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SOME SOIL PROPERTIES WHICH INFLUENCE THE USE OF LAND IN WEST VIRGINIA

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The importance of the soil in planning and putting into operation those practices which are necessary to insure adequate conservation and increased production make it especially desirable to present all available information regarding the soils of West Virginia at this time. Present information is too meager for more than a preliminary report, but an outline of the general objectives, methods of study, interrelations among methods, and skeletal results is required to provide a background for any later revisions and detail. It is hoped that some of this background material will help to clear away any confusion which may exist regarding the meaning of certain soil properties and measurements as applied to West Virginia conditions.

Some soil properties can be seen but not measured. Others are measurable but cannot be seen. The meanings of some are well understood; others are questionable or obscure. All of these and many more complications enter into the study of soils as related to soil management for increased crop growth and for soil conservation. One question answered raises new questions. Progress in the field means new demands on the laboratory, and new laboratory techniques require field samples to interpret their meaning. Farm and field response follows small plot results, or the reverse, and invariably there is an interlocking of all the approaches to a particular problem. Soil, crop, climate, animals, and man in their varied forms are all responsible for the yield from the land, and new developments must finally satisfy them all.

The role of the soil in agricultural problems varies greatly in importance. Sometimes it is dominant; at other times it seems incidental to the crop or to the practice

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of man. In any case, soil is the foundation of the farm, and its use is of utmost importance in determining the continuation of various farm enterprises. As the understanding of the soil increases, there will be greater opportunity to use it wisely.

The results reported here were obtained by studying soils as they occur in the field and by collecting samples from areas representing typical conditions throughout the state. All factors in the field that can be seen are described in specific terms. These observations and descriptions are shared by several individuals, and the soil distinctions are made to conform with the present systems of classification and mapping by the Soil Survey Division of the Bureau of Plant Industry, Soils, and Agricultural Engineering and the Soil Conservation Service. Samples are commonly taken in roadcuts or excavations to afford detailed observation. Pasture areas are most frequently chosen because of the important role of such land and the relative univormity afforded with respect to treatment, erosion, and use. Timber, clean-tilled, or hay lands are, however, sampled at times if the soil conditions seem especially significant or typical of problem areas. In any case, attention is given to present plant growth and to root development relative to the soil.

The samples collected are taken to the laboratory and studied by chemical and physical means in such detail as seems desirable to assist in characterizing them. Standard laboratory procedures are used in most cases, but adaptations are applied where standard methods seem to be inadequate. Field notes and laboratory data are compiled, studied, and compared with results from plot studies and with theory to form a better framework of facts and understanding.

PREVIOUS WORK

The soil-survey maps and bulletins which have been completed by the Soil Survey Division of the United States Department of Agriculture, Bureau of Chemistry and Soils, and by the West Virginia Geological Survey for every county in the state provide fundamental field information regarding soils and slopes in West Virginia. From the laboratory approach, three bulletins of the West Virginia Agricultural Experiment Station provide basic analytical data (5, 12, 42) These cover chemical analyses of 485 soil samples representing important soil series within the state and serve as a valuable source of information. They show that average limestone soils are less acid besides containing more total phosphorus and nitrogen than the soils derived from sandstones and shales. All the soils analyzed were relatively high in total potash except a few sandy samples. These various results were shown to correspond roughly with crop response to lime and fertilizer in the state, but emphasis was placed upon the limitations of the information presented. It was pointed out that various soil differences were seen within particular soil types as mapped in the field, that total chemical analyses were obviously inadequate to judge the immediate availability of soil nutrients, that limiting factors such as soil drainage were not evaluated, and that many problems of fertility would necessarily require field plot experimentation for their solution. In recent years the progress of agronomic science has thoroughly demonstrated the necessity for considering the various factors indicated.

Progressive change in the field mapping of soils has placed greater emphasis upon the soil itself and less on the material from which it was derived. The degree of erosion has gained recognition along with the other soil features, and greater detail allows for more soil separations. Consequently the recent surveys provide much more information. They represent a challenge to find out what the separations mean in terms of approved laboratory procedures and soil-management practices.

