	17

Sandy soils contain only small amounts of available water and never hold enough to carry growth through the season, even though plants can use a larger percentage of the moisture originally contained in such soils. Even clay soils do not carry enough water, including all moisture to a depth of 3 to 4 feet, to satisfy the entire demands of deep rooted crops such as corn. Is it any wonder shallow rooted turf grasses so often suffer? The supply must be replenished by rainfall, irrigation, or movement up from the subsoil.

Movement of Water In The Soil

When rain falls upon a soil absorption takes place and the excess gravitational water passes down through the soil as a result of the pull of gravity, and capillary water is left surrounding the soil particles. Absorption and downward movement is rapid in sands because of the large spaces existing between the soil particles. Clays seldom contain large spaces because of the minute size and close packing of the individual particles. These small spaces together with the resistance offered by the particles themselves prevents rapid downward movement. The pressure of air in the minute pore spaces hinders the entrance of water especially if the subsoil is dense or full of water. Only as the entrapped air manages to escape is water absorbed. This is why heavy showers are often of so little benefit. Tile drains in such soils facilitate the entrance and movement of rain water by providing a channel for the escape of entrapped air.

Movement of Capillary Water Important

Since plants depend upon capillary or film water for their main supply, its movement in the soil is of great consequence, especially when the diminishing supply in the surface soil can be partially replenished by capillary rise. Soils made up of fine particles have a greater capacity and can move water to greater heights than the coarser soils, but the rate of movement is most rapid in the coarser soils. Very often the rate is so slow in clay soils that plants perish before water is brought up from the subsoil to meet the demand. The friction is so great that the actual movement is very inefficient. All things considered it is the soils of intermediate texture, sandy loams, loams and silt loams which most readily meet the needs of the growing plant for water.

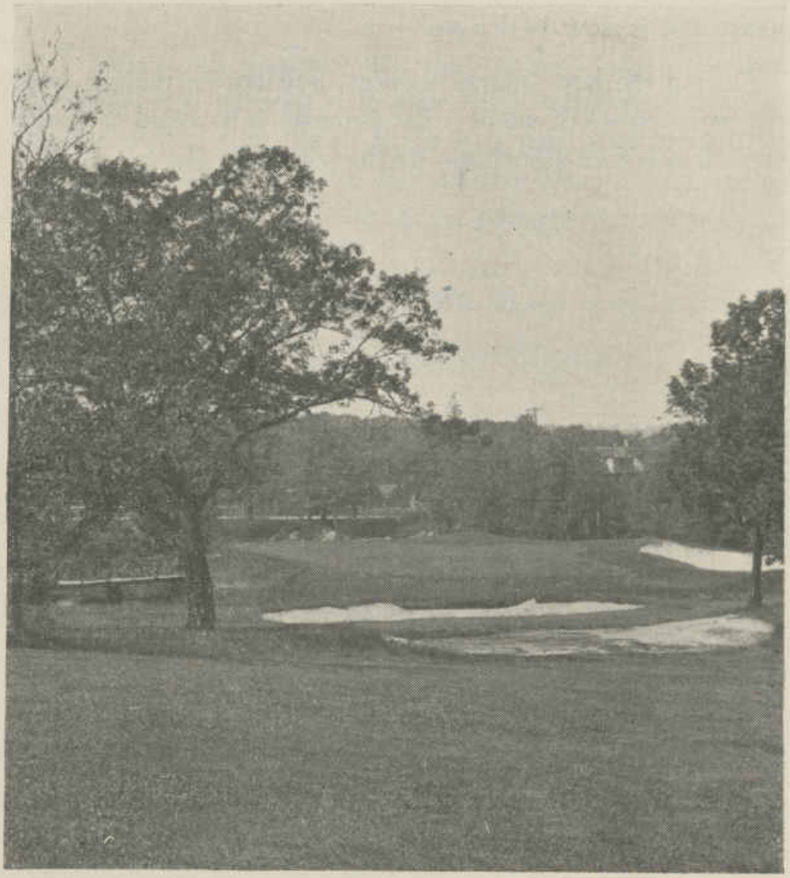
When a soil becomes dry the capillary rise of water is greatly retarded, because such soils resist wetting. Hence soils must be damp if rapid rise of water is to take place. Movement is also slower when the films surrounding the particles are very thin due to the friction offered by the particles themselves.

Maintain Soil Conditions Which Favor the Retention and Rise of Capillary Water

Since water so often limits growth, it is essential to produce soil conditions which insure maximum retention and rapid capillary rise of water. Providing adequate drainage is the first essential. On the heavy soils this increases the amount of available water and produces conditions which favor more effective absorption of water. It is only on greens that soil texture can be thoroughly modified. The huge expense generally prevents such practice on fairways. During the construction of greens great care should be exercised to provide soil of good texture. There are altogether too many instances where this has not been done. All things considered a loam soil is best. Such soils readily absorb water, have a good water holding capacity and can move water rapidly by capillarity. On fairways the sandy soils present the greatest problem. Such soils should be kept as compact as possible to facilitate the capillary rise of water, especially if the water table is near the surface. Increasing the supply of humus by growing green manure crops, and the liberal use of manure prior to seeding benefits such soils by increasing their water holding capacity.

The bad effects incident to light sprinkling are generally appreciated. It tends to encourage very shallow root development, because roots rapidly grow towards moist areas. This surface layer dries out first and the turf does not obtain water because capillary rise is slow in dry soil.

During the hot summer months, mid-day sprinkling results in enormous losses of water. Evaporation is so rapid that much water is lost before absorption by the soil takes place.



Number 17 at the Country Club of New Bedford,
North Dartmouth, Mass.

CHAPTER IV

The Functions of Organic Matter in the Soil

The importance of the soil organic matter is generally recognized by the greenkeeper, but some of its functions are not always clearly understood. Organic matter is the great natural source of nitrogen for turf, but it also affects the physical condition and water-holding capacity of the soil. Almost all of the organic matter exists near the surface and is the chief characteristic of all soils. The absence of organic matter, and the bacteria associated with it, is one of the chief reasons why the deeper soil layers fail to support plant life when brought to the surface. Generally speaking, soils well supplied with active organic matter are fertile soils.

Decay of Organic Matter Produces Humus

The surface layer of soil constantly receives additions of organic matter, either leaves or other debris from vegetation growing on the soil, or manure and other animal or vegetable residue. In the soil, these materials soon lose their original structure and break down into dark colored substances called "humus." Since the dark color of most soils is due to humus, color can be used to obtain some idea of the amount of humus in a soil. Light colored soils always contain less humus than dark colored soils. That humus is, essentially, a product of bacterial decay is shown by the fact that its formation ceases when mixtures of soil and organic matter are sterilized with antiseptics or by heat. The upper soil layers where organic matter is abundant contain hosts of bacteria but with increasing depth, they rapidly diminish. The number of bacteria in the surface layer of a fertile soil is almost inconceivably large. A teaspoon often contains millions of these minute organisms. Provide a suitable environment and they become ceaseless workers.

When organic matter is added to the soil, the changes which it undergoes depend upon the conditions of aeration, drainage, temperature and cultivation. With suitable temperatures and abundant supply of air, the organic matter may be completely resolved into simple substances with much the same final result as though it had been placed into a furnace. Naturally, such conditions do not favor the accumulation of humus. With a more limited supply of air, destruction of the organic matter is not complete and a portion of the original material persists as humus. In the soil, both types of change go on. More humus is found in soils continuously in turf than in a continually cultivated soil because of the differences in the amount of air admitted into the soil. Clays contain more humus than sandy soils through which air is always being drawn, and the accumulation reaches its maximum in water-logged soil where access of air is effectively cut off. This is the condition existing in marshes and it is here that muck and peat accumulate.

Humus Main Source of Nitrogen

Humus is the great source from which plants obtain needed nitrogen and since all plant and animal tissue contain nitrogen, the soil supply is increased whenever vegetable or animal matter is applied to the soil. The air above the soil contains huge amounts of nitrogen but legumes are the only plants which can utilize this nitrogen, and since clovers are discouraged on golf courses, this inexhaustible source cannot be drawn upon. During electrical storms, some nitrogen of the air is converted into available compounds and washed down in rains. The soil supply is thus increased by from 5 to 10 lbs. of nitrogen per acre annually —amounts which are insufficient for golf course turf. A group of bacteria exist in the soil which are capable of assimilating free nitrogen of the air but there is no definite information as to the amount which may be fixed. It is safe to say that it is not sufficient to supply the demand of the turf. The use of nitrogenous fertilizer must be resorted to when soils are low in humus and nitrogen.

How Nitrogen of Humus is Made Available

The nitrogen in humus exists in organic compounds, largely insoluble in water, and not directly available to the turf. This nitrogen must be converted into other forms. During decay, the soil bacteria convert the organic nitrogen first into ammonia, the form of nitrogn in sulphate of ammonia, and then a special group of bacteria change the ammonia into nitrate nitrogen. This is the form preferred by most plants. Unfortunately, nitrate nitrogen, unless taken up by the turf, leaches out in the drainage water and is thus lost. Storing nitrogen in humus is a wise provision of nature to guard against excessive loss.

Very often dark colored clay soils, even though they contain considerable humus, may need nitrogen, especially if they have been cropped over considerable periods. The remaining humus resists further decay and fails to yield sufficient nitrogen to satisfy the demand of the growing turf.

