Soil Sampling Procedures for the Southern Region of the United States

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continued on inside back cover

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Foreword

Since it is not practical to test the entire volume of soil in a field or area, we must rely on samples taken from the field or area to determine the chemical and fertility states. The first basic assumption of a soil testing program is that soil can be sampled in such a way that the results of the collected samples will accurately reflect the nutrient status of the soil. More recent fertilization and tillage practices, e.g., banding fertilizer, no-tillage and ridging, have increased the heterogeneity of fertility patterns in soils. Sampling systems that were adequate for practices used in the past are likely to be quite inadequate given these changes. Research in the Southern Region has supported the variation that exists both horizontally and vertically within fields as well as due to past practices of fertilizer placement.

This bulletin contains chapters that reflect the latest research in sampling and experience of the authors to improve the accuracy of sampling soils. The suggested procedures and considerations are designed to improve the overall accuracy of a soil testing program that will reflect the chemical and nutrient status of soils. Plant growth whether it be for production or aesthetic value, depends on the accuracy of assessing the nutrient status of soils.

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Soil Sampling Procedures for the Southern Region of the United States

Contents

Practical Aspects of Soil Sampling

Wayne E. Sabbe[1]

Introduction

An excellent soil sampling procedure does not necessarily lead to a correct fertilizer recommendation but a non-representative soil sample will lead to an incorrect fertilizer recommendation. A non-representative sample can occur because one or more of the parameters necessary for correct sampling may be violated. These parameters include: depth, frequency, and timing of samples; too few cores per sample; samples taken incorrectly for assessment of desired nutrient(s); and sampling that does not represent the field.

The current statistical approach to obtaining a representative soil sample has assumed that each observation (sample or core) is independent from the other observations. Therefore, the approach was to obtain samples based on classical sampling designs such as: random (simple or stratified), systematic, or composite. However the zigzag method of sample collection became the choice of the National Soil and Fertilizer Research Committee (Fitts, 1956) because of its relatively high efficiency (compared to a random method) and its simplicity in utilization.

The principles of soil sampling for fertilizer recommendation have been revised (Peterson and Calvin, 1982) after their presentation in 1944 (Cline). Recent practices in fertilizer application method and tillage operations have introduced sampling principles to include these modifications (Mengel, 1982 and Moncrief, 1984).

Considerations

All combinations of fields/nutrients have variations in three directions plus a time (temporal) variation. The objective of a soil sampling procedure is to obtain laboratory analyses that are a true mean representation of that field or area.

Size and Shape of Fields

Several authors (Keogh and Maples, 1967; Cameron et al., 1971; Cypra et al., 1972) have reported that the number of samples required to determine the mean of a field did not increase proportionally with an increase in field size. This was especially true for a field size of above 30 acres (Keogh and Maples, 1967).

Certain authors (Swenson et al., 1984, Keogh and Maples, 1967) reported that while field size did not notably affect number of samples to obtain a mean value, each field had a soil test parameter (e.g., NO_3, P or K) that mandated the minimum number of samples. This parameter had the greatest allowable variation among the parameters and thereby required a greater number of samples to define its field mean. Unless the minimum number from that field was obtained, thereby describing the mean of that parameter, a correct interpretation and thus a correct recommendation could not be given.

Nutrients

The mobility and seasonal biological activity that affects certain nutrients suggest that time of year and depth of sampling need to be considered. Sampling for the mobile nutrients (nitrate and sulfate) needs to occur annually to rooting depths (24 to 48 inches) and should be done when biological activity is low and if possible, immediately before initial nutrient utilization by the crop. A good sampling procedure for nitrate/sulfate would be to obtain samples at the same depths at approximately the same month each year.

Immobile nutrients (P, K) require both fewer depth samples (usually one sample to a specific depth) and less specific time of sampling (e.g., spring). However, a definite time and depth of sampling is prescribed. In reality, if both mobile and immobile nutrients can be obtained by one sampling then the restrictions placed on proper sampling for mobile nutrients will provide adequate precautions for immobile nutrients.

Sampling Patterns

Sabbe and Marx (1987) proposed a zigzag scheme for sampling both rectangular and triangular field shapes. The zigzag pattern requires choosing a beginning area to the field and a point within this area for the initial sample. The other samples are taken from points predetermined from the initial sample point and are such that the entire field is sampled. The zigzag pattern follows a course with samples taken from specific distances depending upon the size and shape of the field.

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Regional Variable Theory

Using classical statistics the objective of determining the representative mean for each field thus leads to a uniform fertilizer recommendation for that field. With the advent of fertilizer application technology it is now possible to profit from the variation within a field by applying fertilizer if it is needed and at the needed rates at specific areas with a field. A statistical procedure known as Regionalized Variable Theory (RVT) (James and Wells, 1990) has been evaluated as a method for increasing fertilizer efficiency. The RVT approach assumes that a soil test value from any point in the field gives an estimate of the value of a neighboring point (Sabbe and Marx, 1987). Each observation within a field is not independent from other observations, therefore, the values are spatially dependent. While the use of RVT requires rather intensive soil sampling there are three immediate advantages: 1) it estimates a soil test value at any point in the field, 2) can demonstrate the relationship between two soil properties, even if one property were sampled less intensively, and 3) it gives additional information in the less-sampled property. Contour maps for each nutrient can be drawn for the field with fertilizer then being applied according to the map. With time this method of application should result in a field that is spatially uniform for each nutrient.

Assmus et al. (1985) used an adaption of RVT for incorporating the strip sampling technique. The strip sampling, done in a horizontal and vertical pattern, had the ability to modify the fertilizer application by specifying direction of application.

Research Considerations

An aspect of the soil testing program that requires sampling is correlation and subsequent calibration. These two research components, which lead to fertilizer recommendations, must be conducted where the soil test levels of small areas are known. Therefore, a more concentrated effort is warranted to obtain these values. A practical suggestion would be to obtain soil samples from a large area of the field using a grid or zigzag method of sampling. The data from these samples would be used to obtain kriged or contour maps of the area (Marx and Thompson, 1987). The maps would indicate where the desired soil test levels may be located, thus giving direction for more detailed sampling. An additional benefit to this approach is the ability to assist in designing both the plot shape and direction of replication and treatments (McBratney, 1985). The result should give the direction of greatest variation to replications and direction of last variation to treatments.

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Sampling for Soil Nitrogen

J.J. Camberato and H.R. Deaton [2]

An increased concern for NO_3 contaminated groundwater and its possible link to agricultural activities, as well as a decrease in profit margin, is increasing the interest in fine-tuning N fertilization. One method of fine-tuning N rate recommendations is to measure the amount of inorganic soil N and adjust the recommendation as a function of that found in the soil sample.

Soil sampling for NO_3-N has been routinely used in the arid and semiarid regions of the United States (Hergert, 1987), but has not been used in the humid regions until recently (Thicke, 1989). In the arid and semiarid regions, soil NO_3 is measured in the root zone and subtracted directly from the standard N rate recommendation. Sampling depths range from 1.5 to 6 feet.

Recently, a soil NO_3 test for determining sidedress N recommendations for corn has been introduced in the Northeast and Midwest (Magdoff et al., 1984; Blackmer et al., 1989; Fox et al., 1989). The climate in which this test is utilized ranges from moist subhumid to humid (Thornthwaite, 1948). This test, referred to as the Magdoff Pre-Sidedress Nitrate Test, the Vermont Test, or the Late Spring Nitrate Test, is an in situ N mineralization index, rather than a residual NO_3 test, because the measured NO_3-N is smaller than the actual amount of N made available to the plant during the growing season (Thicke, 1989).

Current Nitrate Soil Test Practices in the Southern Region

Three states in the Southern Region-Arkansas, Oklahoma, and Texas- perform soil NO_3 tests and use the results to alter N rate recommendations. The climate in Texas ranges from arid to humid with most of the state classified as semiarid, dry subhumid, and moist subhumid (Thornthwaite, 1948). Most of Oklahoma is dry subhumid and moist subhumid. The climate in Arkansas is humid. Oklahoma and Texas have similar programs, whereas that of Arkansas is distinctly different.

Oklahoma and Texas use soil NO_3 testing for making N rate recommendations on winter wheat and bermudagrass (Johnson, 1982, Johnson and Tucker, 1988; Larry Unruh, personal communication). They recommend taking soil samples for NO_3 analysis to a depth of 24 inches. Texas suggests 10-20 cores per uniform field area and Oklahoma 16-20. The samples are dried at 40-45°C (TX) and 100°C (OK) overnight before shipping to the laboratory. The soil NO_3-N test practiced in Oklahoma and Texas is a residual N test, as the amount of NO_3-N found in the sample is converted to pounds of N per acre and subtracted from the standard N rate recommendation. Although the recommended sampling depth is 24 inches, most farmers in both states only sample to 6 inches. Hence, in most cases, the N rate recommendation is reduced only by the NO_3-N content of the plow layer.

Arkansas suggests that soil samples from cotton fields for NO_3 analysis be taken at least to 18 inches and deeper, dependent on the rooting depth (Wayne Sabbe, personal communication). Sampling depth for grass pastures is 6 inches.

It is recommended that 15-20 soil cores be taken from the 0 to 6 inch depth and 6 cores be taken to the deeper depth per uniform field area. The soil is shipped to the laboratory in a cardboard box at field moisture contents. The sample is air dried before measuring NO_3-N.

Standard N rate recommendations are altered dependent on the crop and the soil NO_3-N level (Table 1). For cotton and grass pastures, only a portion of the NO_3-N measured in the soil profile is subtracted from the standard recommendation. Standard recommendations for cotton are 80, 90, and 100 lbs N/acre, dependent on soil type and area of the state. The soils on which cotton is grown are mostly silt loams. The standard recommendation for bermudagrass pasture is 50 lbs N/year in the spring plus 0, 50, and 80 lbs N/acre after each cutting for yield goals of 2, 4, and >4 tons/acre/year, respectively. Recommendations for fescue pasture are 50, 100, and 150 lbs N/acre for low, medium, and high yield levels, respectively.

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Table 1. Adjustment to the standard N rate recommendation for cotton and grass pastures based on soil NO_3-N as practiced in Arkansas.