In 1937 a bulletin was published concerning the systematic grouping of West Virginia land into classes based on use and agricultural value (36). It brought together all of the available information regarding soils, slopes, erosion, stoniness, climate, etc. into a general classification. The groupings are necessarily generalized because of lack of detailed information as well as limitations of scale, and, although the classes as shown have many uses, the author has indicated the need for further information about the soils and other limiting factors. As additional field and laboratory results become available, it is to be expected that refinements will become possible in any such classification, and there is always the hope that new developments will show the way to overcome apparent limitations with consequent shifting of land classes.

FIELD SAMPLING AND DESCRIPTIONS

It seems neither necessary nor wise to follow a rigid system of soil sampling and description in this study. Some samples must be collected with particular objectives in mind, whereas others are taken for more complete analysis and general comparison. Most profile samples are taken from all clearly defined horizons of a particular soil profile, and an attempt is made to record all pertinent information. Some of the results reported, however, were obtained by sampling only the surface soil or some particular horizon within the soil profile.

Sites are selected to represent various soil types as we know them, and detailed descriptions are taken so that there will be a minimum of confusion as to whether the soil typifies the type or belongs in some new subdivision of mapping. Whatever the situation, the notes will permit relocation of the site and are detailed enough to enable a field specialist to form an opinion as to the soil represented.

Most samples are collected from untreated soils, but treated samples may be taken if the history is known. In taking profile samples, the total depth has been governed by one of two things. If a structural B horizon is evident, samples are taken through this and into the apparent C horizon. If no B horizon is recognizable, the sampling is carried down until parent rock predominates or interferes. Compared to soil-profile sampling in various other states, it is evident that the average depth will be less in West Virginia because of the relatively shallow thickness of the soil mantle in many places.

It has not seemed practical to subdivide surface or subsoils into very thin layers in all sampling, but in order to determine certain details regarding the distribution of organic matter within surface soils in pastures, a number of determinations were made with samples of $1\frac{1}{2}$-inch depths. Other surface soils have been subdivided only insofar as distinct differences were evident which would normally be considered as justification for recognizing an A_0 or A_2 as well as an A_1 horizon.

LABORATORY METHODS

All chemical data reported are for air-dry samples put through a 2 mm. sieve, except pH, which is determined before the soil reaches air dryness, and except organic matter, which is determined on dry material ground to pass a 60-mesh screen. Gravel contents ($>$ 2 mm.) would affect the calculation of results to an important extent in certain cases, but this factor is neglected unless specifically mentioned.

TEXTURE

Mechanical analyses in the laboratory have been made by the pipette method with sodium oxalate as a dispersing agent and a 15 minutes' stirring in a drink-mixing machine (37). This method has seemed effective in dispersing the various samples studied.

SOIL STRUCTURE

Dispersion measurements have been made essentially as described by Middleton (29). Pore-size distribution was determined as previously described by the authors (45). Evacuation of samples before wetting is used as standard procedure in accordance with the suggestion made in the above reference that prior evacuation prevents physical disruption of natural samples, thus giving a more accurate picture of the true pore-size distribution. As an index of the fine-pore content and water-holding capacity, moisture equivalents have been determined by the Gooch crucible method (9).

Field and laboratory observation supplied much of the present information about soil structure which no known methods are designed to measure.

Organic Matter

Organic matter was determined by the method of Walkeley and Black as modified by Browning (8). This determination seems to give accurate relative values for surface soils unless unusual quantities of fresh organic matter are present. In that case it is probably unreliable (44), but few if any of such samples are involved in the present results.

With subsoils, data have been published (32) showing that there are wide differences in the ease of oxidation of the organic matter, but it would seem that the relative values for oxidizable material might be reasonably satisfactory. Results in this laboratory cast considerable doubt upon the validity of lower subsoil comparisons by this method. There is apparently some factor other than organic matter which sometimes introduces unreasonable fluctuations in the values obtained for similar subsoil horizons. These wide variations are usually obvious, but they seem unpredictable and lend doubt to the use of lower subsoil values in any except the most general types of comparisons.

Acidity

Soil reaction, expressed as pH, is measured with the glass electrode in a 1-2½ soil/water suspension. Fresh field-moist soil was used in most cases with 24-hour soaking in water before the determination. Variations from this procedure are noted. Dried and stored samples have invariably showed a decrease in pH which is only partially reversible by soaking. Greatest differences are with high-base subsoils or limed surface soils. Samples collected in summer or early fall have somewhat lower pH values than those collected in the winter or spring.