The transformations which nitrogen undergoes in the soil form a cycle. Plant or animal residues decay and nitrogen is released in forms which the growing plant may again utilize, or it

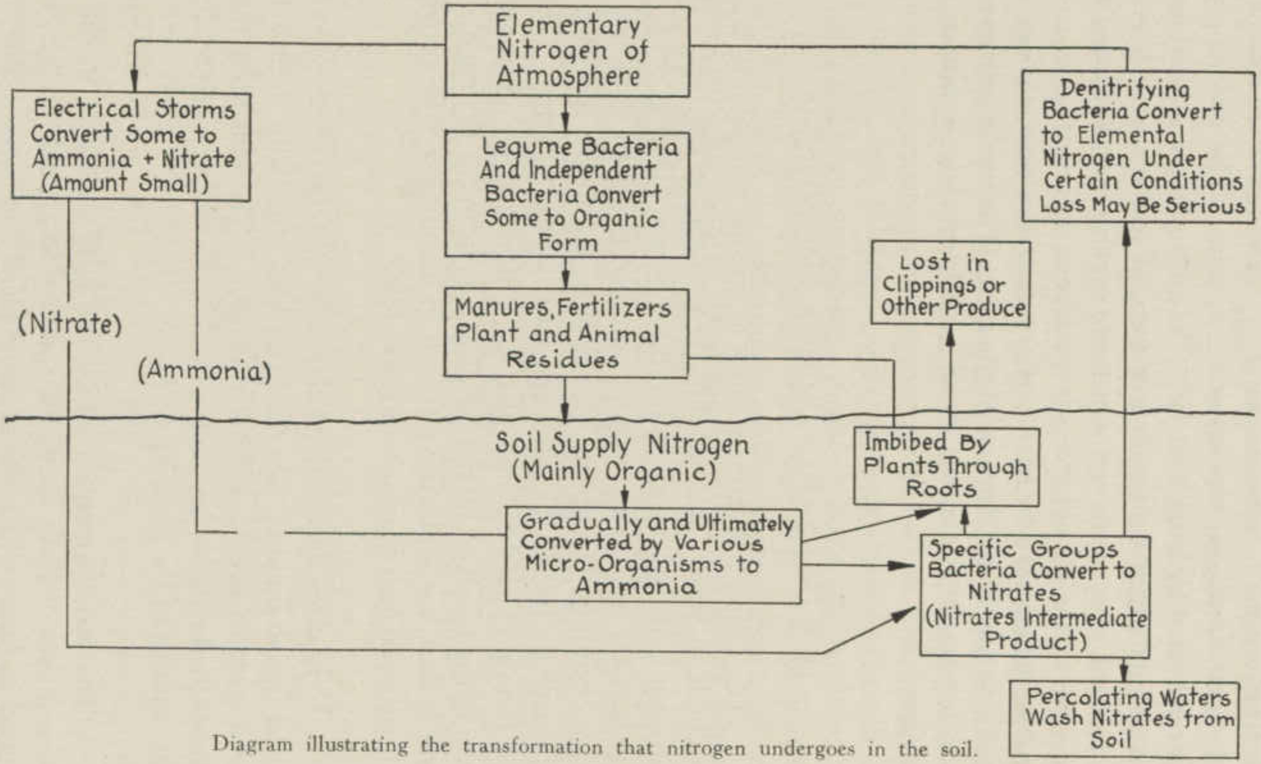


Diagram illustrating the transformation that nitrogen undergoes in the soil.

is lost in the drainage water. This process repeats itself each season but some loss occurs constantly. A part of this is replenished by air nitrogen washed down in rains and as a result of the activity of certain groups of soil organisms. When legumes (clover, beans, peas, etc.) can be grown frequently, the soil supply can be maintained because the minute bacteria contained in the root nodules draw upon the inexhaustible supply of the air and convert it into forms which the plant can utilize. Since clover is discouraged on golf courses, this means of gathering nitrogen is not available and the soil supply must be maintained by resorting to the use of fertilizers.

Factors Affecting Decomposition of Humus

These processes of decay with the resulting formation of available nitrogen in the form of nitrate, do not take place at all times. In winter it practically ceases, and during cool spells or when the soil is quite dry, the rate may diminish to a point where the growing plant fails to obtain an adequate supply of nitrogen. The bacteria responsible for decay resemble plants in that they also require a favorable environment to enable them to perform their work. They work best when the temperature is in the neighborhood of 70 to 90 degrees fahrenheit. Below or above this their activity diminishes until it ceases. These micro-organisms require water, and free aeration of the soil to supply needed oxygen. The presence of a base in the soil, such as lime, to neutralize the acids they produce, also promotes more rapid decomposition.

Attention has already been called to the factors which promote the accumulation of humus. They are exactly opposite to those which produce decay and liberation of nitrogen. Decomposition must take place if normal plant growth is to continue, so it is necessary to maintain an adequate supply of organic matter in the soil. This is not so difficult as it might first seem.

Humus Helps Soil Withstand Drought and Holds Plant Food

The amount of water humus can hold is large and may exceed 100 per cent. However, much of this water is unavailable. Plants growing in peat (almost entirely humus) often wilt even though peat still contains about 50 per cent of water. Yet it is a well known fact that soils well supplied with humus resist drought better than soils low in humus. The difference is probably not so much in the greater amount of water held as in that the humus soil absorbs a large amount of water temporarily during a heavy rain and then lets it work more slowly down into the soil. Thus the water is kept within reach of the plant roots for a longer time.

Humus is also able to absorb plant food materials such as ammonia, phosphoric acid and potash. Thus it tends to reduce the danger of loss from leaching.

Humus Modifies Soil Texture

The texture of sand and clay soils is materially modified by humus. It acts as a weak cement holding the particles of soil together, and serves both to bind the coarse grained sandy soils and by forming aggregates of the finest particles to make the clay soils more open.

Methods of Increasing Humus in Soil

While turf soils need humus, its use is sometimes overdone. The amounts of humus formed from turf roots is considerable. Throughout the growing season as new roots develop, the older ones die and add organic matter to the soil. If established turf is encouraged to make a consistent growth the organic matter will take care of itself on most soils. It is only on the heavy clay and light sandy soils that organic matter presents a real problem, and this is best solved in connection with soil preparation prior to seeding.

Established greens receive frequent top-dressings of material containing considerable organic matter. This practice provides ample humus. In fact many greens probably contain more than is necessary, and this humus, together with the excellent moisture conditions, makes worms troublesome. The excellent results produced by top-dressings high in organic matter may be partially due to the large nitrogen requirements on greens. Nitrogen is constantly removed in clippings and suffers further loss by leaching. These losses must be replenished. Only enough organic matter should be used in top-dressing mixtures to produce the desired texture and additional plant food supplied by the use of fertilizers.

New greens should receive only enough manure or other humus material to give the desired texture and resilience. Yet the same result can often be obtained by varying the proportion of sand or clay. Here again needed plant food can be added in more concentrated form. Imbedding layers of manure below the surface *serves no useful purpose*. It harbors worms and places the plant food beyond reach of the short grass roots. Such practice does not encourage deeper root development.

On most fairways the best way to insure sufficient organic matter is to encourage growth of a dense heavy turf. This is accomplished by providing adequate drainage, sufficient plant food and in some instances water should be provided during periods of dry weather.

Light sandy soils present a real problem and may require top-dressing with a heavier soil containing an abundance of humus. This not only adds humus but the finer soil particles as well.

New fairways often require organic matter, especially if the soil is a heavy clay or sand. Manure is often used to good advantage when it can be obtained at a reasonable price. Green manure crops plowed under some time before seeding add considerable organic matter. One of the legumes—clover, cow peas, soybeans, etc.—should be used. Acid tolerant legumes are best if the soil is acid. They not only supply organic matter but nitrogen as well, which is gathered from the air. The seed should be inoculated before seeding to insure the presence of the bacteria which gather the nitrogen. Good cultures are easily obtained. Since legumes usually respond to phosphate fertilizers it is generally well to apply 250 to 300 pounds of acid phosphate. If a combination seeder and fertilizer drill is used it can be applied simultaneous with the seeding. The phosphate serves later to stimulate root development of the young grass seedling.

CHAPTER V

Soil Composition and How Plant Food Becomes Available

Soils differ greatly in their power to sustain turf growth partly as a result of plant food deficiencies. Certain soil types are notoriously high in some elements and low in others. Some are low in all essential plant food elements. Naturally soils which have been heavily cropped need more fertilizer than those which have been carefully handled and frequently manured. Black soils, while often superior to the light colored soils may have been so badly depleted of plant food that new seedings fail to produce desirable turf. Had deficiencies been recognized prior to seeding, time and money could have been saved and good turf obtained.

Soil Deficiencies Usually Confined to Three Plant Food Elements

Turf depends upon the soil to supply seven of the ten necessary plant food elements. All soils contain abundant supplies of four of these, so only one or more of the three elements, nitrogen, phosphorus and potassium, need be added in fertilizers. These are usually referred to as ammonia, phosphoric acid and potash.

Total Amount of Plant Food Elements in Various Soils

Soils consist of a mixture of humus or organic matter and solid mineral particles. Practically all of the nitrogen exists in the humus, and the elements phosphorus and potassium occur principally in the mineral portion, although the humus also contains limited amounts of both. Sand particles consist of silica mainly, and hence are low in plant food elements. It is in the silt and clay particles that phosphorus and potassium are most abundant.

Peats and mucks, consisting mainly of partially decayed plant residues, are high in nitrogen and often low in phosphorus and potassium. Sand usually contains very little humus and the finer mineral particles, and is low in all plant food elements, especially if derived from sandstone, but may contain sufficient potash if derived from granite rocks. Sandy loams, loams, and clays vary in their humus content and if low in humus are low in available nitrogen. They are usually well supplied with potassium, but may need additional phosphorus, particularly on new seedings.

The plow layer of an acre of good loam soil contains roughly about 2,500 to 3,500 pounds nitrogen, 1,000 to 1,400 pounds phosphorus and about 40,000 pounds potassium. Sands usually contain less than one-third to one-half as much nitrogen and phosphorus, and may be low in potassium. While peats and mucks may contain eight to ten times as much nitrogen, they are low in phosphorus and potassium.

The roots of closely clipped turf rarely extend beyond several inches and obtain most of their plant food from this shallow layer of soil.

Even the sandy soils contain sufficient total plant food to support growth over a number of years, if the turf could draw upon the entire supply, but only materials dissolved in the soil water are available, and frequently solution from the insoluble soil materials does not occur fast enough to satisfy the demands of the turf. Actively growing turf requires a uniform and continuous supply of soluble food, and unless such a supply is assured, poor growth results. In a general way, soils highly charged with plant food yield soluble material more rapidly than those of lower content. Solution takes place more rapidly in sandy soils than heavy soils, so it would be folly to attempt to raise the total plant food content of sands to equal that of heavy soils.

Amounts of Soluble Plant Food in Soil Solution

During the growing season, only small amounts of dissolved plant food are found in the soil under turf grasses. These amounts are so small that very exact chemical methods are required for their determination. Soluble nitrogen is rarely found. As soon as solution occurs, the nitrogen is taken up by the turf roots. A million pounds of soil water, under these conditions, rarely contains more than several pounds of soluble nitrogen. In fallow soil as much as 30 to 50 pounds or more of soluble nitrogen may be present. The dissolved potassium is never very high, and the soil water may contain less than a pound of soluble phosphorus. These amounts are never sufficient to maintain growth over extended periods. Conditions favoring rapid replenishment of the soil solution, as the turf roots imbibe food must be maintained if normal growth is to take place.