Cotton		Pasture	
Soil NO_3-N	Reduction in Recommendation	Soil NO_3-N	Reduction in Recommendation
lbs/acre	lbs N/acre	lbs/acre	%
< 25	0	< 50	0
26 - 40	10	50 - 100	50
41 - 60	20	> 100	100
> 60	30		

Perceived Limitations to Nitrate Soil Tests in the Humid Southern Region

Other than Arkansas, Oklahoma, and Texas, states in the Southern Region do not routinely use soil NO_3 testing. Researchers in the non-testing states perceive three major limitations to the utilization of soil NO_3 testing-few seasons with enough carry-over N to warrant testing, the need and difficulty of sampling to a depth greater than the plow layer, and the potential for measured NO_3 to be leached after measurement. However, several management practices, such as preplant applications of manure and legume cover crops, result in large and unpredictable quantities of soil N, in which it would be useful to have a reliable technique to adjust additional N applications.

The majority of states in the Southern Region have annual water surpluses in excess of 12 inches, and most of the excess occurs during the winter months (Nelson and Uhland, 1955). This may minimize the number of seasons with significant NO_3 carry-over from one crop to the next and is one reason the use of a soil NO_3 test in the humid Southern Region may be limited. Hergert (1987), using annual average percolation data from Stewart et al. (1975), thought that most states west of the Mississippi river, having water surpluses less than 7 inches, could use NO_3 tests with an appropriate data base. Only Texas, Oklahoma, and Arkansas have regions with less than 7 inches of surplus, as evaluated by Stewart et al. (1975). However, the more detailed average annual water surplus data presented by Nelson and Uhland (1955) reports Florida, and the Coastal Plain region of South Carolina and Georgia to have surpluses less than 8 inches.

Many soils in Florida and the Coastal Plain have sandy surface horizons, and the leaching hazard is considered great, even when the water surplus is less than 8 inches (Nelson and Uhland, 1955). Although the surface texture of these soils is sand to loamy sand, the subsoil is usually finer textured-sandy loam to sandy clay loam. The subsoil, in comparison to the surface horizons, has higher moisture holding capacity and lower saturated hydraulic conductivities (Quisenberry et al., 1987), hence a lower leaching potential. To be productive soils without irrigation, the subsoil must be well within the rooting zone.

There is evidence that soils with fine-textured subsoils can retain NO_3 in the root zone. Nitrate was found to move rapidly from the loamy sand Ap and B horizons of a Marlboro soil in Georgia, but slowly through the sandy clay subsoil (Boswell and Anderson, 1964). Most of the N applied in November remained in the upper 5 feet of soil after 1 year (Boswell and Anderson, 1964; Boswell and Anderson, 1970). Researchers in Maryland working with soils similar to those prevalent in the Southern Region found that rates of N fertilization to a corn crop altered the spring N requirements of the subsequent wheat crop (Meisinger et al., 1982). Reduced leaching of NO_3 from the previous crop, due to limited winter rainfall, resulted in high corn yields without additional N in two seasons on three soil types in North Carolina (Kamprath, 1986).

States in the Northeast and Midwest Regions using the Magdoff test suggest sampling depths of 1 foot, except Michigan, which suggests a depth of 2 feet. Nitrate N in the 1 foot sample is an excellent predictor of NO_3-N in the 3-foot rooting zone (Pottker et al., 1987; Magdoff, 1991). Soils of these Regions on which the tests are used are primarily loam and silt loam textures, comparable to many soils in TN, KY, VA, and MS. Water movement through these soils is predominantly preferential flow (Cerrato et al., 1985, Magdoff, 1991). Water moving through the profile flows through large pores bypassing the general soil matrix and removing only that NO_3 in the large pore itself. With preferential flow, the pattern of NO_3 is a decreasing concentration of NO_3 with depth with a distinct enrichment of NO_3 in the surface soil (Pottker et al., 1987).

Water movement in uniform sandy soils is likely miscible displacement, which results in a bulge of NO_3 moving down the soil profile with the wetting front (Endelman et al., 1974; Smika, 1977). With this type of water movement, the NO_3 content of a 1 foot sample will be of little value for predicting N availability to the crop (Blackmer et al., 1989). Soil samples for NO_3-N analysis in soils with sandy surfaces may have to be deeper than 1 foot to successfully predict N fertilization needs.

Soils in the Southern Region are extremely diverse. Water flow through the silt loams of TN, KY, VA, and MS is probably similar to that of the silt loams of the Midwest and Northeast, preferential flow. Water movement through the deep sands of Florida, the Coastal Plain, and the Sandhills regions is miscible displacement. The movement of water through the many layered soils of the Southern Region, those with sandy surfaces overlying fine textured subsoils, has not yet been clearly defined. The depth of sampling for an effective NO_3 testing program is likely different for each type of soil. Sampling depths greater than 1 foot are difficult and would likely hinder adoption of NO_3 testing, even if reliable adjustments to N rate recommendations could be made.

The potential for NO_3 in the soil profile being leached, subsequent to its measurement, is also thought to limit the usefulness of soil NO_3 testing in the Southern region. This is a minimal problem when the sampling depth encompasses most of the root zone and if sampling coincides with the period of maximum plant uptake of N (Magdoff, 1991). At this point in time, the plant is taking up N rapidly, the soil is generally below field capacity, and evapotranspiration often exceeds precipitation. All these factors reduce the risk of NO_3 being leached from the soil profile. Although loss of NO_3 after measurement is not perceived as occurring often, a "flagging" system is in place in Vermont to highlight these situations when they are important. The potential for rapid loss of N from the sandier soils of the Southern Region must be considered when implementing a soil NO_3 testing program.

To determine whether soil NO_3 testing can be used successfully in the more humid areas of the Southern Region and on the sandy and layered soils will require much research. To determine if a NO_3 test of any type will be successful, sampling depths of greater than 1 foot should be examined initially. If soil samples need to be greater than 1 foot, a methodology must be developed that allows samples to be taken easily and rapidly, so that the practice will be adopted by farmers and agricultural consultants. However, note that sampling depths of up to 6 feet are recommended in OR, WA and NB (Hergert, 1987). The time of sampling should be as close to the time of fertilization as possible to make the best measure of crop available N and to avoid basing N fertilization recommendations on N that is subsequently lost from the profile.

Early Status of Soil Nitrate Testing in the Southern Region

Recent overviews of soil nitrate testing in the South indicate considerable research activity (John Grove, University of Kentucky and Greg Evanylo, Virginia Polytechnic Institute and State University, personal communication). Preliminary results show that there are situations, fields receiving manure and sludge and with legumes in rotation, where significant accumulations of soil NO_3 do occur. And, several researchers have found a useful correlation between the soil NO_3 measurement and response to N fertilization. In corn, the sampling depth being examined is 1 foot, whereas a 3-foot sampling depth looks promising for wheat. Continued correlation/calibration research is needed to implement the soil nitrate test in the Southern Region.

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Soil Sampling for Soil Testing Purposes: Conventional Row Crop Tillage

Dr. Jim Woodruff [1]

Definition/Objectives

Conventional tillage for the purposes of this chapter encompasses the use of moldboard plows or rototillers with chisel plows or subsoilers, drag and/or disk harrows to completely disturb the soil surface and mix lime and fertilizer into the plowed layer. In conventional tillage, the added nutrients tend to become uniformly distributed throughout the depth of the plowed layer through the mixing action of the turning plow or rototiller and harrowing over a period.

A soil test begins with the collection of a soil sample from a defined soil area. The sampling objective is to obtain a small volume of soil that will accurately reflect the chemical properties such as pH and extractable nutrients in the soil area being sampled. To be effective, the sampling procedure must be adapted to fit specific land management variables such as cropping system, tillage, and methods of fertilization. Soil morphology must also be considered. The objective here is to discuss the factors that should be considered for effective soil sampling under conventional tillage for row crops.

Management History

Management history encompasses all previous practices that have occurred in a field before sampling. Knowledge of these practices allows the development of the most effective soil sampling strategy

Cropping System

In cropping systems, most row crops will be rotated either with other row crops or with close growing annuals or perennials. Some crops to be grown in the future will not receive direct fertilization. For example, in cropping systems including peanuts, better results are obtained from potash applied to the crop in the proceeding year rather than on the peanut crop. Also in double cropping of small grain followed by soybeans, it is often best to add enough fertilizer to the small grain to provide for both crops. Thus knowledge of crops in the rotation is important in planning when to sample. It is best to sample soils in the fall for spring planted crops and in the summer for fall planted crops. Farm records are essential and should include a farm map, crop rotations, soil test results, and liming and fertilization practices.

The cropping system and intensity of use also influence the frequency of sampling needed. Where double cropping is practiced, it is advisable to sample annually to ensure that adequate nutrient levels are being maintained. Otherwise soils should be sampled at least once during each rotation sequence.

An important consideration affecting the number of cores needed arises where a row crop is to follow a perennial sod crop, especially a pasture, which has been plowed for the first time in several years. There is usually a buildup of immobile nutrients such as phosphorus and calcium in the top few inches because of past top dressings. There may also be nonuniform distribution of nutrients resulting from manure droppings when the field has been pastured. The first plowing does not achieve uniform mixing. It is best in this case to increase the number of soil sampling cores to 20 or 30 or more cores than to take the usual 15 to 20 cores. More cores will lessen the effect of one core taken from any given spot and will provide a more accurate average.

Intensity of Management

The intensity of management varies with the value of the crop and the yield goal. Normally the higher value cash crops such as tobacco and vegetables receive higher rates of fertilizer than field crops such as soybeans and corn. On the other hand, irrigated corn with a high yield potential will receive more fertilizer than dry land corn. More intensive monitoring of soil nutrient levels is required where higher rates of fertilizer are applied. This is true especially where ammonium nitrogen rates are high on soils with low buffering capacities. Often the soil pH is lowered considerably during the growing season because of nitrification of ammonium. Under conditions of intensive management, it is advisable to sample annually to ensure the maintenance of soil pH and to detect the removal of fertilizer nutrients by intensive cropping.

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Cultural Practices

Cultural practices include plowing and other tillage procedures for preparing the seedbed and controlling weeds, and include the associated fertilizer placement practices.

Row crops may be planted flat or on raised beds formed with middle busters, ripper bedders, bedding disks, or other bed-shaping equipment. Both tillage and method of fertilizer placement influence the choice of soil sampling pattern.

Tillage Method

Level seedbed: sample between the rows before the rows are obliterated by tillage to avoid fertilizer bands. More precise depth of sampling and uniform cores are also achieved if the field is sampled before plowing or disking in preparation for the next crop.

Bedded or ridged seedbed: Avoid sampling the valleys between beds or ridges. Take cores in the shoulder of the ridge between the row and middle valley away from any fertilizer bands. Avoid taking soil from below the bedded material so as not to include soil where lime and fertilizer have not been mixed into it by tillage. Where fields are being sampled before bedding or ridging, take cores to the depth reached by the tillage implements used, following the same procedures as prescribed for sampling level seedbeds.