Buffer Curves

These are obtained by adding base to a 1-2½ suspension of the soil in water and determining the pH after essential equilibrium has become established. $Ba(OH)_2$ and $Ca(OH)_2$ gave the same results for a number of samples; hence $Ba(OH)_2$ is used because of its higher solubility. Two-day contact has been found necessary for essential equilibrium. For convenient reference to field liming as well as for comparison with results of the next method to be described, pH 7 is considered as essential saturation with bases, although it is recognized that higher pH values are required for saturation from any theoretical point of view. There seems to be no practical gain by accepting a theoretical saturation point well above the aim of all field-liming programs. In the same way that Pierre defined lime requirement relative to the desired pH (33), so for the present purposes all base-saturation comparisons refer to saturation at pH 7.

Exchangeable Bases and Exchange Capacity

These have been determined for most samples by a slight modification of the widely used neutral, normal, ammonium-acetate method (6). In addition, bases have been determined by the Kappen acid-equilibrium method (21), and in some cases exchange capacity has been obtained from buffer curves as described above. The method used will be indicated in connection with the data.

A comparison of the methods mentioned for determining bases has shown a fairly satisfactory correlation between the two, although the Kappen method gives consistently higher results and the differences tend to be greater with shaly samples than with highly leached terraces or sandy uplands.

This apparently indicates a certain degree of action by the acid upon the unweathered minerals of the shale, whereas with the terraces and sands there are almost no fresh minerals except quartz, which has no basic properties.

Soluble Phosphorus

All determinations have been made by the well-known Truog method (48).

Exchangeable Potash

Potassium has been determined on an aliquot of the neutral, normal, acetate leachate by the method described by Brown et al. (7).

SOIL-PROFILE PROPERTIES

Soil Color

It is obvious that individuals may vary widely in their descriptions of color, and color standards, therefore, offer a considerable advantage. Some difficulty has been encountered in matching against the standards used (39), but this is ordinarily not serious. Certain standards which are lacking, notably greyish brown, would seem likely to match many surface soils better than the brownish greys given. The standards invariably recognize less red in a number of soils than is described by most people, but this may be justified, since soils of certain other areas undoubtedly show more real shades of red than are characteristic of West Virginia. The Hagerstown subsoil, for instance, is often described as reddish brown or even as red by some people, whereas the standards seem to indicate a bright brown or dark orange. Another example is the Upshur, which seems red to most people but is light brown or, in some locations, weak or light reddish brown by the chart. Calvin soil is also considered red, and in the case the chart is more in agreement, the most common chart designation being dusky red. Some horizons, however, match certain shades of brown.

These apparently represent the widest divergencies between ordinary local opinions and the color standards. By using the standards as the basis for all soil descriptions these local opinions are probably unimportant.

In any interpretation of soil colors in West Virginia, it is obvious that inherited colors should be distinguished from developed colors insofar as possible. Most of the uplands show strong inherited colors which are nothing more than the color of the parent rock carried over into the soil. Examples are the Upshur and Calvin, which are derived from red shales. Many of the other shallow upland soils could be cited as well. Such colors may be significant if they are associated with parent rocks having certain specific chemical or physical properties, but in many cases it is believed that these inherited colors have little meaning in terms of characteristics which influence the nature or fertility of the soil. If true, this is unfortunate, since inherited color is a relatively clear-cut characteristic which is likely to be accepted as the basis for soil-type distinctions in preference to other less obvious properties which may have some fundamental significance. For example, there would probably be a strong tendency to group reddish acid-shale soils into the Calvin series, although variations in the depth and development of the soil profile or in base content on such shale might be very great. A mature soil with distinct B horizon would sometimes be seen, whereas in other cases the soil would be little more than a thin mantle of weathered soil material with slight organic-matter enrichment overlying the parent rock. The deep soil would be recognized as a different series if it were well defined, but color would probably overshadow depth unless the surveyor was especially alert. This might lead to a lumping of fundamentally different soil profiles on the basis of the superficial similarity in color, although it would be unlikely that the color would be an important characteristic, either pedologically or practically, whereas soil depth and horizon development are of recognized significance. Similarly, variations in base content might be large and important, but inherited color would tend to determine the soil separation.