How Plant Food Becomes Soluble

Soluble nitrogen results from decay or decomposition of the humus or organic matter of the soil, by soil bacteria and fungi. The nitrogen existing even in soluble organic matter is not directly available to the plant, but must be resolved into simple forms. A host of bacteria and fungi attack the complicated organic compounds and release nitrogen in the form of ammonia. Then specific groups of organisms rapidly convert the ammonia nitrogen into nitrate nitrogen. This is the form preferred by most plants. During decay the carbon is converted into carbon dioxide, or carbonic acid, and any mineral plant food elements contained in the organic matter are released in forms available to the plant. Phosphorus and potassium are also dissolved by the soil water from the insoluble mineral soil constituents.

Factors Affecting Rate of Solution

Soils never contain sufficient soluble nitrogen to satisfy the turfs throughout an entire season, but the organisms which bring about the decay of humus inhabit all soils. Dark color in a soil is usually an indication of the presence of humus, and large nitrogen content. Yet if black soils have been under crop for a long period without additions of manure or green manure crops, soluble nitrogen may not be produced in amounts sufficient to satisfy the needs of the turf. The residual humus resists further decay and is of little value except as it improves the physical condition and water-holding capacity of the soil. This fact is frequently overlooked on new seedings. An established turf increases the humus content of the soil. As new roots are formed the old ones die and upon decay their nitrogen is again converted into forms suitable for use. It is necessary only to supply sufficient nitrogen to balance the losses due to leaching and removal of clippings.

All well drained soils contain hosts of bacteria which multiply rapidly if conditions permit. The organisms which liberate available nitrogen require oxygen and water. They are most active when temperatures range from 70 to 90 degrees Fahrenheit, and in fact cease operations during the cold winter weather. Activity begins again with the advent of warmer weather in the spring. This is Nature's method of conserving nitrogen during the period when plant are dormant, because nitrate nitrogen leaches from the soil if not taken up by the plant roots. If the soil is too acid the activity of the organisms which convert ammonia to nitrate nitrogen is greatly retarded, and in extreme cases ceases entirely.

Phosphorus exists in the soil as lime, iron or aluminum phosphate. The two latter predominate in acid soils. The rate of solution depends upon soil reaction, state of division of the phosphate, and presence of carbonic acid. Acid soils do not yield phosphorus as readily as non-acid soils because iron and aluminum phosphates are less soluble than lime phosphate. For this reason phosphate applications for new seedings should be heavier on acid soils than on non-acid soils. The finer the individual particles containing the phosphorus the more rapid does solution occur because of the larger surfaces exposed. The principle is universal. Granulated sugar dissolves more rapidly than lump sugar for the same reason. When soluble phosphates are added to the soil they are precipitated in a very fine state of division. This permits rapid solution when the demand for phosphorus is great.

Plant roots excrete carbonic acid, and it is also formed during decay of soil organic matter. Its presence in the soil water increases the rate of solution of phosphorus.

The soil supply of potassium exists in complicated minerals such as feldspar and mica. The soil water in contact with these minerals gradually dissolves potassium, and if charged with carbonic acid solution takes place more rapidly. Some of the minerals hold the potassium so tenaciously that solution is extremely slow. Finely divided minerals containing potash yield soluble potassium more rapidly than if coarse. When heavy soils, containing large amounts of potassium respond to additions of potash fertilizers it is because the existing potassium is held in combinations which resist the solvent action of the soil water. When soluble potassium fertilizers are added to the soil the fine clay particles retain the potassium, and yield it to the soil water when the plant takes up the potassium already in solution.

What Constitutes a Fertile Soil?

Productive soils are more than so much dirt. They are manufacturing plants, teeming with microscopic life. Raw plant food materials are easily converted into forms which the turf can utilize. The fertile soil is an efficient factory where a uniform and constant supply of plant food is produced to meet the demands of the growing turf. It is capable of speeding up to take care of any abnormal demands. To be effective it must be well drained, and yet supplied with moisture to meet the demands of plants and bacteria. It must be well granulated and friable so plant roots and bacteria obtain needed oxygen. This condition permits rapid extension of the roots which reach out in their search for food and water. Some readily decomposable organic matter is required by the soil organisms, as a source of plant food and energy. The residual humus improves soil structure and increases the water holding capacity of the soil. After good turf is established the old roots as they decay increase the soil supply of organic matter. While acid soils are desirable on golf courses to discourage clover and weeds it must be recognized that too much acidity may reduce the efficiency of some soil processes. If the above conditions have been fulfilled, and climatic conditions are favorable, good turf growth depends upon the presence of sufficient plant food. If not already present fertilizers can be used will full assurance that marked benefits will result.

CHAPTER VI

The Nature of Soil Acidity and Effect of Fertilizer Materials on Soil Reaction

Soils in regions of moderate to heavy rainfall gradually tend to become acid in character. Rain water as it passes down through the soil slowly removes basic or alkaline and leaves an acid soil residue. The rate of change varies and depends principally upon the amount of rainfall and character of the material from which the soil was derived. In regions of limited rainfall soils rarely become acid. Very little water percolates down through the soil, and soluble alkaline materials are not washed out. In fact these materials accumulate at the surface due to upward movement of water and evaporation at the soil surface.

Most of the golf courses in the United States are located in areas where acid soils develop. Since clover and weeds can be controlled by regulating soil acidity, a clear understanding of how it is produced and measured is of vital importance in turf maintenance on golf courses. During recent years soil chemists have obtained a clearer picture of soil acidity and devised simple, accurate methods for its determination.

How Soils Become Acid

The chemist groups chemical compounds into three classes. They may be acids, bases or salts. Acids and bases have opposite chemical properties, and may be commonly distinguished by their different behaviour towards an indicator such as litmus. An acid turns blue litmus red, and a base turns the red paper blue. Muriatic and sulphuric acids are common acids of commerce. Vinegar contains acetic acid. Lye and quick lime are basic substances.

When an acid and base are allowed to react together, they are said to neutralize each other. Each loses its distinctive properties and a salt is produced. Generally salts are neutral substances. However, some have acid properties and others are basic. Soils consist of complex and simpler organic and mineral salts. These may be acidic, basic or neutral in character and the soil reaction depends upon which predominates.

A simple example probably best explains how soils become acid. If a fragment of granite rock, reduced to a fine powder, is placed in a vessel and agitated with pure water for a time, the water will change in reaction, becoming basic. It turns red litmus blue. The granite powder is no longer neutral but acid in character. This same phenomenon takes place in the soil as water percolates through it. Basic material passes into solution and is washed out leaving an insoluble acid residue.

If the acid granite powder is suspended in water containing a little salt, the water soon becomes acid, and the powder loses its acidic properties. The basic part of the salt has been taken up by the insoluble rock powder and soluble acid released. This is what takes place when ammonium sulphate or potash salts are applied to the soil.

The soil contains two kinds of acids, insoluble and soluble, sometimes referred to as potential and active acidity. The insoluble or potential acidity is the reservoir from which the soluble or active acidity is produced. It is this latter which controls clover and weeds. Soils containing large amounts of insoluble acid are capable of yielding much soluble active acid.

Methods of Determining Soil Acidity

A large number of methods for the determination of soil acidity have been devised. Most of the older methods measure the insoluble or potential acidity, and serve as criteria of the amount of lime required to neutralize the acids. The newer methods determine the active acidity and measure its intensity. The use of these methods enable the greenkeeper to follow the soil reaction and eventually obtain a condition unfavorable to clovers.

The term Ph is arbitrarily used to express active acidity. A neutral substance, that is one which is neither acidic or basic, has a Ph of 7. Figures less than 7 represent increasing degrees of acidity, and those greater than 7 increasing degrees of basicity. A soil of Ph 6 is ten times more acid than one of 7, and one of Ph 5, one hundred times. Thus it is evident that small differences in Ph represent large differences in soil reaction. Most plants grow best in the range of Ph 6 to 8.

When extreme accuracy is demanded Ph determinations must be made in the laboratory with elaborate apparatus. Portable sets now on the market are sufficiently accurate for field use, and can be employed as a guide in attempts to modify soil reaction. In principle the method depends upon the fact that certain color indicators develop characteristic colors at different Ph values. In operation the soil is allowed to come in contact with the proper indicator and the color developed is compared with those on an accompanying chart. Ordinary water should never be used in making the test. It often contains sufficient lime to give erroneous results. Rain water serves as the best substitute for distilled water. Obviously the indicator solution must remain in intimate contact with the soil sufficiently long to permit maximum development of color.

Effect of Fertilizers on Soil Reaction

The different fertilizer materials affect soil reaction. They either increase or decrease soil acidity. Soils have a remarkable power of resisting change so it is difficult to demonstrate the effect of single applications. It is only when applications are continued over an extended period that marked changes occur. Sandy soils are more easily changed than loam and clay soils.

The continued use of ammonium sulphate increases soil acidity, but the effect is delayed if the soil contains particles of limestone. The ammonium sulphate reacts with the limestone fragments forming calcium sulphate which is washed out in the drainage water. While this hastens the removal of lime carbonate, acidity cannot develop until removal is complete. When the limestone disappears, or if originally absent from the soil, calcium or other basic substances contained in the mineral soil particles, enter into combination with the sulphate. The resulting soluble compounds disappear in the drainage waters, and an acid residue eventually remains. Acidity develops most rapidly in soils already near the neutral point.

The ammonia taken up by the soil particles is gradually released and converted into nitric acid by the nitrifying bacteria of the soil, and combines with more calcium. The resulting compound is either taken up by the plants or leached from the soil.

Ammonium phosphate also tends to make the soil more acid but is not as effective as ammonium sulphate. Acid soils always contain iron and aluminum oxides, materials which have but little effect upon soil reaction. So long as either exists in the soil the phosphoric acid combines with them forming insoluble iron and aluminum phosphates. Consequently, lime or other basic material is not leached from the soil. The nitric acid formed by the action of the nitrifying bacteria on the ammonia however, is capable of removing basic material from the soil, and it is this action that increases acidity

Sodium nitrate tends to make the soil less acid. The sodium is basic in character and is left to neutralize soil acids when the nitrate portion is taken up by the plant.

The effect of organic nitrogenous fertilizers depends upon the amount and character of the mineral materials they contain.