Fertilizer Placement

Knowledge of the location of applied lime and fertilizer is important for developing valid sampling procedures.

Broadcast: This method of fertilization usually involves bulk spreading of dry materials before preparing the seedbed of planting, but may include the broadcasting of fertilizer nutrients through fertigation techniques in which liquids are applied through overhead sprinkler systems while the crop is growing. Under conventional tillage systems, the nutrients added by broadcasting tend to become uniformly distributed over time throughout the depth of the plowed layer. Soil cores may be randomly taken from areas fertilized in this manner and should reflect the average fertility of the field.

Banded: Fertilizer is often placed over the seed row in a band or banded a few inches beside and below the seed to provide a portion of the total fertilizer needed and to give stimulation of early growth. Avoid sampling these areas that may give upward bias to the actual nutrient levels in the field.

Permanent Strip: In certain intensively managed row crops, semi-permanent rows may be maintained over buried trickle tubes that carry water and fertilizer to the crop. In these special cases and others where concentrated strip fertilization is practiced, and the permanent row strip is maintained to promote fertilizer efficiency, the fertilized area over the rows should be sampled and the unfertilized area between rows should be omitted from the sampling.

Sidedressed: Portions of the total fertilizer are commonly sidedressed 6 to 8 inches beside the plant row during the growing season. These nutrients will raise the nutrient levels within the area of placement above the field average. High rates of ammonium nitrogen sidedressing will lower the soil pH within the area of placement. The area near the row affected by sidedressing should be avoided if sampling is done before the field is plowed.

Sampling Pattern

In all cases where the crop rows are intact, it is advisable to use a systematic core sampling plan using the knowledge of the method of fertilizer placement and following a zigzag pattern across the field to obtain at least 15 to 20 cores, despite field size. If the field has been tilled before sampling and the location of crop rows is obliterated, then more cores (20 to 30) should be gathered at random in a zigzag pattern to lessen the effect on field results from sampling some of the fertilizer bands.

Morphological and Nutrient Considerations

Natural Variation

Row crops are grown on all soils of the southern region. These soils occupy several physiographic divisions differing in parent materials, topography, and drainage. Among the more extensively row cropped divisions are the Coastal Plains, Piedmont, Mississippi Alluvium, and Great Plains. The most extensive of these physiographic divisions is the Atlantic and Gulf Coastal Plain on which a major part of the row crops are grown across the southern region from Virginia to Texas. Although all ten of the taxonomic soil orders are found in the southern region, the Ultisols are the dominant soils. These soils generally have low nutrient - holding capacities in the plowed layer. Morphologically, many of these soils feature prominent elluvial horizons that allow rapid leaching of mobile nutrients to deeper clayey horizons, evoking special consideration when sampling for soil fertility testing.

Depth of Sampling

Soil samples should not generally be taken at arbitrary depths in conventionally tilled and row cropped land. For example, some soils have shallow plowed layers over soil horizons that differ greatly in chemical composition. Care must be taken to ensure that each core includes material from only one horizon to include for the field composite sample. As a rule, it is best to take core samples to the depth of plowing so that the core sample represents the nutrients present in the entire zone of mixing.

Subsoil Sampling

Rapid movement of mobile nutrients out of the plowed layer to deeper clayey layers is a well-known phenomenon in many southern region soils with low nutrient holding capacity in the surface. In some soils the underlying clayey horizon is too deep for nutrient considerations retained there for shallow rooted row crops. On the other hand, a great many soils have a clayey layer starting at 20 inches or less below the soil surface. It has been observed that in particular, potassium, sulfur, and boron may move from the plowed layer within a few weeks after the soil is fertilized and can be detected in the clayey horizon. The speed of movement depends upon the amount of rainfall.

Soil cores taken from the plowed layer on many southern soils reveal low levels of the mobile nutrients, yet few crop responses may be found where these nutrients are applied. Subsoil core samples taken from the top four inches of the clayey layer may give more meaningful information for sulfur and potassium needs on these soils. Many row crop farmers use subsoil chisels under the row to a depth of approximately 16 inches to break traffic pans and allow roots to grow through to extract the moisture and nutrients stored in the clayey subsoil layer.

Sampling Soils Under Reduced Row Crop Tillage

J.L. Kovar [1]

With the current emphasis on soil and water conservation, reduced tillage systems are now replacing conventional systems. Reduced tillage systems, however, can take many forms, with tillage intensity varying significantly among the systems. The more intensive systems may involve several trips over a field with a chisel plow, disk, and/or seedbed tool, thus being little different from a conventional system. Less intensive systems are those that utilize ridges or stale seedbeds. No-till, of course, is the most conservative system.

The objective of this chapter is to discuss the changes in soil sampling procedures that are necessary when a reduced tillage system has been adopted. The type of system utilized and changes in fertilizer management are the most important factors affecting the manner in which soil samples should be collected. Tillage intensity influences the degree and depth of mixing of soil and added nutrients. Unlike conventional systems, in which added fertilizer is mixed well with the surface soil to a depth of 20 to 25 cm, reduced tillage does not incorporate nutrients to such an extent. Except no-till, the degree of soil and fertilizer mixing can be similar, but the depth of incorporation is not. In addition, the method of fertilizer application influences the spatial distribution of nutrients before any tillage. Because of these factors, changes in both sampling depth and sampling patterns are necessary under reduced tillage systems.

Effect of Tillage on Nutrient Distribution

Various researchers have reported that surface broadcast applications of immobile nutrients, such as phosphorus, P, and potassium, K, can lead to significantly higher nutrient levels in surface soil layers (5 to 10 cm) as tillage is reduced. Mengel[1] found that after seven years of continuous corn grown under four tillage systems, clear differences in the vertical distribution of P and K were evident (Table 1). Under conventional tillage, both P and K were distributed uniformly throughout the 0 to 22.5 cm layer (plow layer). Added P and K were mixed to a depth of less than 15 cm under the chisel system, indicating that some nutrient stratification had occurred. In both the ridge till-plant and no-till systems, levels of P and K were significantly higher in the 0 to 7.5 cm layer (Table 1).

Similarly, Taction et al.[2], reported that after a three-year double-crop rotation of wheat and soybean, fertilizer P, both surface applied and incorporated to a depth of 5 to 8 cm with a disk, increased soil P levels mainly in the upper 7.5 cm of soil. Some downward movement into the 7.5 to 15 cm layer occurred as P application rates increased from 0 to 128 kg ha^{-1}.

In another study, Mackay et al.[3] found that after 12 years in a corn-soybean rotation, exchangeable K levels in the 0 to 7.5 cm soil layer in the row were 2.4-

Table 1. Soil Test P and K levels after seven years of continuous corn grown under four tillage systems.

Sampling Depth	Tillage System: Conventional		Chisel		Ridge Till		No-till	
	P	K	P	K	P	K	P	K
cm	mg/kg							
0 - 7.5	39	143	86	240	77	225	91	283
7.5 - 15	49	175	38	128	26	113	31	120
15 - 22.5	31	135	15	105	11	95	17	105
22.5 - 30	13	110	13	105	8	100	13	105

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Table 2. Soil pH of the 0 to 5 and 5 to 15 cm layers after 10 years of N application in two tillage systems.

Annual N Rate	Soil pH After 10 Years			
	Conventional		No-till	
	0-5 cm	5-15 cm	0-5 cm	5-15 cm
kg/ha				
0	6.45	6.45	5.75	6.05
84	6.40	6.35	5.20	5.90
168	5.85	5.83	4.82	5.63
336	5.58	5.43	4.45	4.88

fold greater under no-till than under conventional tillage. In the 7.5 to 27.5 cm layer, however, exchangeable K levels were similar in both tillage systems. Mackay et al.[5] concluded that the stratification of K in the surface layer resulted from both the surface application of K fertilizer and the annual return of corn residue to the surface.

Due to the mobility and transformations of nitrogen, N, broadcast applications of N fertilizers do not result in stratification of readily available N, although it has been shown that significantly higher levels of organic N appear in surface layers as tillage is reduced[4]. More importantly, surface broadcast applications of N usually decrease pH values in surface soil layers. The effect depends on the rate of N applied, as shown by the data of Blevins et al.[5] in Table 2. After 10 years, soil pH in both the 0 to 5 cm and 5 to 15 cm layers in the no-till treatments was significantly lower than in the conventional tillage treatments. Under the conventional system, the residual acidity resulting from N application was distributed more evenly throughout the surface 15 cm of soil. The severe surface acidification under no-till, especially at the high N rates (Table 2), suggests that problems with herbicide efficiency and aluminum, iron, and manganese toxicities are possible. Other research[1,2,4] indicates that the potential for an increase in surface soil acidity, due to surface N application, grows as tillage intensity is reduced.

Effect of Fertilizer Management on Nutrient Distribution

Fertilizer management adds another variable to the problem. Subsurface placement of N, such as occurs when anhydrous ammonia or UAN solution is knifed into the soil, can create zones of undesirable acidity below the surface soil layer. Mengel[1] reported that injection of anhydrous ammonia resulted in the formation of acid zones in the 7.5 to 15 cm soil layer (Table 3). The effect is evident among the chisel, ridge, and no-till treatments. Under conventional tillage, however, the pH is more uniform throughout the surface layers (Table 3). As with surface N application, moldboard plowing mixed the acidified and non-acidified zones each year.

Application of P, and sometimes K, in a band below or below and to the side of the seed row is often used in reduced tillage systems-especially no-till. If the position of the row does not change significantly over a number of years, zones of residual P and/or K will develop[7]. Reliability of soil test results then can vary, depending on whether subsamples from these zones are included in a composite sample. Kitchen et al.[8] found that an exponential decay function given by:

$$Y = A \exp^{-Bx} - C$$

Table 3. Soil pH* after seven years of continuous corn with anhydrous ammonia (280 kg N/ha) injected between rows.

Soil Depth	Tillage System			
	Conventional	Chisel	Ridge Till	No-Till
cm				
0 - 7.5	5.6	5.9	5.6	5.8
7.5 - 15	5.5	5.3	5.1	5.1
15 - 22.5	5.6	5.6	5.6	5.6
22.5 - 30	5.8	6	6.1	6.2

* *Samples collected from the midrows of all treatments.*

where Y is the soil-test value, x is the lateral distance from the band, A and B are empirical constants, and C is the soil-test concentration when unaffected by the P band, could be used to describe soil-test P at increasing lateral distances from the residual bands in three soils. Residual P could not be detected 6 cm from the band and P in the bands increased with increasing P rate. Since K also is relatively immobile in the soil, the distribution of soil-test K may be similar to that reported for P, when K fertilizer bands remain undisturbed. Therefore, in fields that contain residual bands, random sampling can result in inflated soil-test values and an underestimation of fertilizer requirements. Mahler[9], however, found that this problem could be avoided if the number of subsamples collected for a composite sample was increased significantly.