The authors realize that such detailed difficulties as described could be found within practically any soil type mapped anywhere, because of the impossibility of making all the minute distinctions which occur in nature. The illustration is used to indicate that a factor such as soil color cannot be expected to provide a sound basis for use of the land, because inherited colors are not fundamentally important and are likely to obscure less obvious soil characteristics which do determine the capacity and use of the land.

Developed soil colors are not always easy to distinguish from inherited colors and are not always simple to interpret, but ordinarily they seem to promise more meaning. The pale yellow and grey of the Monongahela and Cookport series are obviously a result of development and suggest leached, erosible, infertile soil. The uniform reddish brown (strong brown or dark orange by the color chart) of the Hagerstown has developed and seems indicative of a well-aggregated soil with high fertility. The pale grey, mottled with rust brown in the subsoil of Tyler, Purdy, Atkins, and Blago, has developed and apparently indicates a generally high but fluctuating water level with reducing conditions predominant most of the year. With Blago the high water level is probably more consistent than with the lighter colored soils mentioned.

In surface soils the organic-matter content tends to dominate other coloring agents, giving the gradation from light to dark which is often accepted in soil groupings. Generally throughout West Virginia a surface soil is rated as dark if it has more than about 4 percent of organic matter. The average upland is a loam or a silt loam in texture, and this influences the amount of organic matter required to give a certain degree of darkness. Clays are not likely to be considered dark unless the organic-matter content is 5 percent or more, whereas sandy loams appear dark with 3 percent or even less.

This discussion is intended to draw attention to the factor of soil color, which is being considered in the present studies. Certain color differences will be mentioned in connection with other soil factors and with laboratory measurements. It is hoped that accumulated data and experience may add significance to the various color distinctions, but there is at present little known proof of the importance of particular colors in West Virginia soils.

Depth and Gravel Content of the Soil Mantle

In West Virginia, where upland soils are ordinarily rather shallow, the total depth of unconsolidated material over the solid rock is one of the most important factors determining the ultimate use of the land, particularly its use for any deep-rooted crops.

The depth of soil material represents a balance between rock weathering and natural or accelerated erosion. Aside from bottomland and terrace soils deposited by stream action, there is a tendency for the deeper mantles of upland material to accumulate on the lower part of slopes. Here it is recognized as colluvium and is distinguished from the adjacent upland in detailed soil mapping. These deep colluvial soils are potentially among the most productive soils of the state. Often they are suited to more intensive cropping than the adjacent upland. Solid rock is often covered by six feet or more of soil material containing only minor quantities of shale and stone. This material is normally deepest on the lower part of slopes and thins upward toward the ridge tops. Where there is no colluvial influence, upland shale soils are normally only 20 to 30 inches in total depth.

It is difficult to estimate the acreage of deep colluvial soils because their occurrence is a matter of degree, and their contacts with the residual upland are poorly defined. It seems, however, that colluvial soils with bedrock buried deeper than 3 to $3\frac{1}{2}$ feet are much more abundant than is commonly believed. Various instances are known where this depth of material extends at least half way to the top of long slopes, reclining on slopes of 30 percent or more. There are also considerable areas of such soils on rock or old erosion terraces at various levels above the valleys, separated by shallow soils derived in place. It is difficult or impossible to separate all such areas from the ordinary upland even in detailed mapping, but full attention would seem justified in detailed farm planning because of the urgent need for productive crop land on most West Virginia farms.

The colluvial benches should not be confused with the high acid terraces derived from old alluvium and often found in similar positions. True colluvial soils are less strongly leached, darker colored, have better structure, and have no subsoil "pans" like many of the alluvial terraces. They are most readily recognized by their content of unsorted, angular rock fragments. Colluvial soils are as fertile as the bordering upland and are invariably more productive because of their greater depth, whereas alluvial terraces are ordinarily less fertile and more limited in their productive capacity.