Acid phosphate decreases soil acidity. When applied to an acid soil insoluble iron and aluminum phosphate are produced and its lime released. The term acid phosphate is a misnomer so far as effect on soil reaction is concerned. Bone meal has the same effect only more marked because it contains more lime.

Potash fertilizers increase soil acidity. The potassium is taken up and held by the soil particles, and an acid residue is left in the soil solution.

Extreme Acidity Associated With Low Fertility

Very acid soils are often low in fertility. Extreme acidity retards conversion of soil nitrogen to nitrates by depressing the activity of the soil nitrifying bacteria and other beneficial soil bacteria. Nitrate nitrogen is the form preferred by most plants. The growth of molds and fungi is often favored by acidity. These organisms require nitrogen and may deprive the turf of its limited supply. In acid soils phosphoric acid is held as insoluble iron and aluminum phosphate, and solution may not occur rapidly enough to satisfy the entire demand of the turf for phosphoric acid. Hence it is probably unwise to create greater acidity than is required to discourage clover and weeds.

Acidity at Which Clover Fails

Agricultural workers have investigated the effect of acidity on the growth of clover. It makes its best growth at Ph 6 to 8. At Ph 5 growth usually ceases. At Ph 5.5 it is very doubtful if clovers can survive, especially if the grasses are growing vigorously, and there is probably no advantage in attempting to increase soil acidity beyond that point.

The ball is held up best in turf composed entirely of grasses. Poor "lies" are obtained on turf containing clover. Hence soil conditions favorable to the growth of grasses but unfavorable to clover, must be maintained. Regulating soil reaction helps discourage clover. Sufficient acidity is most easily obtained in regions where soils are normally slightly acid, but the persistent use of acid producing fertilizers will eventually prove effective even on non-acid soils. When a point is once reached where clovers fail, the soil should be maintained at that reaction, so as to make other conditions for growth as favorable as possible.

CHAPTER VII

Lime in Sand, Soil or Water Often Overcomes Acidic Properties of Sulphate of Ammonia

Clovers are lime-loving plants and do not grow well on acid soils. This fact makes it possible to rid greens of clover, because the best grasses appear to thrive on soils sufficiently acid to discourage clover. Acid producing fertilizers, such as sulphate of ammonia, are commonly used on greens to create conditions unfavorable to clovers and weeds. Yet in many instances this treatment has not been effective.

Soils Become Acid Slowly

Soil acidity develops slowly. Soils have a remarkable power of resisting change and hence acidity is slow in asserting itself. Loam and clay soils possess this power of resistance to a marked degree and develop acidity more slowly than sandy soils. One application of sulphate of ammonia is not sufficient to create the conditions desired, and it is only when repeated applications are made that a neutral or alkaline soil develops the desired acidity.

Lime Often Added to Greens in Sand, Soil or Water

In many instances, particularly in limestone regions, the sand and soil used in top-dressing mixtures contain sufficient lime carbonate to entirely overcome the acid producing power of the small amount of sulphate of ammonia used. The local water supply in such regions may contain sufficient lime to produce the same result. Since it is not possible to increase the rate of application of sulphate of ammonia without danger of injuring the turf, care must be used in selecting sand and soil for top-dressing use, if acid soils are desired.

Casual inspection of a sand used in top-dressing mixtures, showed the presence of lime rock particles. This sand came from a pit which supplies large quantities of sand to the Chicago district. Upon analysis it was found to contain 20 per cent lime carbonate. Each time a green received 500 pounds of this sand in the top-dressing mixture it was equivalent to applying 100 pounds of crushed agricultural limestone. The green chairman and greenkeeper on this particular course would commit murder rather than scatter a 100 pound bag of crushed limestone on the green. Yet the greens had received repeated applications of lime unbeknown to either of them. The same condition obtains on many courses in the Chicago district and undoubtedly in other districts also. Soils in limestone sections often contain 2-5 per cent lime carbonate and here again the greens receive a generous dose of lime whenever such soil is used in the top-dressing. If 2000 to 3000 pounds of this soil are applied to a green it receives about 100 pounds of lime carbonate which is capable of counteracting soil acids. At least 65 pounds of sulphate of ammonia must be applied for each 100 pounds of lime carbonate simply to overcome the alkaline properties of the lime. Additional sulphate must be applied to create acidity. Such heavy applications are never made, and as a result greens do not become acid even though sulphate of ammonia is used repeatedly. If acidity is desired any sand or soil used in top-dressing mixtures must be tested for lime carbonate.

In limestone regions it is often difficult to find local supplies of sand free from objectionable lime. If acid soils are desired it may be necessary to obtain sand from other areas. Acid soils, however, are often encountered even in limestone areas.

Rough Test for Lime in Sand and Soil

The presence of lime carbonate in sand or soil can be easily detected. Whenever an acid is poured onto lime carbonate a gas called carbon dioxide is liberated. The liquid froths and the gas escapes into the air. To test a sample of sand or soil procure some muriatic acid from a nearby drug store and pour it on the suspected material. If lime carbonate is present carbon dioxide gas will be liberated and escape. The amount of gas liberated serves as a rough measure of the amount of lime carbonate present. Often a few tiny bubbles emerge at the surface even though the sand or soil does not contain lime carbonate. This is escaping air which was trapped by the liquid. In case of doubt hold the dish to the ear. If a hissing sound is audible the material undoubtedly contains some lime carbonate.

Accurate determinations of the amount of lime carbonate present can be obtained by submitting samples to a chemist, or the State Agricultural college. Most state colleges test samples without charge. The samples should be carefully labelled and forwarded in good containers, together with a precise statement of what is wanted.

Very little can be done with water supplies containing lime, so far as removal of the objectionable lime carbonate is concerned. No more water should be used than is absolutely required by the turf. Larger amounts simply increase the quantity of lime carbonate in the soil, and makes the development of acidity more difficult.

Number 10 at the North Hills Country Club,
St. Louis, Mo.

CHAPTER VIII

Essential Plant Food Elements and How Plants Feed

In some respects the plant is a more remarkable mechanism than the animal. Its power to utilize simple chemical compounds, and convert them into complex organic food materials is unique. The animal cannot maintain its life processes by the use of simple chemical materials, but lives at the expense of food materials originally manufactured by the plant, consuming these directly, or the flesh of other animals that originally satisfied their food requirements by the consumption of plant materials.

While the plant is a manufacturing establishment capable of producing complex materials, the individual plant units or cells resemble the cells of animals in that they require these manufactured foods for their existence. Thus the plant is a factory capable of producing complex organic food materials to supply the demands of its various parts. An understanding of the mechanism of plant growth is essential, and is the foundation upon which plant feeding rests.

Our knowledge regarding essential plant food elements, and their utilization in the plant has been accumulated within the last eighty years. Prior to that time erroneous theories existed because they were not properly tested by experiment. The painstaking work of chemists and plant physiologists is responsible for our present information. While many problems still await solution, the broad principles now known are sufficient for practical purposes.

Plant Food Manufactured in Leaf

It is in the leaf that the complex organic food materials are manufactured by the process called photosynthesis. The green color of the leaf is due to the presence of a substance called chlorophyll. In its presence energy rays from the sun convert the raw materials, water and carbon dioxide into a sugar which is water soluble. The sugar is used either for the building of more complex materials, as a source of energy, or is stored for future use. When stored it is generally converted into starch which is insoluble. During photosynthesis oxygen is released as a by-product of the reaction, and escapes into the atmosphere.

The raw materials carbon dioxide and water are obtained from different sources. Water imbibed from the soil, enters the roots and passes up to the leaves through the stems. The atmosphere always contains small quantities of carbon dioxide gas. This enters the leaf through small openings, generally most abundant on the under side of the leaf, and dissolves in the water contained in the leaf.

Since the products of photosynthesis are so essential to the plant, and are produced only in the leaf, sufficient leaf surface must be maintained to insure their production in ample amounts. This is most important in the fall when reserves must be built up, and stored in the turf roots, for use in the spring while new leaves are being formed. Raising the mower blades, but not enough to impair the playing condition of the turf, increases the leaf area and insures increased sugar production. Unless closely cut, vegetatively planted greens develop a decided and objectionable nap, so great care must be exercised in attempting to build up reserves by permitting longer fall growth.

Sometimes all efforts to obtain turf on heavily wooded areas fail. Even varieties of grass supposedly adapted to shade refuse to produce turf. The dense leaf growth in the trees effectively absorbs all the active light rays and the leaves of the grass below fail to receive sufficient energy rays to permit the production of much needed food.

Plants Require Oxygen

All forms of life require energy. Without it they are as helpless as the engine without fuel. Combustion of fuel supplies the energy which operates the engine. If oxygen is available plants and animals can release and utilize the energy stored in the products of photosynthesis. The animal obtains oxygen by breathing. The oxygen reacts with the carbonaceous material, sugar, releases energy and resolves the complex material utimately into the simple substances, water and carbon dioxide, which are exhaled. These are the ultimate products produced when sugar burns. The same type of action takes place in the plant. The aerial portion of the plant can obtain an unlimited supply of oxygen from the atmosphere, but the roots also demand oxygen. This must be obtained from the air existing in the interstices between the soil particles. Most of the beneficial soil bacteria also require free oxygen. The air capacity of the soil is dependent upon its physical condition. Good turf cannot be expected on tight or water-logged soils, because these fail to provide the roots and bacteria with needed oxygen. Tight soils can be improved by the liberal use of organic matter prior to seeding, and water-logged soils obviously need drainage.

Carbon Cycle in Nature

The cycle of carbon is an example of the remarkable balance provided by nature. It is released as carbon dioxide gas when any living organism obtains energy from complex carbonaceous compounds. Green plants absorb the carbon dioxide gas and under the influence of light build it into complex substances, releasing oxygen which escapes into the atmosphere. Plants accumulate and store these complex materials, and hence absorb more carbon dioxide gas than is released in their respiratory processes. Animals depend upon plants for their carbonaceous food requirements. During respiration oxygen is taken up and carbon dioxide exhaled, which accumulates unless used by plants. If confined in a closed glass box an animal finally dies. Death occurs when the atmosphere becomes sufficiently polluted with carbon dioxide. In the presence of light a plant placed in this vessel purifies the air. The carbon dioxide is taken up and converted into sugar and oxygen is released. Eventually animal life is again possible. Under natural conditions this constant cycle maintains itself, and as a result the atmosphere contains a relative constant though small amount of carbon dioxide. Some of the carbon in our bodies may have been a component part of some plant or animal many thousands of years ago.