Effect of Modified Nutrient Distributions on Plant Uptake

Considering the research that has been done, it is evident that both tillage practices and fertilizer management affect the distribution of nutrients in the soil. The bioavailability of nutrients, however, depends not only on the ability of the soil to supply nutrients, but also on the ability of the plant to absorb the nutrients present. Previous studies[10,11,12] have shown that soil water content in surface layers is higher under reduced tillage, thus enhancing the ability of plant roots to absorb nutrients. Although research on the effect of tillage on the distribution of plant roots is not extensive, the available data indicate that root distribution also changes as tillage is reduced[3,4]. The data of Thomas and Frye[3] (Table 4) show that root length density under no-till can be significantly greater in the surface layer-0 to 5 cm in this case-than under conventional tillage. This suggests that the crop would be better able to acquire the available nutrients in this soil layer.

The results of several studies corroborate this hypothesis. Blevins et al.[6] reported that K uptake by corn grown under a no-till system was 30% greater than uptake under a conventional system. Similarly, Mackay et al.[5] calculated that P and K uptake from the 0 to 7.5 cm soil layer was 39% and 52%, respectively, of total uptake under no-till, compared to 28% and 26%, respectively, under conventional tillage. In another study, Tacion et al.[2] found that wheat and soybean yields were not affected when P fertilizer recommendations were based on soil P levels in either the 0 to 7.5 cm layer or the 0 to 15 cm layer, although additional P fertilizer was required to satisfy recommendations based on P levels in the 0 to 15 cm layer. They concluded that when sampling soils for available P, the 0 to 7.5 cm layer, rather than the plow layer, should be sampled for both no-till and disk tillage systems.

Recommended Sampling Procedures

As is evident, tillage intensity and fertilizer management are the most important factors that determine the manner in which representative soil samples should be collected from fields under reduced tillage. The depth to sample depends on the intensity of the tillage. The position to sample, relative to the row, or the number of subsamples to combine for each composite depends on whether fertilizer materials are banded or surface broadcast.

In reduced tillage systems in which a chisel plow or disk is used, some mixing of soil and surface broadcast nutrients occurs. The amount of mixing, however, is less than that under conventional tillage; therefore, nutrients and soil acidity can become stratified in the upper 7.5 to 10 cm of soil. Soil samples collected from this zone will be adequate for making P, K, and lime recommendations in most cases. If N, P, and/or K have been injected to a depth greater than

Table 4. Comparison of corn root length density under conventional and no-till systems.

10 cm, prior to chiseling or disking, it will be necessary to sample to a depth equal to that at which the material was placed.

In no-till systems in which fertilizer is surface broadcast, samples should be collected from the 0 to 7.5 cm or 0 to 10 cm layer to assess P and K requirements. It also may be advantageous to sample the 10 to 20 cm layer, as nutrients in this layer become important in dry years. If N is surface broadcast, an additional sample from the 0 to 5 cm layer should be collected to determine pH

If N or P and K are injected (banded), samples should be collected in such a way as to account for the increase in soil acidity and nutrient levels in the fertilized zone. Kitchen et al.[8] suggest that when the band location is known, a composite sample should consist of one in-the-band sample for every 20 between-the-band samples with wide (76 cm) band spacing and one for every eight samples with narrow (30 cm) band spacing. If the location of the fertilizer band is not known, samples should be collected randomly. However, approximately twice as many subsamples should be collected for each composite sample as would normally be taken from a field where fertilizer is broadcast. Tyler and Howard[15] found that 10 cores per composite was satisfactory, whereas Kitchen et al.[8] and Mahler[*] suggest 30 to 60 cores per composite are required. The exact number of subsamples to take will vary with nutrient concentration in the band, relative to that in the bulk soil. As concentration in the band increases, relative to that in bulk soil, the number of subsamples per composite also should increase[8]. In all cases, samples should be collected to a depth of 15 cm.

In ridge till or stale seedbed systems, the time of sample collection also is important. If fertilizer is surface broadcast, the soil with the highest nutrient content is shifted from the row to the midrow during planting. When ridges or beds later are reformed, the surface layer of soil (5 to 10 cm) in the row middle is displaced back into the row. Therefore, after planting, but prior to reforming the ridges, soil samples should be collected from the midrow. If sampling occurs after the ridges are reformed, samples should be collected from the row. Sampling to a depth of 12 to 15 cm will give the best estimate of nutrient status. If, on the other hand, fertilizer materials are injected, procedures similar to those for a no-till system with residual bands should be followed.

Unfortunately, little correlation data are available to indicate whether the modified procedures outlined above produce soil samples that approximate the "true" soil-test values. It can be argued, however, that sampling methods used under conventional systems generate representative samples simply because samples are collected from the soil in which root length densities and nutrient levels are generally greatest. If root growth patterns and nutrient distribution change under reduced tillage, it follows that soil sampling procedures should be modified to account for these changes.

The recommendations given in this chapter are based on the need to monitor soil acidity and P and K availability. To determine the availability of mobile nutrients, such as nitrate and sulfate, sample collection procedures need not be modified for reduced tillage systems. As under conventional tillage systems, sampling should occur every three to four years. Sample every two years under no-till with surface applied N to monitor pH in the 0 to 5 cm layer. Micronutrient recommendations can be made from samples collected by the above procedures. There currently is little evidence that tillage affects micronutrient availability to such an extent that separate sampling procedures are warranted. The procedures discussed in this chapter assume that reduced tillage is followed. If deep plowing occurs, sample to plow depth.

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Pastures and Forages

Steven C. Hodges [a] and Dan Kirkland [b]

The primary reason for soil sampling forage crops is to assess the potential for response to inputs of lime or fertilizer. To achieve this objective, the sampling methodology must deal effectively with spatial variability and vertical stratification of soil chemical properties resulting from past management practices and deposition by grazing animals, as well as changes with time. Soils, fertility levels and management vary tremendously throughout the Southern Region, thus sampling methods could reasonably be expected to vary. This report is based on a survey of sampling methods within the region and the available literature upon which these recommendations are based.

Spatial Variability

A number of studies have examined the problem of spatial variability (Hammond et al., 1958; Hemingway, 1955; Hileman et al., 1961; McIntyre, 1967; Sabbe and Marx, 1987). In their review of these and other studies, Beckett and Webster (1971) concluded that a major portion of the variability occurs within a few square meters of a sampling point, that variability tends to increase with sampling area (although this increase may be relatively small), and that agricultural practices such as grazing, manuring, fertilization and liming tend to increase the variability present within a particular field. Whitney et al., (1985) and Sabbe and Marx (1987) reviewed the practices most commonly recommended to improve the usefulness and reliability of composite soil samples to represent the sampling unit.

Sample Uniform Soils

All states in the region recommend separation of fields into sampling units based on uniform soil types, cropping history, erosion, or past management practices. Uniform area may be defined using detailed soil maps if available, or based on observed similarities in color, slope and texture. Trouble spots in particular should be sampled separately or excluded, since their inclusion can have profound effects on the whole sample and the resulting recommendation.

For perennial forage and pasture crops, the presence of a permanent ground cover can make it difficult to correctly identify uniform soil areas. Abrupt changes in soils can occur within a small area in strongly sloping and/or rocky fields. The use of soil maps and careful observation of the soil as it is sampled can decrease variability resulting from soil heterogeneity, but such areas should be avoided where possible. Grazing can result in concentration of nutrients within a relatively small portion of a pasture, often at the expense of less productive areas. If these areas can be defined, they should also be sampled separately.

Sample Size and Area

For practical purposes, the minimum sampling unit should be no smaller than the smallest unit which the farmer will lime and fertilize separately (Cline 1945). Little will be gained by separate sampling if management will not use the information. Recommended sampling areas and numbers are based primarily on studies for row crops (Cline, 1945; Keogh and Maples, 1967; Fitts and Nelson, 1956; Reed et al., 1953). There is very little research on the size of the sampling area and number of samples required to obtain a representative sample within perennial pastures, which typically occur on marginal and inherently more variable soils. Using a systematic grid sampling technique in 25 ha paddocks, Friesen and Blair (1984) found that pH could be estimated within 10 percent of the mean with only one subsample, whereas P required between 25 and 121 subsamples and K required 29 to 78 subsamples. They reported that 30 subsamples would be adequate to estimate the mean of all parameters within 20 percent. While recommended sample areas in the United States have ranges as low as one composite sample for each 3 to 4 acres (1.2 to 1.6 ha), within the Southern Region one composite sample comprised of 15 to 20 subsamples (cores) is generally recommended for each 10-15 acres (4 to 6 ha).

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The diameter of the subsample can also affect sample variability. Soil probes 0.75 to 4 in (2 to 10 cm) in diameter are typically used in the Region. McIntyre (1967) reported a decrease in sample variability as the sample diameter increased from 1 to 7 in (2.5 to 17.8 cm).

Avoid Areas of Nutrient Concentration

Grazing animals tend to congregate and deposit large amounts of excrement and urine around watering areas, shade, fences and gates, resulting in high concentrations of nutrients in these areas. At a stocking rate of 4 dry cattle/ha, During and Weeda (1973) estimated that dung influences nutrient uptake on an area 5 times that actually covered by feces. This would result in 40% of the pasture area being affected by dung in the first year, and 75% affected in 3.5 years. The increased number of sheep required to exert similar grazing pressure would increase the potential for spreading and mixing of feces. Hilder (1966) found that 50% of a large (37.2 ha) rotationally grazed paddock received 83% of the feces.

The high concentration of nutrients in patches of urine and feces throughout the field can also strongly affect soil test recommendations. Dale (1961) reports that K in urine patches can effect soil test levels as much as seven months following deposition. In grazed pastures, the enhanced growth of vegetation in the affected areas usually indicates higher nutrient concentrations, but urine patches are more difficult to identify and avoid in well fertilized fields.

Sampling Strategies

In the establishment of forage crops, spatial variability is dealt with in the same manner as with annual crops. Recommended practices to obtain representative samples include random sampling or zigzag sampling of homogeneous soil units (Cline, 1944; Reed et al., 1953; Petersen and Calvin, 1965).