Studies of numerous cores near Morgantown (17) in Monongalia County have revealed some of the deeper profile characteristics and water relations of colluvial soil of this area (17). Relatively strong leaching of bases has occurred to depths of about four feet, below which the pH and the base content increase. This increase in pH and bases seems associated with increased mottling and increased clay content. The layer above four feet up to within about 20 to 30 inches of the surface is strongly acid (pH 4.8 to 5.0) and quite silty (17,18). It apparently corresponds with the Y horizon, which has been described in other areas (13,50), occurring below the structural B horizon. The silty horizon has low coherence and is considered as the main zone of weakness and movement in soil slips of this area (18). Recognition of this horizon in the field can probably be used as a criterion of the danger of soil slipping. If tile drains are placed in such soil, they should probably be located at the base of this leached, silty layer to assure that none of this material can become supersaturated and start to flow down the slope. The failure of some tile or ditch drains probably has resulted from improper depth placement in such soils.

There is considerable information about the depth of upland soil profiles in the Eastern Panhandle (11) and about the importance of this factor to the orchard industry. Probably not enough attention has been given to soil depth throughout the remainder of the state, particularly in connection with the growth of alfalfa, fruit and forest trees, and to some extent, corn. On many of the shaly uplands the soil material has been found to contain 50 percent or more of gravel within 18 to 24 inches of the soil surface, with firmly bedded shale or sandstone at 36 inches or less. In extreme cases, of course, the shale predominates up to the immediate surface, but the depths and the gravel content listed are quite general in the true Gilpin, DeKalb, Calvin, and other major upland soils.

A certain amount of gravel dispersed through a soil profile is probably beneficial in maintaining permeability and preventing erosion, but when the content of coarse material exceeds about 50 percent of the total soil weight in the main plant-root zone, it is believed that the crop is likely to suffer very seriously. With alfalfa or apple trees a depth of three feet to firmly beeded shale is obviously insufficient for best results. With corn, gravel contents approaching 50 percent within the 12 to 18-inch depth are believed likely to be seriously limiting to growth. Corn roots seldom extend much below 18 inches in this region.

With grasses and white clover on pasture plots in Greenbrier County, the growth and response to treatment has seemed little influenced by a measured gravel content of

10 to 20 percent, but stunted growth, drouth damage, lack of clover, and persistence of inferior grasses has been evident where the gravel content is 50 to 60 percent of the surface soil. This gravel is mainly chert or flint and practically nonporous.

Much more study is needed to determine the full significance of gravel content as well as of total soil depth. The above suggestions are offered on the basis of a number of measurements of gravel proportions in the soil and a variety of observations as to root relations and crop success. It is hoped that further information will permit more specific suggestions as present studies are continued. In any final analysis the nature of the gravel must undoubtedly be considered as well as the total amount, because the porosity and other properties of gravel are quite variable.

Soil Textures

This soil factor can be evaluated in the field within moderate limits, but it is important to have laboratory data as a check on field evaluation. It is not considered essential at present to make mechanical analyses of all the soil materials sampled but rather to have a body of representative results accumulated for reference and to make occasional analyses of new samples for specific purposes. Considerable data have been obtained, and it is felt that these serve the initial purpose, although other mechanical separations will be required from time to time, especially in connection with soil structure or aggregation studies.

The important role of mechanical composition of soils is obvious since texture is related to practically all of the fundamental physical and chemical properties. It is not the particle size alone, however, but also the mineralogical make-up which governs the various reactions of the mineral fraction of soils.

Mechanical analyses of 18 complete profiles indicate that 8 surface soils are silt loams, 8 are loams, 1 is a clay loam, and 1 is a clay. If we average the various horizons of the corresponding subsoils, the results show 12 clays 4 clay loams, 1 silt loam, and 1 loam. Since 7 of the silt loam profiles are from limestone areas, it is believed that these textures average heavier than the general uplands. Most of the shaly uplands are apparently loams or shaly loams, and many of the subsoils are gravelly clay loams by laboratory measures. They contain more sand and gravel than silt loams and are generally less erodible on that account.

The data on mechanical analysis, particularly the clay contents, will be discussed further in connection with other soil measurements.

Soil Structure

Soil structure may be defined as the arrangement of soil particles, whether as individual or as compound units. In general, structure should be considered as a fundamental soil property rather than as a property imposed by man; but on land that has been converted to various uses, the present particle arrangement, at least in the surface soil, is almost certain to reflect the use to a considerable extent. Even so, the fundamental nature of the soil evidenced by natural structure is not easily overcome, and it is to be expected that many structural distinctions can be drawn along soil lines regardless of use. Differences due to use may be segregated independently of soil type in other cases.