Essential Mineral Plant Food Elements

Besides the carbon, hydrogen and oxygen used to build sugar, and obtained from carbon dioxide and, water turf grasses in common with all other plants, require seven other chemical elements to produce normal growth. These are nitrogen, sulphur, phosphorus, potassium, iron, magnesium and calcium.

Nitrogen, sulphur and phosphorus, together with some of the products of photosynthesis are utilized in building proteins, an exceedingly complex group of substances. The proteins are the essential constituent of the living portion of the individual plant cells. The mechanism of their formation is not clearly understood. Apparently organic acids are produced during their formation. The plant uses calcium to neutralize these acids and make them insoluble. The presence of exceedingly small quantities of iron are essential to the formation of the green coloring matter (chlorophyll) in the leaf. If absent, chlorophyll is not produced. Magnesium also appears to be an essential constituent of chlorophyll. It is also found as an essential constituent of complex substances in the seed. Potassium appears to affect production of carbohydrates, sugar, starch and cellulose. The last named is the main constituent of the cell walls. It gives the plant form and rigidity.

All seven mineral elements are obtained from the soil. While the air contains enormous quantities of elemental nitrogen most plants cannot draw upon this inexhaustible supply. Clovers and other legumes can however utilize atmospheric nitrogen. The encroachment of clover in poor fairways is often due to this fact. The impoverished soil does not supply the grasses with sufficient nitrogen to permit active growth. The clover survives and spreads because it can get needed nitrogen from the air. Thus clover control depends upon modifying soil reaction, and supplying sufficient nitrogen to encourage the growth of desirable grasses.

The growing turf obtains its supply of essential plant food elements from the soil. Plants can only utilize materials which are dissolved in the soil water. Dissolved materials are capable of passing through the walls of the root and thus enter the plant. The soil water at any one time never contains enough plant food to satisfy the entire demand of the growing turf. Thus the rate at which the soil water is replenished with soluble plant food from the insoluble soil materials distinguishes a fertile from an infertile soil.

Approximate Composition of Turf Grasses

Freshly cut grass clippings lose from 60 to 70 per cent of their weight on drying. Thus they contain from 60 to 70 per cent water and 30 to 40 per cent dry matter.

If the dry grass is burned the ash remaining does not exceed five per cent. The volatile matter consists principally of carbon, hydrogen and oxygen. However, nitrogen and much of the sulphur also escape during burning. The mineral constituents constitute the smallest portion of the plant material.

CHAPTER IX

Elements and Characteristics of Various Groups of Fertilizer Materials

The rational use of fertilizers must be based upon a knowledge of the functions of the plant food elements—particularly nitrogen, phosphoric acid and potash, and the effect of these on clover and weeds must be considered also. These secondary effects, due either to the plant food elements themselves or some other non-essential constituent of the raw fertilizer material deserves particular attention. It may require careful management and considerable time to overcome the bad effects produced by the injudicious use of unsuitable fertilizers.

Functions of Specific Plant Food Elements

Nitrogen is the most important plant food element in turf maintenance, and is most largely used by turf grasses. It is responsible for dark green color and active vegetable growth. Deficiencies of nitrogen are easily recognized. If the turf is thin, light green in color and not growing actively, the need for additional nitrogen is unmistakable, provided other conditions such as good drainage, proper physical soil conditions, favorable climate and sufficient moisture exist. Abundant clover on fairways points to a *limited nitrogen supply*. Clover is a legume and by virtue of the nitrogen fixing bacteria contained in the nodules or sacs present on the roots can utilize atmospheric nitrogen. Turf grasses cannot draw upon this inexhaustible supply of nitrogen, but must depend upon the soil to satisfy its demand. Consequently the clover satisfies its nitrogen needs, becomes more aggressive, and may predominate in the turf.

The large amounts of nitrogen removed from greens in clippings is rarely appreciated. Analyses made last year showed the nitrogen content of dry clippings vary from 1½ to 3 per cent. The higher nitrogen content was from turf fertilized with quick acting nitrogenous fertilizers, yet the average green receives more nitrogen than was applied to this turf. Three hundred pounds of clippings removed from a green contain about one hundred pounds of dry matter. If the nitrogen content is only two per cent, two pounds of nitrogen are removed. Since nitrogen constitutes one-fifth the weight of sulphate of ammonium this is equivilent to ten pounds sulphate of ammonium. If the nitrogen content is three per cent, three pounds of nitrogen, equivalent to fifteen pounds sulphate of ammonia are removed. These amounts are exclusive of any losses due to leaching in the drainage water. Is it any wonder that greens require constant applications of nitrogenous fertilizers?

Turf grasses require only limited amounts of phosphoric acid. It is an essential constituent of the living protein or protoplasm of the plant cell. Root development is stimulated by the presence of abundant phosphoric acid, so it is essential to provide this plant food element on new seedings to insure rapid root development and obtain a uniform stand of turf. Unlike nitrogen, the need for phosphoric acid is not easily recognized, but in established turf it is rarely necessary to provide very much phosphoric acid in fertilizers. On green apparently the top-dressing mixture contains sufficient phosphoric acid to satisfy the demands of the turf.

In the presence of abundant phosphoric acid, particularly if the source is bone meal or acid phosphate, the growth of clover may be greatly encouraged. The extensive use of fertilizers high in phosphoric acid are unnecessary on established turf and may defeat any program designed to rid the turf of clover.

Potash is essential to the formation of a class of substances called carbohydrates. There are three groups as regular constituents of plants namely, starch, sugar and cellulose. Sugars are built in the green leaves under the influence of active rays of the sun from simple substances. The sugars are one of the raw materials from which other complex organic compounds are built in the plant. Cellulose is the material which makes up the cell walls and hence gives form to the plant. The wood of trees and shrubs is almost entirely cellulose.

Clovers require abundant potash. Hence repeated applications of potash may result in increasing the amount of clover in turf. Most soils are supplied with sufficient potash to maintain normal growth of turf grasses, and it is doubtful if benefits from its use will be obtained except possibly on light sandy soils, peats and mucks. Because of the danger of encouraging clover, potash fertilizers should be used sparingly and only when soil conditions indicate its possible need.

Sources of Plant Food

There are a variety of plant food materials which can be used as fertilizers. Some contain only one plant food element, while others may supply two or more. Their value and efficiency depend upon the amount, kind and availability of the plant food they contain. The choice is also affected by local soil conditions. On sandy soils some materials are rapidly lost in the drainage waters, others are slower acting and provide for longer feeding.

When mixed fertilizers are purchased the plant food constituents of necessity cost more than where the various raw materials are procured. The manufacturer must be reimbursed for the cost of mixing. The value of mixed fertilizers depend primarily upon the percentage of plant food contained. These are expressed in figures which represent the percentage composition of nitrogen, phosphoric acid and potash, and are expressed in that order. Thus a 6-3-2 contains six per cent nitrogen, three per cent phosphoric acid and two per cent potash. Nitrogen is usually reported both as nitrogen and its equivalent in terms of ammonia. Thus sulphate of ammonia contains approximately twenty per cent nitrogen or twenty-five per cent ammonia.. These can be converted into one another by using the factors .82 or 1.215. To convert nitrogen into ammonia multiply the percentage of nitrogen by 1.215 and if expressed as ammonia multiply by .82 to obtain the percentage of nitrogen.

Ordinarily best results on established turf will be obtained by selecting mixtures of higher nitrogen content and lower phosphoric acid and potash content such as 6-3-2, 12-6-4 etc. On new fairway seeding a larger proportion of phosphoric acid usually produces better results.

There are three different classes of nitrogen containing materials depending upon the kind of nitrogen, namely, organic, ammonia and nitrate nitrogen. Eventually any form of nitrogen is converted to nitrate nitrogen when applied to the soil. The mechanism of this process was explained in a previous chapter.

Nitrogen is the only one of the three plant food elements subject to loss. Any nitrogen existing as nitrates in the soil, or converted to this form by soil processes, dissolves in the soil water and is not retained by any soil constituent. Consequently it is lost in the drainage water unless taken up by the plant. Nitrogen is the most expensive plant food element so the danger of loss must be constantly considered, especially since it is the most critical element in turf culture.

The general characteristic of the different classes of nitrogenous materials deserves special consideration.

Organic Nitrogen

Materials containing organic nitrogen are derived from animal or plant residues. Some of the common materials are the various manures either fresh or dried, bone meal, cottonseed meal, soy bean meal, dried blood, tankage, fish scrap, Milorganite, etc. They vary in their nitrogen content and in the rate at which the nitrogen becomes available to the plant.

Most of the nitrogen contained in these materials is not soluble in water, and all of it must be converted into other forms before the plant can use it. When added to the soil the bacteria decompose the organic matter, and liberate nitrogen in the form of ammonia. This is subsequently converted to nitrate nitrogen by a specific group of soil bacteria. The rate at which decay takes place determines how rapid results will be obtained from their use.

The advantage of organic fertilizers accrue from the fact that decay takes place over a considerable period and thus a uniform and continuous supply of available nitrogen is assured. Such a supply is essential if uniform and continued growth of turf is to be obtained.

There is less danger of burning or injuring turf with organic forms of nitrogen than any other. The different materials differ in this respect. If decay takes place rapidly the danger increases. Dried blood, in particular, is apt to burn because decay is very rapid.

The effect of organic materials on soil reaction depends upon the individual material, particularly the amount of lime or other basic material which they contain. Thus bone meal due to the large amount of lime it contains decreases the acidity of the soil. Analyses of manure show that it contains about four per cent lime, so a ton contains about eighty pounds which is equivalent to about one hundred fifty pounds lime carbonate, (ground lime stone). Dried blood on the other hand contains very little lime and since the nitrogen is converted to nitric acid its use will eventually increase acidity.

Ammonia Nitrogen

The two principal sources of ammonia nitrogen are ammonium sulphate and ammo-phos. The nitrogen in both these materials exists as ammonia. Both are water soluble and quick acting. They must be used with caution on turf because of the danger of burning or scorching the grass.

When applied to the soil the ammonia is taken up and held by the clay particles. This tends to hold the nitrogen temporarily in the shallow surface layer where maximum root development occurs and may explain why ammonium sulphate sometimes serves as a more effective source of nitrogen than nitrate of soda even when applied to give equal amounts of nitrogen. The nitrate nitrogen is not held and may move down into the lower soil layer below the root zone.