Other sampling strategies have been examined, the most promising of which seems to be a cluster sampling strategy (Friesen and Blair, 1984; Vallis, 1973). This method has been studied mostly in Australia, but appears to have promise, especially for assessing change in soil chemical properties. In a comparison of systematic grid, zig-zag, stratified zig-zag (stratified based on soils) and cluster (stratified based on soils) strategies, Friesen and Blair (1984) found that precision of cluster sampling was equal to zig-zag and stratified zig-zag sampling strategies although far fewer subsamples were required.

Sampling Depth

Establishment

For establishment, the sampling depth should be determined by the depth of incorporation of lime or fertilizer. While this usually results in a sampling depth of 6 to 8 in (15 to 20 cm), the effective depth of incorporation seldom exceeds 4 in (10 cm) when disking alone is used for incorporation. Many pastures in the region are located on rocky soils where sampling depth may be limited to the actual depth of the soil.

For some deep-rooted crops, subsoil sampling may give a better indication of fertilizer response. In their review of K nutrition of forage legumes, Lanyon and Smith (1985) concluded that alfalfa had the flexibility to use soil K reserves from the surface soil, the subsoil or both. Assessing K needs requires an understanding of the nature and distribution of soil K reserves. In Arkansas, coastal bermudagrass failed to respond to K applications over a 5-year period even though surface soil levels were low (Hileman et al., 1961). Potassium levels were found to increase substantially below the 12 in (30 cm) depth.

Established Perennial Pastures

Over time, nutrients become stratified with depth in untilled soils as a result of recycling of residual plant tissue, the deposition of urine and feces in grazed pastures, and surface applications of lime and fertilizers. Frequent or heavy applications of N-containing fertilizers and manures N can lower pH in the undisturbed surface as well. Askew (1932) noted that subdivision of the surface soil was required for accurate characterization of fertilized pastures. Welch and Fitts (1956) sampled established sods at 3 in (7.5 cm) intervals in soils of the Piedmont and Coastal Plain of North Carolina and found marked decreases in organic matter, pH, P and K with increasing depth. Similar data are widely reported in established, fertilized fields (Wells and Parks, 1961; McIntyre, 1967; Jordan et al., 1966; Walker et al., 1970). Hileman et al. (1961) in Arkansas, found similar decreases in pH with depth, but recorded significant increases in K and Mg below 14 in (35.5 cm) in one location.

Proper assessment of lime and fertilizer needs may require that sampling depth vary with the forages produced, intensity of management, inherent soil properties and the factor most limiting production. The morphological differences between grass and legume roots affect their capacities for P uptake from soil. Most grasses produce a dense network of fine fibrous roots which penetrate the soil to a depth of 25 to 50 cm. This root network extensively explores the soil mass and is able to extract sufficient P from soils that would not supply adequate P for legumes or other plants with a less extensive root system. Forage legumes are taprooted or have heavy, branched roots which are much less extensive and fibrous than grass roots. On the other hand, legumes such as alfalfa and sericea lespedeza have taproots which may extend 5 m or more into deep soils. Grasses typically have greater ability to grow at low P levels, but usually display less total uptake than clovers and forbs at high soil-P levels.

In the Southern Region, management systems range from unfertilized native pastures to intensive systems for production of irrigated hybrid bermudagrass or alfalfa hay. The more intensive the production system, the greater the potential for rapid changes in nutrient status, especially in the top 2 to 4 in (5 to 10 cm). The needs for lime, P and K also vary greatly within the Region.

The relative immobility of surface-applied P and lime and to a lesser extent K, have caused concern over the effectiveness of these treatments, especially for deep-rooted crops. Uniform mixing of lime in the surface 6 to 12 in (15 to 30 cm) prior to establishment is important for sensitive crops. The reaction rate of lime is greatly reduced when applied to an untilled soil, reducing its ability to effect soil pH changes. To accurately assess the lime requirement of established plantings, Adams (1984) recommended sampling of profile layers, with the upper 5 cm sampled separately. It is critical to prevent extremes of pH in this upper zone that contains large numbers of feeder roots. Pearson and Hoveland (1974) reviewed the effectiveness of surface-applied lime on forages and found that deep placement of lime seldom proved more effective than surface applications, probably due to the poor mixing inherent in both methods. Thom and Rice (1986) state that surface applied lime will provide adequate neutralization of soil acidity for both renovation and no-till seedings of forage legumes if applied at least six months before seeding, and that surface-applied lime is effective for maintaining pH for established legumes. Hileman et al. (1961) found that lime applied to the surface of a strongly acidified profile was effective in the upper 2 in (5 cm), and less so in the next 4 in (10 cm). Corroborating evidence for the effectiveness of surface-applied lime can be taken from experience with no-till research (Taction et al., 1982; Blevins et al. 1977). These studies recommend sampling the 0 to 3 in (0 to 7.5 cm) depth for lime and P requirement - the zone which can be affected by management practices.

Mobility of surface-applied lime may be greater than frequently credited based on short-term studies. Follett and Wilkinson (1985) cited evidence suggesting that lime applied concurrently with N fertilization can form residually basic nitrate salts of Ca and Mg which are mobile and can help correct subsoil acidity. Percival et al. (1955) presented evidence that surface-applied lime may increase pH as deep as 20 cm into the soil profile after 4 to 5 years.

The reviews of Mays et al. (1980) and Follett and Wilkinson (1985) concluded that forages may effectively use surface-applied P. O'Donnell and Love (1970) found than over 30 percent of the root system of Kentucky Bluegrass occurred in the upper 5 cm of the soil, and was capable of removing significant amounts of P from soil at this depth. Massey and Sheard (1970) reported that many actively absorbing roots of alfalfa are in the top 1.5 in (3 cm) of the soil. Wilkinson (1984) compared P placed in rows 20 cm apart and 5 or 10 cm deep with surface-applied P and found no significant difference in P uptake, P content, or yield of Coastal bermudagrass in the Piedmont of Georgia. Apparent P recovery in the forage was much greater for surface-applied P.

McIntyre (1967) concluded that the sampling depth required to accurately assess the needs for lime and P is too shallow to assess needs of N and K, especially in permeable soils where rooting and leaching patterns may differ. Similarly, Hileman et al. (1961) found that shallow surface samples were inadequate to predict the response of Coastal bermudagrass to K inputs where large amounts were available lower in the soil, even though shallow samples were adequate to reflect needs of P and K. Vaught et al. (1977) found that a one year old stand of alfalfa on a Pembroke silt loam in the Western Pennyroyal area of Kentucky did not respond significantly to P and K additions over the following six year period. They attributed this lack of response in part to the supply of these nutrients from soil below the 6 inch (15 cm) depth. Applications of P_2O_5 at 135 and 180 lbs per acre and K_2O at 200 lbs per acre increased soil test levels significantly in the upper 6 inches (15 cm), with much smaller changes at the 6 to 12 inch (15 to 30 cm) depth. In a five-year study on sandy soils (Lakeland-Norfolk association) of Alabama, Jordan et al. (1966) found that 0-2 in (0-5 cm) samples were not only adequate to predict P and K responses, but were better correlated with relative yields of Coastal bermudagrass. They found no response to lime additions even though pH dropped to 4.9 during the study.

In summary, a shallow sampling depth can fail to detect nutrients such as N and K deeper in the soil profile which are available to some forage species.

This could result in overfertilization with these nutrients. A deep sampling depth could overestimate pH and nutrient levels in the upper 2 to 4 in (5 to 10 cm) surface zone, leading to inadequate fertilization or liming for sensitive crops. Friesen and Blair (1984) found that sample variability in the upper 2 in (5 cm) could be significantly altered by inconsistency in the sampling depth, whereas a 4 in (10 cm) sampling depth resulted in less variability and was sensitive to changes in the surface. A routine sampling depth of 2 to 4 in (5 to 10 cm) combined with deeper samples at establishment and at less frequent intervals would result in the best assessment of soil fertility status. The deepest sampling depth should be determined by rooting depth of the forage and soil fertility levels at time of establishment. This would prevent excessive fertilization if subsoil levels of K were adequate, and prevent excessive acidification and topsoil depletion where stratification of immobile nutrients in the upper 2 to 4 in (5 to 10 cm) is important.

Time of Sampling and Frequency

The correct time of year to sample varies with the objective. Samples should be taken at least six months before establishing perennial pastures to allow as much time as practical for lime to react, particularly where legumes will be planted. Where winter kill resulting from K or P deficiency may be a problem, late summer or early fall may be the best time to sample. At this time of year, soils are generally dry enough to support truck-mounted sampling and application equipment. On the other hand, demand for nutrients is most intense during the early stages of regrowth of perennial forages (Mays et al., 1980). Thus, cool season perennials could be sampled in July or August and warm season perennials in February or March. McIntyre (1967) recommends sampling just before the effective nutrient use period. He further cautions against sampling grazed pastures when K storage within the forage is high.

For established native pastures and other low input pastures, soils should be sampled every three to five years. For hay crops, samples should generally be sampled every other year. Where intensive hay production is practiced (> 150 lbs N/acre/yr), especially on sands and sandy loam soils, the potential changes in lime and nutrient levels justify annual sampling.

Thatch Removal

Thatch buildup can greatly influence the measurement of soil P, K and lime requirement. Although much of the thatch may be removed by the lab in preparation, several states recommend that the undecayed portion be discarded while others suggest sampling only the mineral soil. Thatch buildup is not a serious problem in forage systems, but where present, it seems appropriate to follow Cline's (1945) recommendation to remove all vegetative matter not incorporated with the soil. As in fields where reduced tillage is practiced, this may best be accomplished by scraping away the loose vegetation with a boot or sampling tool.

Recommended Procedures in the Southern Region

Table 1 summarizes recommended soil sampling practices in the Southern Region based on contacts with a representative from each state in the region. Interestingly, several respondents contacted by phone were initially unaware of differences between recommended sampling depth for established, perennial forages and annual row crops and later called back to correct their responses. This reflects the low level of research activity in the area of soil testing for pastures and forages.

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Table 1. Recommended soil sampling practices in the Southern Region of the United States.