Soil structure is being studied by detailed observation, by aggregation and dispersion measurements, and by moisture-tension determinations which indicate effective pore-size distribution. All three of these approaches have yielded certain information, but there is always considerable difficulty in interpreting the information obtained. Much work remains to be done toward perfection of the relation of various structural indices to practical conservation and production problems; but even with present knowledge, structure can often be used as an index of soil fertility or productive capacity as well as of permeability to water and plant roots. It is not always the structure itself which is important, but the other soil properties known to be associated with a particular structural type.

The structure of loam, silt-loam, and sandy-loam surface soils in West Virginia pastures and cultivated land is largely a matter of degree, that is, the degree of aggregation of the primary soil particles into units of sand size or larger. With silty, sandy, or loamy soils these surface aggregates are normally quite porous, conforming with definitions of granules (4,22,24). If silt loams, sandy loams, or loams are strongly aggregated, the structure is ordinarily favorable for high water intake, resistance to erosion, easy tillage, good aeration, and high crop yields. Conversely, weak aggregation, or a tendency toward single-grained structure, is unfavorable in all the ways mentioned. This is more true of silt loams than of sandy loams, since the primary particles of sand are large enough to allow more favorable conditions than silt. But even with sandy loam, surface aggregation is important. It not only assures an adequate supply of coarse pores for rapid water intake but also tends to provide a higher water-holding capacity.

The main binding agents for surface silts and sands are humus and fibrous roots, whereas with clays there is an inherent capacity for aggregation that varies with the amount and the type of the clay (4). In West Virginia, clay aggregates are typically angular and compact. Tillage of clay or silty clay surfaces ordinarily involves considerable difficulty, because the soil is too sticky when wet and too cloddy when dry, with only a very limited range of moisture conditions suitable for working the ground. Fibrous roots and abundant organic matter of the proper kind tend to eliminate the sharp-angled aggregates and clods and to lend permeability to the structural units, but even large quantities of organic matter may only partially eliminate the difficulties. Organic matter that is actively decomposing offers more promise than inert material (10), and surface mulches are effective in promoting an improved physical structure, but many problems remain unsolved in the use of clay surface soils.

Soil aggregation is difficult to evaluate with certainty in the laboratory, but useful relative indices are obtained by any one of several methods (29,51). Middleton's dispersion ratio and its modifications have proved rather satisfactory in estimating the relative erodibility of soils when all external factors are kept constant (29).

In West Virginia this measurement has been applied to a number of soil profiles. The results have been rather variable within soil types or apparently similar horizons, but certain characteristic differences are obtained. According to the standard suggested by Middleton (29), most West Virginia soils are quite erodible, showing a higher dispersion ratio than 15 percent. Aggregated clays show ratios as low as 20 percent; leached sandy and silty materials have ratios from 75 percent to 100 percent. Data by Browning and Sudds (11) show similarly high dispersion ratios. Soil dispersion naturally cannot take into account such a factor as gravel content, which affords considerable protection against erosion in many upland soils (26). Subsoil permeability, too, is rather high on the average in West Virginia, affording another factor opposed to excessive erosion. Considering these and possibly other soil factors, and the fact that rainfall is not ordinarily of the torrential type, it would seem that the borderline between erodible and non-erodible soils might be set at a somewhat higher value than 15 percent on the average. Otherwise the other soil and external factors should be given greater relative consideration. From observations, it is suggested that for the high, silty, and loamy terraces, for the yellow and grey silty limestone soils of the Eastern Panhandle and of the Greenbrier Valley (Pickaway, Frankstown, and Frederick silt loams), for the silty uplands of the southern Ohio River area, and for the silty ridge-top soils of most of the shale upland areas, the high dispersion ratio gives a correct indication of high erodibility. But for a large part of the sloping uplands over the rest of the state, the shale content and the subsoil permeability prevent the soils from being classed as highly erodible. With other uplands (Westmoreland, Meigs, Upshur, Cavode) the dispersion ratios are not so high, but the soils are often highly erodible because of slowly permeable clay layers close to the surface. In any case, erosion control in West Virginis is recognized as primarily a matter of keeping the soil covered with vigorous, close-growing vegetation most of the time, so that soil factors governing crop growth are often more significant than such a factor as ease of dispersion. When tillage is planned, however, the soil factors discussed are important. Good surface aggregation, high gravel content, and deep, permeable subsoils all contribute to the control of run-off and erosion. Slope is often a less important factor than these soil characteristics in determining run-off and erosion, as can be seen from the severe erosion losses on many cultivated fields with slopes of 5 percent or less. Soils that are naturally erodible cannot be heavily cropped without destructive erosion even on gentle slopes. This fact is sometimes overlooked in a state like West Virginia, where most of the land is so steep that cultivation is difficult except on the few gently sloping areas.