Even though ammonia nitrogen is applied to the soil it is converted into nitrate nitrogen by soil bacteria, just the same as the ammonia produced by decay of organic nitrogenous materials.

As is well known both the above materials increase soil acidity and thus their use aids in the control of clover.

Nitrate Nitrogen

The main source of nitrate nitrogen is nitrate of soda, often called Chili saltpeter. Nitrate nitrogen is the form preferred by most plants, but as we have already seen all other forms are converted to nitrate in the soil.

Nitrate nitrogen is water soluble and quick acting. It must be used carefully because of the danger of burning turf grasses.

The general use of nitrate containing fertilizers now on the market is being discouraged on turf grasses. They tend to make the soil less acid and encourage coarse grasses, weeds and clover. Their continuous use also has a bad effect on the physical condition of heavy soils.

Sources of Phosphoric Acid

The commercial sources of phosphoric acid are limited Bone meal, acid phosphate and ammo-phos are the chief materials, although basic slag is extensively used in Europe.

Any of these materials can be used without danger of burning the turf except ammo-phos. Bone meal and basic slag are very slow acting and also contain considerable lime so they unduly encourage clover.

Phosphoric acid is fixed in the soil and hence can be used without danger of loss by leaching.

With the exception of ammo-phos all phosphate fertilizers tend to make the soil less acid due to the liberation of lime, wher added to the soil. The effect is least with acid phosphate. Be cause of the greater availability of the phosphoric acid, it is bet ter to use acid phosphate than bone meal on new seedings.

Sources of Potash

The main source of potash is muriate of potash, derived from the Stassfurth mines in Germany. It is water soluble and liable to burn the turf. Potash fertilizers increase soil acidity, and are not subject to loss by leaching because the clay and humus in the soil hold the potash and gradually release it to the soil solution.

Since potash is the least important of the three plant food elements it need not be further considered.

CHAPTER X

Composition and Properties of Individual Fertilizer Materials

The functions of the individual plant food elements and general characteristics of the larger groups of fertilizer materials were discussed in the previous chapter. The individual materials vary in their plant food content, the rate at which the plant food is made available, and in their secondary effects upon the soil. The more important characteristics of the principal materials deserve consideration because a knowledge of these properties must serve as a guide in the choice of fertilizers for greens and fairways.

ORGANIC NITROGENOUS MATERIALS

MANURE—While barnyard manure varies greatly in composition, good manure has the following average composition:

	Per cent	Pounds per ton
Nitrogen	.5	10
Phosphoric Acid	.3	6
Potash	.6	12
Water	72.0	
Ash	8.3	
Organic Matter	19.7	394

About one-half of the nitrogen and three-quarters of the potash are water soluble. Manure may contain 4.5 per cent of lime, which is equivalent to about ninety pounds per ton.

During composting the non-nitrogenous organic matter (straw, etc.) breaks down, and the availability of the plant food elements is increased. There are some losses of nitrogen, but these can be largely prevented by keeping the pile compact and moist. Composting improves the mechanical condition of the manure, due to the decomposition of the straw, and kills the weed and clover seeds voided by the animal.

So far as plant food is concerned it is often possible to supply these more cheaply from other materials. One of the chief benefits of manure results from the beneficial effect of the organic portion on the physical condition of the soil, and is best secured when the manure can be incorporated with the soil. This is not possible on established fairways.

While manure does not contain large amounts of plant food, applications are usually heavy so that the total amounts of plant food applied may be considerable. A ten-ton application furnishes about 100 pounds nitrogen, 60 pounds phosphoric acid and 120 pounds potash. Poor results from substituted materials are often due to failure to apply sufficient quantities of plant food.

MUSHROOM SOIL—This material is the spent soil from the mushroom beds. Originally it consisted of a mixture of 7-12 parts manure and 1 part soil. The heat developed in the benches results in loss of moisture so the final product usually contains from 35 to 50 per cent moisture. The amount of plant food varies considerably depending on the ratio of manure to soil originally used, the extent of decomposition and the moisture content. Samples obtained from the Philmont Club at Philadelphia contained the following percentages of plant food:

	No. 1		No. 2	
	Per cent	Pounds per ton	Per cent	Pounds per ton
Nitrogen	.80	16.0	1.32	26.4
Water soluble nitrogen	.08	1.6	.29	5.8
Total phosphoric acid	.56	11.2	.61	12.2
Total Potash	.81	16.2	.97	19.4
Ash	43.66	......	25.58	......
Moisture	37.98	......	50.04	......
Organic Matter	18.36	367.0	24.38	497.0

Sample number two looked like the better material which is borne out by the chemical analysis. The original mixture evidently contained much less soil per ton of manure than in the case of sample number one.

While mushroom soil contains larger total amounts of plant food per ton than good barnyard manure the proportion of water soluble nitrogen is less. The chief value of mushroom soil is as a source of organic matter, yet the results show that each ton contains about the same amount as good manure.

There is danger of introducing weeds. Mushroom growers are finding it difficult to obtain abundant supplies of manure. Consequently the proportion of manure used in the benches is less than was formerly employed. Sufficient heat does not develop during fermentation to kill all weed seeds.

Considering all items of cost, plant food can be supplied usually cheaper from other materials, and the use of mushroom soil should be confined to situations where the organic matter is needed and cannot be obtained cheaper from other sources.

POULTRY MANURE—Dried poultry manure can be procured from a number of manufacturers. The following plant food content is guaranteed.

	Per cent	Lbs. per ton
Nitrogen	4.9	98
Phosphoric Acid	2.5	50
Potash	1.3	26

The nitrogen is in a form which is quickly converted into available forms. Due to the rapid decomposition, burning of the turf may occur if too heavy applications are made.

SHEEP MANURE—While large amounts of dried sheep manure are sold for use on lawns, it is not extensively used on golf courses, probably due in part to the high cost per ton. The guaranteed composition is as follows:

	Per cent	Lbs. per ton
Nitrogen	2.00	40
Phosphoric Acid	1.25	25
Potash	2.00	40

DRIED BLOOD—There are two kinds on the market, namely red and black blood. They are obtained by drying blood carefully with super-heated steam and hot air. The black blood results from charring due to too high temperatures. Red blood contains about 13.5 per cent nitrogen, while the black blood is a more variable product containing about twelve per cent nitrogen. Dried blood contains traces of phosphoric acid.

Blood decomposes very rapidly in the soil and is a source of quickly available nitrogen. It must be used carefully because it will burn the turf.

The limited supply is in great demand for use as a cattle food, and blood is consequently an expensive source of plant food nitrogen. For this reason it will never be extensively used on golf courses.

COTTONSEED MEAL—The composition of cottonseed meal varies greatly. Where it is not adulterated with hulls the variation in composition may be due to the season, nature of the soil or the climate. Cottonseed meal is in great demand for feed for live stock and the bright yellow meals are preferred for this purpose. The darker meals are usually sold for fertilizers. The dark color may be due to over-cooking, to fermentation or storing in a damp or wet place. If there is no loss of nitrogen, the product is not injured for fertilizing use. Cottonseed meal has about the following average composition:

	Per cent	Lbs. per ton
Nitrogen	6.2	124
Phosphoric Acid	2.5	50
Potash	1.5	30

Very often the nitrogen content is not given on the sales tag, but the protein content instead. The nitrogen content can be obtained by dividing this figure by 6.25. Thus a 43 per cent protein meal is equivalent to 6.8 per cent nitrogen.

Cottonseed meal is excellent for fairways and greens to supply the more slowly available nitrogen. It provides for a long continuous feeding. Due to its demand as a live stock food it is often high priced, and other equally good materials can usually be obtained at lower cost.

TANKAGE—Tankage is refuse from slaughter houses and consists of meat, blood, bone, etc. Animals condemned as unsuitable for food are made into tankage. The nitrogen is derived primarily from meat and blood. When the percentage of bone is large the phosphoric acid is high and nitrogen low, and when there is an excess of blood and meat the nitrogen is high and the phosphoric acid low.

There are a number of grades on the market containing about 6.5, 7.5 and 8.0 per cent nitrogen. The phosphoric acid content varies from 3 to 6 per cent.

Concentrated tankage is another grade and the richest of all. It contains more nitrogen and is a very uniform product. It is made by evaporating wastes which contain animal matter in solution. It contains 10 to 12 per cent nitrogen and small amounts of phosphoric acid.

The tankages are usually high priced because of the demand for use as cattle feeds.

In the soil the nitrogen is quickly converted into forms which the plant can use. There is danger of burning the turf if heavy applications are used. The continued use of tankages high in phosphoric acid tends to encourage clover.

SEWAGE SLUDGES—There are two types of sludges produced in sewage treatment plants, depending upon the method of purification. Most plants use the older Imhoff tank processes, and only one plant located at Milwaukee, uses the new activated sludge process. In the Imhoff tank process air is excluded so as to promote liquefaction of the organic matter contained in the sewage. This results in loss of the most quickly available nitrogen. The resulting sludge is partially dried on sand beds, and has the following approximate composition:

	Per cent	Lbs. per ton
Nitrogen	.70	14.0
Phosphoric Acid	.33	6.6
Potash	.24	4.8

These sludges are of low value, and in poor physical condition. When used they should be thoroughly composted to improve mechanical condition and render the nitrogen available.

Activated sludge is a product produced by the activated sludge method of sewage treatment. In this process air is constantly passed through the sewage. The so-called activated sludge which settles out is filtered and dried. A product of uniform chemical composition and physical condition is produced, which is free of weed seeds and harmful bacteria. The only marketable product is produced by the Sewerage Commission of the City of Milwaukee and is sold under the trade name Milorganite. It has the following average composition:

	Per cent	Lbs. per ton
Nitrogen	5.4	108
Phosphoric Acid	2.5	50
Potash	.3	6

The nitrogen is in organic form, and when applied to the soil, the nitrogen is gradually released in available forms. It is slow acting but provides for long feeding, and can be used with practically no danger of burning the turf.

TOBACCO DUST—A number of greenkeepers use tobacco dust regularly. This material has the following average composition:

	Per cent	Lbs. per ton
Nitrogen	1.8	36
Phosphoric Acid	.6	12
Potash	2.9	58

The potash content may be as high as 6 to 8 per cent, and the nitrogen content occasionally runs as high as 4. per cent.

RAW BONE MEAL—This product is derived from raw bones, which contain considerable organic matter much of which is in the form of fats. The fatty constituents tend to decompose slowly and make the nitrogen slowly available.