State	Sampling Depth		Years Between Samples	Time of Year	Remove Vegetation and Thatch	Reference
	Seeding	Established				
Alabama	plow depth	2-3"	2-3 P, 2 H[1]	NS[2]	NS	Cope et al., 1981
Arkansas	plow depth	3	3-5 P, 1-2 H	prior to greenup	Yes	Soil Sample Form
Florida	plow depth	6	2-3	Early Spring or prior to growth	NS	Hanlon et al., 1990
Georgia	6-8"	3-4	2-3 P, 1 if > 150 lb N/ac	Fall	NS	Plank, 1989
Kentucky	6-7"	3-4	3-4, 1 for High yld. Alfalfa, Clover	Fall (6 mo before seeding)	NS	Thom, 1990; Thom et al., 1987
Louisiana	plow depth	6	2-3	Fall	Yes	NS
Mississippi	plow depth	4-6	2-3	Fall	Yes	Funderburg, 1987
North Carolina	plow depth	4	2-3 P, 1 H	Fall	NS	Baird and Tucker, 1987
Oklahoma	plow depth	6	3-5 P, 1 H	NS	NS	NS
South Carolina	6" or plow depth	2-3	2-4 P, 2 H	Cool:Jul-Aug Warm: Nov-Feb	NS	Clemson Univ., 1982
Tennessee	plow depth	2-3	3-6	Fall	Yes	Jared, 1987
Texas[3]	plow depth	4	NS	Early Spring	NS	Pennington (undated)
Virginia	plow depth	2-4	2-3	Fall	NS	Donohue and Hawkins, 1979

[1] *P = Pasture, H = Intensively managed Hay.*
[2] *NS = Not specified.*
[3] *Unofficial recommendation is to sample both 0-2" and 2-6" intervals.*

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Sampling Soils With Turfgrass

William O. Thom and A. J. Powell, Jr.[1]

Introduction

Turf is a term used to define the interconnecting community of turfgrasses and upper stratum of earth filled with roots and/or rhizomes. Turfgrasses are plants that are regularly mowed to develop a uniform ground cover. Turfgrasses may be those more common forage species adapted for turf, or types that have been selected for this specific use. Both cool-season and warm-season grass types are commonly used for turf in the southeastern region of the U.S.

Turf is maintained to benefit man's environment. It's most important functional purposes are for controlling soil erosion by wind and water, elimination of dust and mud problems, and reduction of glare, noise, air pollution, heat buildup, and undesirable visual elements. Outdoor sports facilities use turf to enhance appearance, reduce injuries, and provide a resilient and uniform surface for leisure and recreation. A well-managed turf enhances beauty and attractiveness around homes, businesses, parks, streets, and in outdoor recreational areas.

Uniformities of cover and stand persistence are the major goals for growing turf. This is different from the major goal of crop plants that is to maximize yield of the harvestable portion of the plant. This makes the correlation of soil test results and recommendations very difficult for turf. Most turf species have a shallow root system, and following establishment all fertilizers are surface applied. The fertility management of these areas emphasizes maintaining a high density of plants with vigorous regrowth potential, keeping these dense stands in place for long periods of time, and maintaining a uniform stand characteristic of the plant species found in the particular turf areas. Therefore, the top inch or so of soil will show large variations depending upon fertilizers applied, irrigation management, and other topdressing treatments.

The Soil Growing Media

The turfgrass growing media is commonly a mixture of organic and inorganic materials that function as a source of nutrients and water, and anchors the grass roots. Common growing media include relatively undisturbed soils, disturbed soil areas, and modified soil areas (additions of sand and/or organic materials). Despite the type of growing media, a knowledge of the physical, chemical, and biological characteristics and functions of soil is important in understanding sampling of these materials.

Sampling Soils

A key point to keep in mind when taking soil samples is that only a pint or two of material may represent several million pounds of soil material. Therefore, care must be taken to assure that the sample accurately represents the area being sampled.

A soil probe, soil auger, garden trowel, or a spade and knife are suitable tools for taking core samples. A clean, dry bucket (preferably plastic) is needed for collecting and mixing the core samples. Soil sample containers and information sheets are available from laboratories that analyze the samples.

A minimum of eight to ten subsamples (cores) should be obtained from any defined sampling area to provide sufficient soil material for drying, grinding, and analysis. Subsamples should be collected in a random pattern, placed in the clean bucket, thoroughly mixed, and placed into the laboratory sample container. The sample identification should be placed on the laboratory container and placed on a corresponding map or identification sheet for the areas to be sampled.

Sampling for Establishment

Soils

Turf areas should be divided into smaller units based on topography, soil type, amount of soil disturbance, and amount of amendment added to the soil. Undisturbed soils vary with location in the landscape, dictating that a minimum separation of sampling areas be based on division into upland, side slopes, and lowland or bottom land. Undisturbed soil areas need to be separated from disturbed soil areas. Disturbed soil areas should be separated into smaller units based on amount of disturbance, soil removal or soil addition.

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Subsamples or cores should be taken to a minimum depth of four to six inches from each defined sampling area. This will provide a sufficient soil depth for correction of any nutrient insufficiencies before establishing the turf.

Sand and modified soils

These include areas in which a layer of sand or special root zone mix is placed over a soil, or gravel drainage layer (i.e., golf greens), and either undisturbed or disturbed soils in which large amounts of sand or organic material have been incorporated into the surface for textural and/or structural improvement. Such modified areas should be sampled separately from other areas of undisturbed or disturbed soil. Subsample cores (8 to 10) should be taken to the depth of the root zone mix or modification as this is the zone of concern in nutrient management.

Sampling for Maintenance

Benefits

The fertility status of a turfgrass soil is constantly changing because of (a) nutrient loss from clipping removal, leaching, and volatilization, (b) nutrient release from plant residues, organic matter, and specially incorporated organic materials, and (c) the application of fertilizers. Turfgrass that has a high degree of visibility or recreational use often requires a high level of management. These high management areas benefit from frequent soil analysis to detect potential nutrient needs. Areas that have a lower degree of maintenance need less frequent soil sampling.

Golf greens are an area that requires a very high level of management while a descending level of management may be experienced for golf tees, golf fairways, athletic fields, corporate turf, home lawns, and utility turf. Areas of high management and visibility usually require both higher levels of fertilizer and more frequent applications to maintain turfgrass quality and persistence. On the other hand, limited care areas such as roadsides only receive fertilization at establishment.

Thatch

Thatch is an accumulation of dead and living plant tissue located immediately above the soil surface. Thatch is highly ligneous, and thus highly resistant to chemical change and microbial degradation. With increased thickness, thatch may become a major area of root proliferation and thus be a significant influence on supplying plant nutrients. Some elements of high management, such as heavy nitrogen fertilizer applications, favor thatch development. Since thatch is almost all organic and very light weight, it becomes a misleading component of a normal soil sample. As a thick thatch layer becomes the main contributor of water and nutrients to the turf, it should be sampled separately. Analysis, similar to other types of organic materials, can be made on the thatch.

In turfgrass areas where thatch thickness exceeds 1/2 inch, the thatch should be removed before taking any soil sample used to measure soil pH, or other nutrients such as phosphorus and potassium. This suggests that turfgrass areas with thick thatch covers should have two samples taken for analysis to more correctly reflect maintenance nutrient needs.

Areas with a thatch thickness of 1/2 inch or less can be analyzed for nutrient needs with the thatch either mixed in as part of the sample or removed before taking the sample cores.

Frequency

High management areas(golf greens, golf tees, etc.) should be sampled each year because of the likelihood of receiving frequent fertilizer applications and watering. Thatched areas (thatch greater than 1/2 inch thick) should also be sampled annually to determine needs for pH correction. Areas such as golf fairways, athletic fields, industrial turf, and high management home lawns can be sampled every two to three years depending on turf quality. Quality reductions are indicated by increasing areas of stand loss, chlorotic color, density reduction, and lack of desirable growth between mowings. Samples should be taken about once every three to four years from home lawns with low management, and utility turf that is not frequently mowed, fertilized or watered.

Depth

Highly maintained turfgrass areas should be sampled to a depth of not more than 2 inches to determine the nutrient needs of the most active roots near the soil surface. If the samples are taken deeper but the roots are very shallow, then the surface soil with the most influence from roots and topdressing treatments will be diluted with the soil below the active zone. Areas with thatch should also be sampled within the top 2 inches since the thatch is a great indicator of shallow rooting.

Areas of lower management should be sampled to a depth of 2 to 4 inches. These include golf fairways, athletic fields, industrial lawns, home lawns and utility turf.

Where there has been a modification of the soil with sand or organic material, these modified areas should be sampled to a depth of 2 to 3 inches.

Number of cores

About 15 to 20 subsample cores should be taken from each sampling area, placed into a clean, dry plastic bucket and mixed thoroughly. A total of about 1 pint of soil or soil plus organic material is needed by the laboratory to perform the requested analysis.

Sampling time

Since turfgrasses are perennial, they can be effectively sampled any time of the year. However, because of nutritional effects upon the heat tolerance of cool season grasses and cool temperature tolerance of warm season grasses, sampling before the most stressful part of the season is suggested. In the transitional climatic zone of the southeast U. S. up to 75% of the fertilizer is recommended for application to cool season grasses during the months of September through December. Warm season grasses are typically fertilized during the summer growing months.

Sampling Problem Areas

When sampling problem areas for soil analysis, it is important to take a representative sample from the problem area, and a representative sample from a normal area next to the problem area. Both samples should be sent to a laboratory for analysis to allow for comparison and more accurate determination of the severity of the problem. Although some conclusions can be drawn from a single sample, having another sample result from soil or growing media near the problem allows evaluation of results on like materials.

The nutrient balance in the turf soil is constantly changing. This is particularly true with the pH of the soil. Soil acidity is continually developing in the more humid regions of the U.S. Leaching of carbonates, sulfates, and nitrates are accentuated in these humid regions where precipitation during much of the year exceeds evapo-transporation. Many fertilizers, particularly nitrogen, contribute to increasing soil acidity. Soil or modified soil areas suspected of having low pH problems should be sampled as needed to a depth of 2 to 3 inches.

On the other hand, high soil pH can develop when large amounts of salts or carbonates are added through long term use of irrigation water applied to high management areas. Salinity can develop when high concentrations of electrolytes or salts exist in the soil. Excessive salts interfere with water absorption, thus giving an appearance of "drying up" while the soil is still quite moist. Since periods of high rainfall will reduce the problem, areas suspected of having "salt" problems should be sampled during dryer periods of the season to assess the maximum severity. Subsample cores should be taken to a depth of 3 to 4 inches.

In turf areas where sand or sand and organic materials have been added to support a special high management use, such nutrients as phosphorus are likely to become concentrated near the surface. This is especially true following several years of continued phosphate fertilizer application when nutrient removal has not been high. Though current research does not indicate toxicity problems from very high soil phosphorus levels, these very high levels become concentrated near the surface and may cause large imbalances in nutrient uptake.

Soils that have been modified with the additions of sand or sand and organic materials often become more of a challenge for nutrient management when the cation exchange capacity (CEC) is low. This factor is important in determining the frequency of applying certain fertilizers, as well as rates of application. Cation exchange capacity should be determined on a modified soil or growing media before seeding by sampling to the depth of modification. During maintenance, the CEC should be determined as part of any test for "salt" problems. In this situation, the subsample cores can be taken to a depth of 3 to 4 inches.

Turf areas that have sand as the primary growing media or where the soils have been modified with the addition of sand, CEC is usually low. This low CEC may allow more leaching of potassium. Also, where clippings are regularly removed, potassium may be depleted from the soil. In these sand modified areas, an annual soil analysis is suggested to monitor soil potassium levels. Unfortunately, few soil test correlations are available for turf grown in these modified soils.

Micronutrients such as boron, copper, iron, manganese, and zinc may be of concern with certain high management areas under intensive mowing, or where some species or cultivars may be identified as having greater needs of these nutrients. Most soil materials contain sufficient amounts of these elements, or most are contained in fertilizer materials commonly used in high management turf areas. Soil pH is the most important factor in determining the availability of these nutrients to the turfgrasses. Therefore, monitoring soil pH with a regular soil sampling program can often keep micronutrient deficiencies to a minimum. However, some of these micronutrients may reach toxic or near toxic levels if used at high rates over a long period. If problems with either micronutrient deficiency or toxicity are suspected, subsample cores should be taken to a depth of 3 to 4 inches.

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Soil Sampling Proceedures for Histosols

E.A. Hanlon, D.L. Anderson, and O.A. Diaz

Correct sampling of Histosols directly depends on the management objectives for which the samples are being collected. A common objective is to assess the soil's contribution to the crop nutrient requirements through a calibrated soil extractant (Sanchez and Hanlon, 1990). However, environmental concerns may require monitoring of nutrients with the objective of detecting some flux in nutrient levels (Anderson et al., 1992). This section will address sampling techniques required to accomplish these two goals for Histosols.

Sources of Variability

Histosols vary both temporally and spatially. The sources of variation spatially are usually associated with the formation of the Histosol (type of vegetation, underlying mineral strata, and drainage) and human activity. The greatest temporal variation is usually associated with human utilization of these soils (i.e., drainage structures, roads, canals, crop production, etc.).

Histosols in Florida were formed in wetlands under anaerobic conditions. Commitment of these soils for intensive agricultural purposes requires the use of extensive drainage structures. With drainage, aerobic conditions promote oxidation. The overall oxidation process results in subsidence, a term which describes decreasing soil surface elevation caused primarily through microbial activity, as well as compaction due to physical settling, vehicular traffic, and tillage operations. Additional losses through water and wind erosion can be significant. Tillage not only increases aeration, but increases the degradation of fibrous materials. This degradation increases surface area and bulk density resulting in reduced drainage capability.

Agricultural Construction

Conversion of Histosols to crop production is usually begun by providing drainage through the construction of canals and ditches. Underlying limestone is often brought to the surface during construction, and soils adjacent to these structures are influenced by these spoils. Proper soil sampling should address these changes in soil characteristics due to agricultural construction.

Ditches: Spoils from ditching to 1 m have traditionally been deposited on the soil surface, often on only one side of the ditch, and distributed through leveling. This underlying limestone/marl material greatly modifies the chemistry of the adjacent soil. Regular cleaning of the ditches also results in increased spatial variability. Diaz (1990) reported that approximately 10% of the surface soil was affected by ditching when the spoil was leveled. Soil pH differences for one such site, an Okeelanta muck (euic, hyperthermic Terric Medisaprist) from the Everglades Agricultural Area, are shown in Fig. 1. Such chemical alteration directly affects plant availability of nutrients such as P and micronutrients. Crop yields may be influenced by these ditch spoils. Soil sampling for crop nutrient recommendations may be greatly affected, resulting in large over- or underpredictions for some nutrients.

Roads and Canals: Permanent roads are adjacent to the larger drainage canals, and are constructed above grade to provide all-weather use. Spoils from canals are often used to build access roads, but spoils may affect between 5 to 15 percent of the land area. Thus, about 15 to 30 percent of the soil variability may be influenced by road and drainage construction.

Other Sources of Variation

Soil depth: Greater spatial variability of soil chemical characteristics were reported by Diaz (1990) on shallower organic soils (depth < 1 m). High spatial variability can be seen in Fig. 1 (Diaz, 1990). The underlying limestone can greatly alter soil pH by upward movement of carbonates with water table fluctuations, or by deep tillage which may mix some of the limestone into the soil profile.

Cropping and Fertilization History: Prior fertilization practices influence the level and uniformity of nutrients within a field. Figure 3 shows two 8-ha blocks of Lauderhill muck. The field on the left was in sugarcane while the field on the right was in sod production. This figure can be directly compared to Fig. 2 noting the parallel between soil pH and Mehlich-I extractable P. As soil pH increases, the extractable P is reduced. The Mehlich-I extraction was designed for soils with pH < 6.5 (SRIEG-18, 1983).

The University of Florida recommends greater fertilization for vegetables than for other row crops grown on Histosols (Sanchez, 1990). Although soil extractable levels reflect greater use of fertilizers used for vegetable production, variability of extractable nutrients has been shown to be lower (Diaz, 1990). Differences due to water movement, soil pH, depth, etc. all tend to add to the variability over both time and distance.

Water table management: Fluctuations in the water table have a direct bearing on the oxygen status of the soil. In organic soils, the change from anaerobic to aerobic conditions causes a dramatic increase in the mobility of nutrients, especially P and N. Diaz et al. (1991 and 1991a) reported that while aerobic conditions enhanced N release, intermittent flooding resulted in the release of a significant amount of P into drainage waters.

Soil Sampling Strategies

Sampling for Soil Fertility

Given an understanding of the above sources of variation, estimates of the number of samples to be composited can be calculated. Table 1 reflects the average number of samples to be composited when using the soil test to provide fertilizer recommendations. This table was developed upon the data presented by Diaz (1990) using the following equation:

$$n = \frac{(t \times STD)^2}{d^2} \quad \text{such that} \quad t = probability\ \frac{1-\alpha}{2}$$

where

- n = required number of samples,
- t = standard normal deviate corresponding to the level of significance alpha,
- STD = sample standard deviation, and
- d = sample mean x percent relative error.

Sampling according to the well-known guidelines of 15 to 20 soil cores taken at random or by a zig-zag path over the field will often result in predictions which are within the 95 percent confidence level, but only at or slightly less than the 20 percent error level (Table 1). To decrease the error level, substantially more effort must be put into the sampling. However, if the known sources of variation discussed above are considered, predictions based upon such samples will be markedly improved.

Sampling for Environmental Monitoring

Recent work by Anderson et al. (1992) has indicated that inherent spatial and temporal variability in diary holding areas on mineral soils reduce the effectiveness of samples for monitoring nutrient buildup. However, for estimating fertilizer needs for forage production, a normal zig-zag or random pattern of sampling adequately predicted the soil's contribution to the crop nutrient requirements.

Table 1. Number of samples required to achieve the indicated levels of confidence and error for selected nutrients and crops (after Diaz, 1990).

	Sugarcane					Sweet Corn			
	Confidence Level (%)								
	90		95			90		95	
	Relative Error (%)								
Measurement	10	20	10	20	Measurement	10	20	10	20
pH	1	1	1	1	pH	2	1	2	1
P	37	9	52	13	P	29	7	41	11
K	54	13	76	19	K	23	8	32	8
Mg	12	3	16	5	Mg	62	16	88	22
Fe	20	5	29	7	Fe	31	9	44	11
Mn	43	11	62	16	Mn	42	11	59	15

Sample numbers represent findings from five 8-ha sugarcane fields and two 8-ha sweet corn fields. Calculations are based on 575 and 230 observations, respectively.

For monitoring purposes, it appears that "cluster sampling" may be the method of choice. Several researchers (McIntyre, 1967; Ball and Williams, 1971; and Friesen and Blair, 1984) have reported similar findings. In this sampling method, several locations are established within the field and all soil sampling is done within a short distance of these locations. Spatial variability is greatly reduced if the locations are selected with knowledge of the sources of variability discussed above.

An additional advantage of this technique is that changes with time are easier to detect when sampling from fixed position within a field. This approach means that the number of samples taken from a field is greatly reduced. While statistical evaluation of the data are proceeding, initial indications are that a small number of observation points are needed for Histosols, from 5 to 10 sites when located away from ditches, canals, and roads.

Summary

The sources of spatial and temporal variation have been discussed and two methods of sampling have been suggested. The more traditional sampling methodology was found adequate for estimating most soil-extractable nutrients with 95 percent confidence, but between 10 and 20 percent error. Similar preliminary results can also be obtained by selecting from 5 to 10 locations within the field and collecting samples within a short distance (<1 m) from each location. The latter sampling technique appears well suited for monitoring nutrient changes with time.