Raw bone contains about 3.5 per cent nitrogen and 22 per cent phosphoric acid. It also contains from 4 to 8 per cent of lime carbonate.

At present market prices plant food can be obtained better from other materials at lower cost. Furthermore the proportion of phosphorous to nitrogen is too high. When sufficiently large applications are made to supply needed nitrogen much more phosphate than is needed by the turf is added to the soil. This together with the lime carbonate tends to encourage clover.

STEAMED BONE MEAL—Raw bone is steamed to remove the fat which is used to make soap. The resulting steamed bone contains about 2.25 per cent nitrogen and 25 to 27 per cent phosphoric acid. The plant food is more quickly available than in raw bone because of the removal of the fat, yet even steamed bone meal is a slow acting material. The same objections apply to its use as raw bone meal.

UREA—This is a new product produced in Germany. It is a synthetic nitrogen material containing 45 per cent nitrogen, which is equivalent to 55 per cent ammonia. This is the highest nitrogen content of any fertilizer now on the market. Urea is water soluble and quick acting. Being water soluble it will burn the turf, if too large applications are made. It is frequently used mixed with Semesan or Uspulin to supply quickly available nitrogen to stimulate turf growth after the fungicide checks the ravages of the brown-patch fungus. When Uspulin or Semesan are mixed with sulphate of ammonia there is danger of loss of ammonia because both are slightly alkaline. This loss does not take place with Urea. The manufacturers claim that Urea has little effect in soil reaction, a large part of it being taken up direct by the plants.

Ammonia Containing Nitrogen Fertilizers

AMMONIUM SULPHATE—This is the most widely used nitrogenous fertilizer on golf courses. It is produced as a by-product at coke ovens. Each ton of coking coal yields about twenty pounds of ammonia. The final product contains twenty-five per cent ammonia which is equivalent to twenty per cent nitrogen.

It is water soluble and quick acting. When applied to the soil the ammonia is held temporarily by the fine soil particles in the shallow surface soil layer. This may be the reason why equal amounts of nitrogen from sulphate of ammonia prove more effective than from nitrate of soda on bent grasses which have such a shallow root system.

Sulphate of ammonia makes the soil acid, although repeated applications are often required to effect considerable change, particularly on heavy soils. The increased acidity is produced in two stages. The sulphate combines with the calcium of the soil and the calcium sulphate formed leaches out in the drainage waters. The ammonia, which is temporarily held by the clay particles is gradually converted to nitric acid by specific groups of soil bacteria. This nitric acid combines with more calcium and may be taken up by the plant, or leached out of the soil.

The repeated use of sulphate of ammonia tends to decrease and eliminate clover and weeds, probably due to the increased acidity of the soil.

If an acid soil is desired, sand and soil used in top-dressing mixtures should be tested for lime carbonate. Frequently they contain sufficient lime carbonate to more than counteract the acid producing properties of the sulphate of ammonia.

AMMO-PHOS—This is a water soluble material containing twenty per cent ammonia, equivalent to 16.4 per cent nitrogen and twenty per cent phosphoric acid. It is very similar to sulphate of ammonia in its action, being quickly available, and liable to burn the turf if too heavy applications are made.

Ammo-Phos also tends to make the soil more acid, but is probably less effective than sulphate of ammonia. In an acid soil the phosphoric acid tends to unite with iron rather than calcium and thus has little effect in removing lime.

Unless the turf requires additional phosphoric acid there is little advantage in using ammo-phos in preference to sulphate of ammonia. This can be determined only by trial.

Nitrate Containing Nitrogen Fertilizers

NITRATE OF SODA—This material is also called Chile saltpeter. It is obtained from large deposits in Chile and contains about 15.5 per cent nitrogen, equivalent to nineteen per cent ammonia.

Nitrate of soda is water soluble and very quick acting. When too large applications are made it burns the turf. Unlike sulphate of ammonia it is never held by the soil, but leaches away in the drainage waters unless taken up by the turf.

The continued use of nitrate of soda encourages the growth of undesirable grasses and weeds. It has a tendency to make the soil less acid, and when used repeatedly may eventually produce a bad physical condition on heavy soils.

Because nitrate nitrogen is the form preferred by most plants, early spring applications of nitrate of soda frequently show quicker results than any other nitrogenous material if the weather remains cool. All experimental results on turf seem to indicate that nitrate of soda should not be used regularly as the main source of nitrogen.

Phosphoric Acid Containing Fertilizers

BONE MEALS—As previously stated bone meal contains from 22 to 27 per cent phosphoric acid. They are all slowly available because none of the phosphoric acid is water soluble. Due to the high lime content they make the soil less acid and encourage clover. Because of the slow action, high cost and tendency to encourage clover it is probable that very little bone meal will be used on golf courses in the future.

ACID PHOSPHATES—The acid phosphates also called super phosphate are made by treating rock phosphates (mined in Florida, Tennessee and the Carolinas) with sulphuric acid. They can be obtained in at least three grades containing 16, 20 and 44 per cent phosphoric acid. Generally the higher the content of phosphoric acid the lower the cost per pound of phosphoric acid.

The treatment with acid converts the insoluble rock phosphate into soluble acid phosphate, and hence this is the most readily available phosphate fertilizer obtainable. When added to the soil the soluble phosphoric acid is precipitated as very finely divided calcium or iron phosphate. In this condition it dissolves rapidly in the soil solution when the turf roots make heavy demands. Phosphoric acid does not leach from the soil.

The name acid phosphate is a misnomer, because it refers to the process of manufacture, and not its effect upon soil reaction. Acid phosphates have a slight tendency to make soil less acid due to liberation of calcium (lime) when the phosphoric acid unites with the iron always present in acid soils.

Acid phosphate should not be used in larger quantities than are required by the turf grasses, because of the stimulating effect of phosphoric acid on clover, particularly if the soil is not acid.

BASIC SLAG—This material is seldom used in this country but is a very common phosphate fertilizer in Europe. It is produced when phosphoric iron ores are used in the basic process of steel manufacture, an excess of lime is used to combine with the phosphoric acid and remove it in the slag.

Basic slag contains about 15 per cent phosphoric acid and large amounts of lime. It is a slow acting material and makes the soil less acid due to the high lime content.

Potash Containing Fertilizer Materials

MURIATE OF POTASH—This is the most widely used potash containing fertilizer. It is mined in Germany and the newly acquired provinces of France. The principal grade imported into this country contains fifty per cent potash.

Muriate of potash is completely soluble in water and hence may injure the turf if heavy applications are used. Although water soluble, potash is not lost from the soil by leaching because the potash is taken up and held by the clay particles of the soil in the same manner that ammonia is held. When the potash is taken up muriatic acid (hydrochloric acid) is released. Consequently muriate of potash tends to increase the soluble acidity in soil.

Clovers have a high potash requirement, and are generally greatly stimulated by applications of potash fertilizers. If clover is not desired potash applications should not be made in amounts exceeding the requirements of the turf grasses.

CHAPTER XI

Principles Underlying the Practical Use of Fertilizers on Greens and Fairways

It is impossible to set forth rules which can be universally applied, yet certain fundamental principles underlying the use of fertilizers on turf grasses have wide application, and if these are thoroughly understood practices best adapted to local conditions can be devised easily.

Fertilizers are only effective when climatic and soil conditions are favorable for the growth of turf grasses. Frequently the distracted Green chairman or greenkeeper attributes poor turf to a lack of plant food, where other unfavorable conditions are equally important, and when fertilizer applications result in failure may unjustly condemn the fertilizer. Sometimes poor growth on newiy planted greens is traceable to the original use of too heavy soil during construction. The puddled soil becomes hard and the roots fail to obtain much needed oxygen. Fertilizers will not overcome the bad effects of faulty drainage. Turf on coarse sandy soil, or thin soils covering gravel knolls rarely obtains sufficient water. The wise greenkeeper corrects or modifies these conditions before making large expenditures for fertilizer and is well repaid for the greater effectiveness of the fertilizer.

The amount and availability of the plant food elements determines whether a material is suitable for use, and affects the rate at which it should be applied. Leather is high in nitrogen but of little value because decay does not take place in the soil. The nitrogen of sulphate of ammonia is ordinarily immediately available. Between these extremes materials of varying degrees of availability can be chosen. The more slowly available nitrogenous materials supply plant food over considerable periods, and are particularly adapted to use on sandy soils where the danger of plant food loss from leaching is great. Phosphate fertilizers also vary in availability, acid phosphate is preferable to bone meal for new seedings because of its greater availability.

Unless the fertilizers contain plant food elements which reinforce soil deficiencies failure attends their use. Both the direct and secondary effects must be considered. Some encourage the growth of fine textured grasses, discourage weeds and clover and others encourage coarse grasses, weeds and clovers. The secondary effects relate primarily to soil reaction. When soil acidity is reduced clovers may flourish, and when increased clovers are discouraged.

The rate of fertilizer application depends upon the amount of essential plant food contained in the material and its availability. Water soluble nitrogen fertilizers are best applied in small amounts at frequent intervals to avoid burning and loss from leaching, and provide a more uniform supply of plant food. Organic nitrogen fertilizers can be applied in larger amounts because soil processes gradually convert the insoluble nitrogen into soluble and available forms. Thin turf usually is an indication of impoverished soil and needs generous fertilizaton to stimulate spread of existing turf. All factors must be considered when fertilizer programs are being instituted.

Fertilization of Established Greens

Greens are in especial need of fertilization. Frequent watering induces heavy growth and increases the losses of plant food from leaching. Large amounts of plant food are constantly removed in the clippings taken off the greens. Mr. Burkhardt at Westwood Country Club, Cleveland, reports an average of 35 pounds of dry clippings removed daily from each green. This is equivalent to 3500 pounds in 100 days. If the clippings contained 2 per cent nitrogen (heavily fertilized turf frequently contains even more) 70 pounds of nitrogen were removed, equivalent to 350 pounds sulphate of ammonia. The large amount of nitrogen removed from greens during a season is rarely appreciated.

Nitrogen is the most essential plant food element, and fortunately need for nitrogen is most easily recognized. It is responsible for active vegetative growth and dark green color. Occasionally only the tip ends of the stolons on vegetative greens are dark green and the main stems are devoid of color. Here the need is so acute that the plant moves nitrogen from the older portion of the stems to the growing tips.