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Figure 1. Spatial variability of pH (2:1, water) in adjacent 8-ha, Okeelanta muck fields showing effects of ditching (center vertical line) and road construction (across bottom) (after Diaz et al., 1991b)

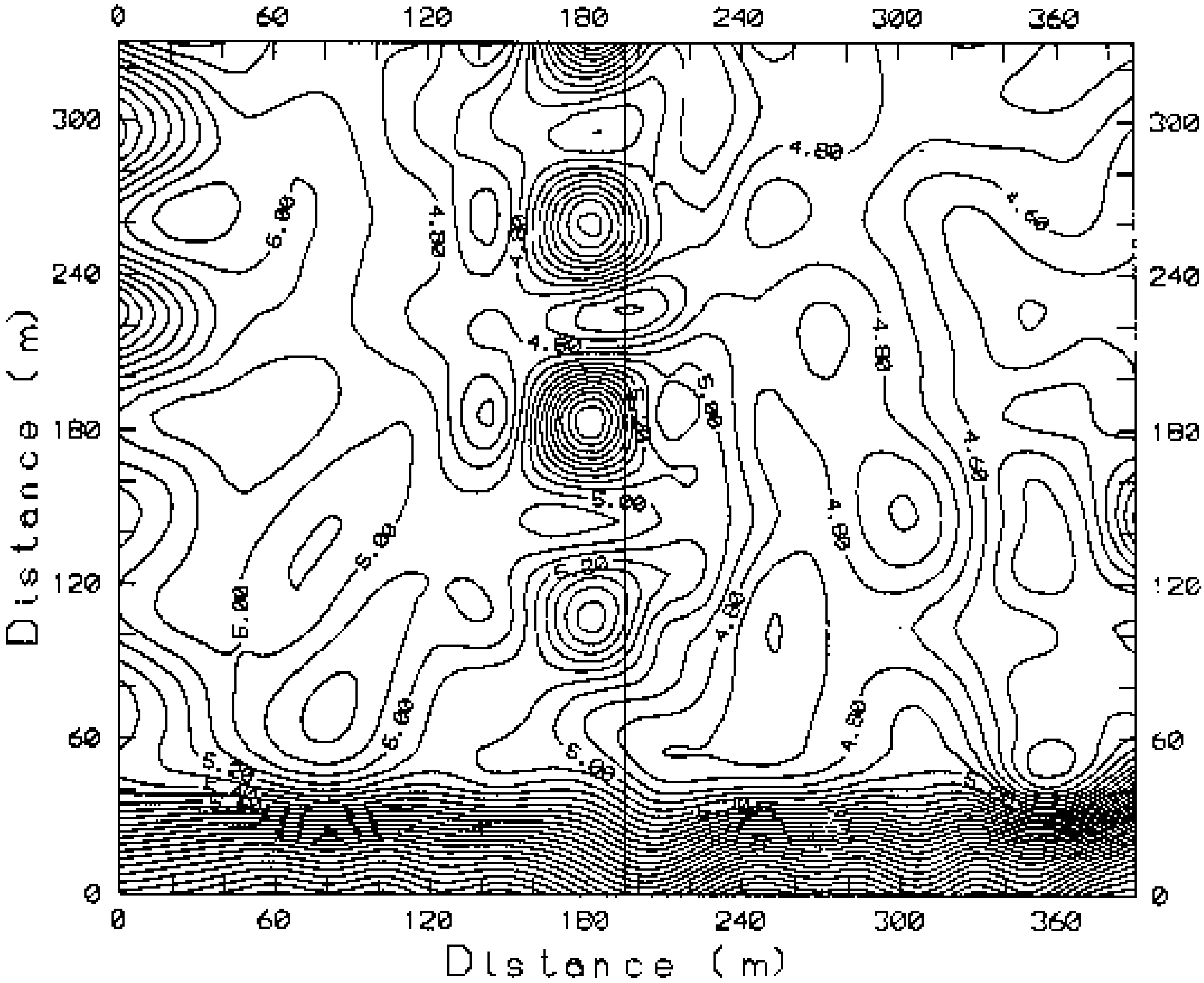


Figure 2. Spatial variability of pH (2: 1, water) in adjacent 8-ha, Lauderhill muck fields showing effects of road construction (across bottom) (after Diaz et al., 1981b)

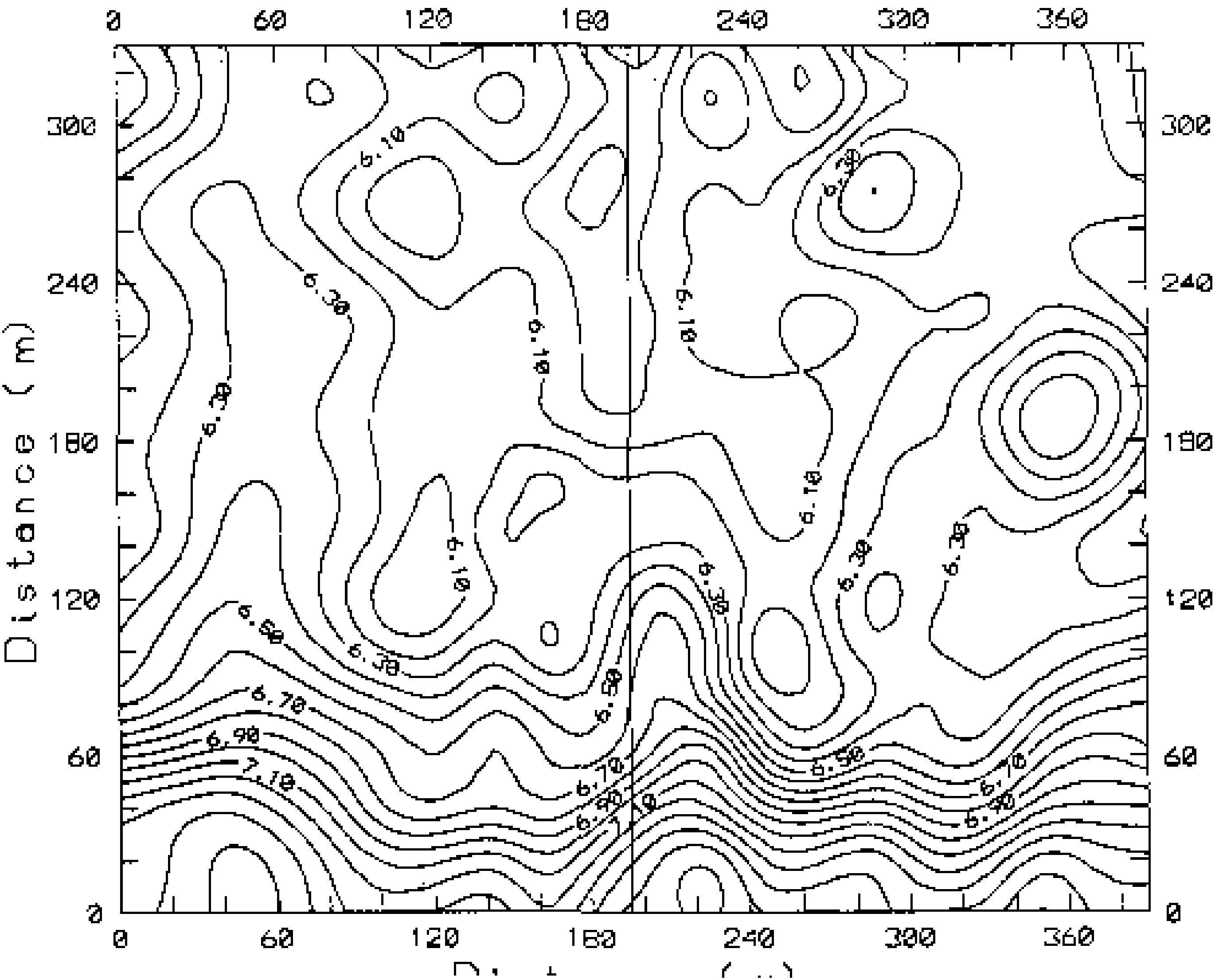
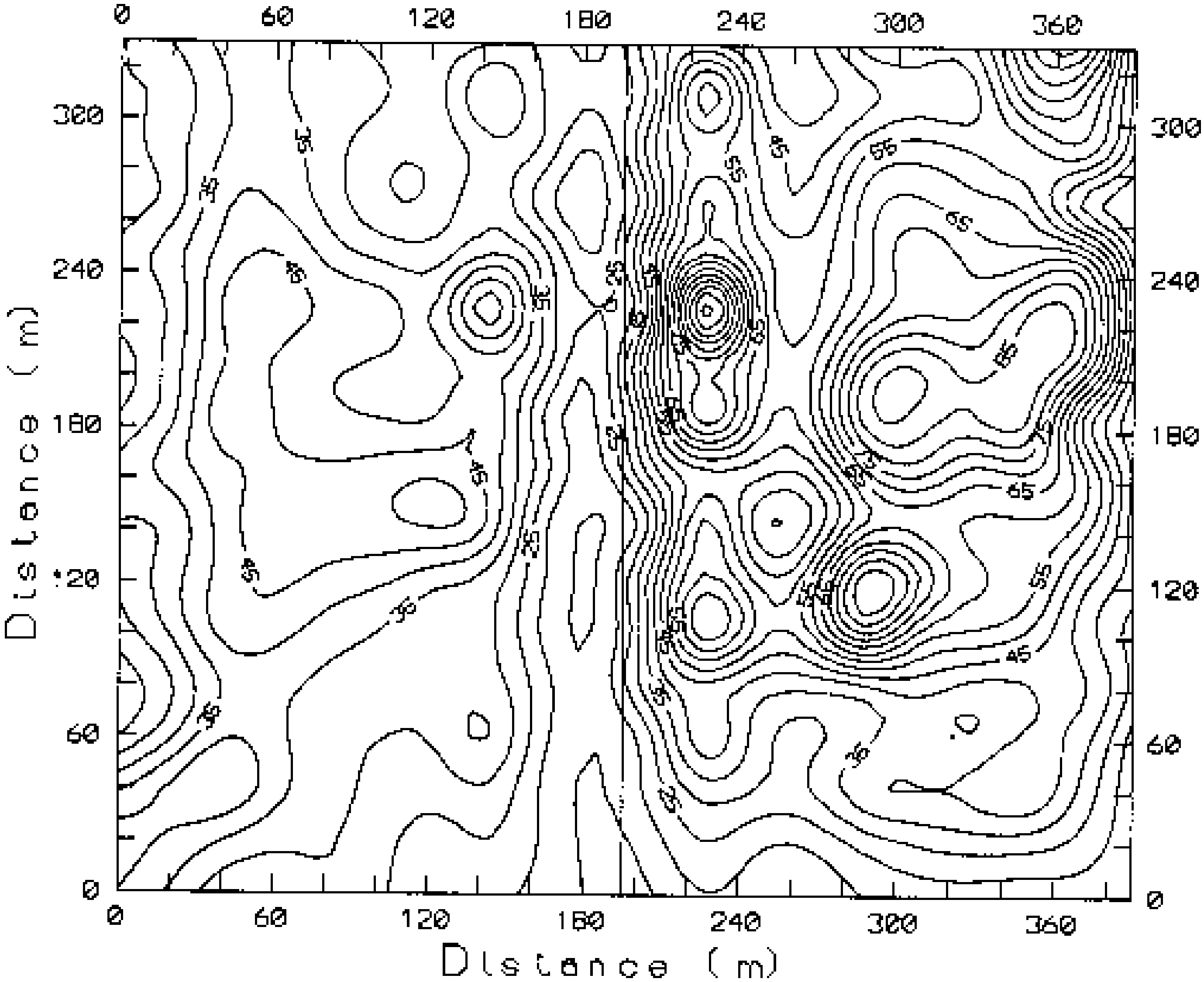


Figure 3. Spatial variability of Mehlich-I extractable P in adjacent 8-ha, Lauderhill muck fields. Field on the left has been under sugarcane production while the field on the right has been managed for sod production (after Diaz et al., 1991b)



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