In order to maintain uniform growth the turf must obtain a uniform and continuous supply of nitrogen. It is not feasible to build up large reserves of nitrogen in the soil because of unavoidable losses from leaching and denitrification. This danger exists even with insoluble organic nitrogen, because it is converted into soluble forms by bacteria in the soil, and if the amount formed is larger than the turf roots can take up and utilize, loss occurs.

Too much nitrogen tends to produce coarse broad leaves, and a weak succulent turf, particularly if readily available nitrogen is used. Such turf is probably more susceptible to diseases such as brown-patch.

All things considered best results are obtained from moderate applications, at frequent intervals, rather than occasional heavy applications.

Where good top dressing containing well rotted manure is used very little response is obtained from additional applications of phosphoric acid and potash. Both tend to encourage clover so their use should be based on trials which demonstrate the need for larger amounts than are contained in top dressing mixtures.

All carefully conducted tests indicate that sulphate of ammonia encourages the growth of the finer textured grasses, and discourages clover, and nitrate of soda has the opposite effect. Consequently sulphate of ammonia should be chosen as the source of quickly available nitrogen, and used to produce these effects. Ammo-phos is an excellent material where additional phosphoric acid is required.

There is also a need for more slowly available nitrogen, to insure a uniform supply. In the past this was supplied by the manure used in compost piles. Near large cities manure is difficult to obtain and many clubs are substituting such materials as cottonseed meal, poultry manure and Milorganite. None of these require long composting and should be mixed with the top dressing just previous to top dressing the green, or they can be spread broadcast over the green and top dressing mixture applied over them.

The amount and character of turf growth must be used as a guide in determining the amount of nitrogenous fertilizer to apply. Because of the danger of burning, sulphate of ammonia applications should not exceed three to five pounds per 1000 square feet in the spring and fall, and one to three pounds in the hot summer months. The organic materials can be applied at rates of 15 to 30 pounds per 1000 square feet. The heavier rates are safe during cool weather, and the lighter amounts during the hot summer months. Naturally heavier applications should be made where the turf is poor. Trials on the particular course should be used as a basis for determining the rate and frequency of fertilizer applications.

There are a number of methods of applying fertilizer which give good results. No matter what the method the importance of uniform distribution cannot be too strongly emphasized. Fertilizers do not move laterally in the soil, all movement being vertical. Uneven applications result in uneven growth and unsightly greens.

Sulphate of ammonia is sometimes applied dry, in solution, or mixed with top dressing. The method selected depends upon individual preferences. When applied dry uniform distribution is difficult to obtain, because of the small amount of material used. Some greenkeepers use the small hand type seeder and apparently secure uniform distribution. Thorough watering immediately following the application is essential to avoid serious burning of the turf. When applied in solution the barrel cart sprinkler is most widely used. The sulphate of ammonia solution runs out of the small perforated holes in the horizontal pipe attached to the barrel, but unless the holes are closely spaced uniform distribution is not obtained. In a few instances the sulphate is fed directly into the watering line by means of a proportioner such as devised by Charles Erickson of the Minekahda Club at Minneapolis. The sulphate is quickly applied and the large volume of water eliminates the danger of burning. Frequently the sulphate is applied mixed with the top dressing. This method reduces the danger of burning because the ammonia is taken up and held temporarily by the clay and humus. Care must be exercised to secure uniform distribution of the sulphate in the mixture. Preliminary mixing with sand or soil to obtain more bulk facilitates mixing.

Sometimes, on newly built greens, fertilizers do not produce marked results. This is usually due to poor soil texture. Sand or humus was not worked into the heavy soil, root systems cannot penetrate into the hard surface soil and suffer for want of needed oxygen. Until this is corrected good turf cannot be expected.

Fertilization of New Greens

Good greens can be obtained without the use of manure provided surface soil of a sandy loam texture is available. Proper soil texture is important, because it is not easily modified after turf is established. Much larger amounts of sand are required to modify the texture of heavy soil than if humus materials are used. Medium to coarse sands are preferable to fine grained sands.

The fertilizer needs of seeded greens are slightly different from those planted with stolons, due to differences in amounts of stored food. The small grass seed contains very little reserve food, whereas the stolon is capable of establishing itself with little outside assistance. Hence seeded greens must receive sufficient phosphoric acid and nitrogen before seeding to insure rapid growth of the young seedling turf plants. Phosphoric acid plays a most important part because of its stimulating effect on root development. Stolon planted greens can be fed from the top in the top dressing mixtures which are applied at frequent intervals.

Phosphoric acid is best applied in quickly available forms, such as acid phosphate. From 5 to 10 pounds per 1000 square feet is sufficient. Applications should precede seeding so the fertilizer can be worked into the shallow surface layer of soil. This is important because later surface applications of phosphate do not move down into the soil rapidly. Nitrogen on the other hand moves freely in the soil so surface applications even after seeding are effective. If sulphate of ammonia is used as the source of nitrogen heavy applications must be avoided because of the danger of killing the sensitive young seedling. Usually not more than 5 to 10 pounds per 1000 square feet should be used, and is best worked into the soil a few days before seeding or planting. If organic nitrogen fertilizers are used larger amounts can be safely applied, and should be worked into the soil so soil processes can release the nitrogen.

Fertilization of Established Fairways

There appears to be an ever increasing appreciation of the value of fairway fertilization. In the past attempts were made to improve poor turf with seed alone. If the soil supplies only enough plant food to support the scattering turf plants, how can the new struggling seedlings establish themselves? Had conditions been favorable for growth the existing plants would gradually spread and fill in the bare spots. Where the stand of turf is poor and the soil is not too hard some seeding, in addition to fertilizer, may be advisable. In the future, however, more emphasis will be placed upon fertilization than re-seeding.

If the turf is thin fertilizer is almost surely needed, and unless steps are taken to obtain dense turf weeds will become prevalent. Moss so commonly considered an indication of sour soil is more correctly an indication of impoverished soil. Profuse clover growth may be due to a lack of nitrogen. The nodules on the clover roots contain bacteria capable of drawing upon the inexhaustible supply of atmospheric nitrogen and convert it into forms the clover can utilize. Thus the clover thrives while the turf grasses languish for want of nitrogen.

Based on the relative amounts of plant food removed by the turf a fertilizer high in nitrogen and potash would seem best for fairways. But most soils contain at least fifteen times more potash than nitrogen and it is only the sandy soils, which are low in potash, that are apt to need additional potash. A fertilizer relatively high in nitrogen, moderate to low in phosphoric acid and with little or no potash gives best results.

In the past manure was extensively used on fairways, but the present tendency is to substitute other materials partly as a result of increased demand for the limited supply, and a more intelligent use of other materials. With manure there is always danger of introducing obnoxious weeds, play is interfered with late in the fall and early spring until the refuse is removed. The supposed advantages of added humus are overestimated because it is impossible to incorporate the manure with the soil.

A ten ton application of manure is considered light, yet at least 80 pounds nitrogen and 50 pounds phosphoric acid are applied to each acre. Failure to obtain satisfactory results with substituted materials are often due to the insignificant amounts of plant food applied. Thus 500 pounds bone meal add only about 12 pounds nitrogen to the soil. Until reasonable applications are made disappointments will continue. Naturally the amount of fertilizer to apply must depend upon the condition of the turf and soil, and the material used. If the turf is poor and thin the soil is usually poor also, and more fertilizer must be applied to encourage heavier growth. A thousand to fifteen hundred pounds per acre of the better organic materials is not unreasonable under such conditions. If it is simply a case of maintenance smaller applications suffice.

When sulphate of ammonia or Ammo-phos are used applications should be light and at frequent intervals. The reasons for this have been stated elsewhere.

Fertilizers are best applied in the early spring or fall or just before winter sets in. Mid-summer applications are rarely effective, due to extended periods of dry weather. When applied in the early fall marked benefits are frequently obtained before winter sets in. Late fall applications should be confined to organic materials and only where there is no danger of bad surface washes.

Fertilization of New Fairway Seedings

The main advantages accruing from fertilization of new fairway seedings result from a quicker growth and production of dense uniform turf. With fall seedings it is possible to obtain a heavy turf before growth ceases, and such turf is better able to withstand severe winter weather. Ordinarily nitrogen and phosphoric acid are most important, but some potash may also be needed on sands. The cost of fertilizing an 18-hole course should not exceed $2000 to $3000, and is a small item of expense. Once obtained it is difficult and expensive to improve poor turf.

The first few weeks following seeding are most critical. The small grass seed contains only enough plant food to initiate growth, and then the young seedling must draw upon the plant food elements in the soil. Its ability to forage for food is curtailed by a limited root system. Unless the soil is abundantly supplied with plant food many weak seedlings succumb and a thin turf results. This is the reason why even supposedly fertile soils so often respond to fertilizer applications prior to seeding.

Phosphoric acid benefits new seedings mainly by stimulating rapid root development, thus enabling the weaker plants to compete with the strong seedlings. This insures a uniform turf. Nitrogen hastens top growth which is also preliminary to extensive root development.

Acid phosphate is a better source of phosphoric acid than bone meal, being more quickly available. When added to the soil the phosphoric acid is precipitated as finely divided insoluble phosphate. The extreme fine state of division permits rapid solution when the plant makes heavy demands. The acid phosphate is best applied prior to seeding and worked into the surface soil with a disc. Surface applications after seeding are not so effective because the phosphoric acid is precipitated at the surface and is slow to work down into the zone where root development takes place.

Nitrogen can be supplied from a number of different materials. If organic sources are used heavy applications can be made at the time of seeding with little danger of burning the seedling or loss from leaching. With the soluble materials lighter applications should be made at the time of seeding to guard against injury to the seeding and reduce the danger of loss by leaching. Later applications should be made as needed.

When mixed fertilizers are used mixtures high in nitrogen, medium to high phosphoric acid and low in potash should be selected. Ten tons of manure per acre is usually considered a very moderate application. At least 80-90 pounds of nitrogen and 40 to 50 pounds phosphoric acid are added to each acre. Unless these amounts of plant food are approximated disappointment is almost certain to attend the use of substituted materials, although somewhat less nitrogen is frequently effective because of the greater availability of the nitrogen in other materials.

The necessity of uniform applications is not generally appreciated. To obtain uniform distribution, so essential to success, a good fertilizer distributor should be used. Either the two-wheel lime and fertilizer spreader or the end-gate type lime spreader is effective. With the former type machine phosphate and nitrogenous materials can be mixed right in the hopper. Fertilizers should be applied prior to the last discing so they can be worked into the soil.

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