Structural Profiles of Soils

On cultivated land the intake of water is probably related more closely to the condition of the immediate surface than to subsoil structure (15). With grass or timber cover, subsoil permeability is ordinarily the limiting factor (16), and by studying entire profiles it is possible to associate certain structural characteristics with types and degrees of soil development which help to reveal the permeability as well as other properties of the soil. In general, it seems possible to refer most of the soils in West Virginia to a relatively few main types of structural profiles as standards. These standards may represent particular soil types, or they may serve as a basis for reference and contrast of various soil features as we know them. They should be considered not as an attempted accurate portrayal but rather as illustrative and schematic, to assist in orienting our concepts of structure.

Figure 1 illustrates a structural profile that is typical of terrace soils developed from slack-water clays. It shows rather strongly developed, large, moderately porous aggregates in the surface where organic matter is abundant. At 5 to 10 inches these units give way to more angular aggregates, or fragments, which are relatively low in organic matter and only slowly permeable. The well-defined cleavage plane still afford abundant space for water movement. Gradually these fragments increase in size, becoming what might be termed blocks. They often tend toward a prismatic shape, although in some cases the horizontal and vertical dimensions are essentially equal. At 15 to 20 inches, the blocks, or prisms, have normally reached a diameter of an inch or more, and it is believed that the fully swollen material permits very little water movement. Below this depth the clay blocks become larger, approaching a massive structure in which water movement is insignificant ($<$ 0.002 inches per hour). The 5 to 10-inch layer, if not the surface itself, ordinarily shows grey and brown mottling indicative of water saturation and lack of aeration during much of the year. Occasionally the mottling is absent to somewhat greater depths.

The structural profile described is also rather typical of heavy upland soils developed from clay shales or fire clay, except that horizontal bedding instead of the massive clay becomes evident in the lower subsoil. The permeability is not much different, and the fundamental physical properties are apparently similar. One difference is that on the normal rolling or hilly upland, the surface water may drain down the slope on top of the impervious layer, so that little or no reduction and mottling are evident. This type of drainage requires a rather coarse, stable surface structure to afford

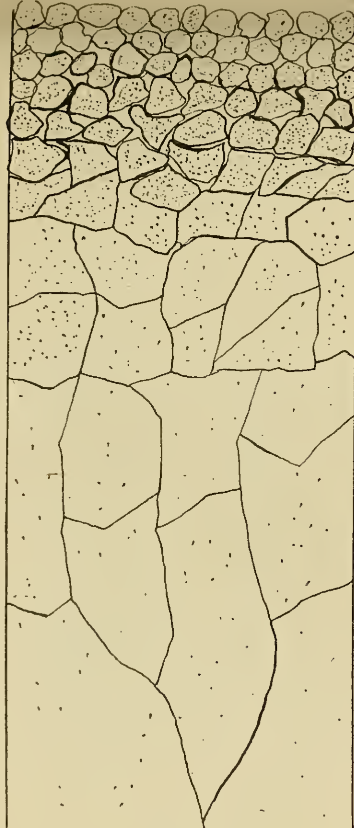


Fig. 1-- Schematic representation of the structural profile developed from certain types of clay. Lines represent primary structural cleavages, permeable to water. Dotted areas are aggregates; the more dots, the higher the permeability. Either open or enclosed areas without dots represent large pores.

This profile does not afford a good index of the base status of the soil, and the productivity is quite variable depending upon the base content and upon general fertility. The subsoil is only very slowly permeable to water. The essential features of this profile are found in the Zoar-Tyler terraces and in much of the Upshur-Meigs and Westmoreland soils. The clay subsoil usually shows horizontal bedding in the case of Upshur, and sometimes with the other soils. If the surface soil is quite silty, the structural units are smaller and less stable.

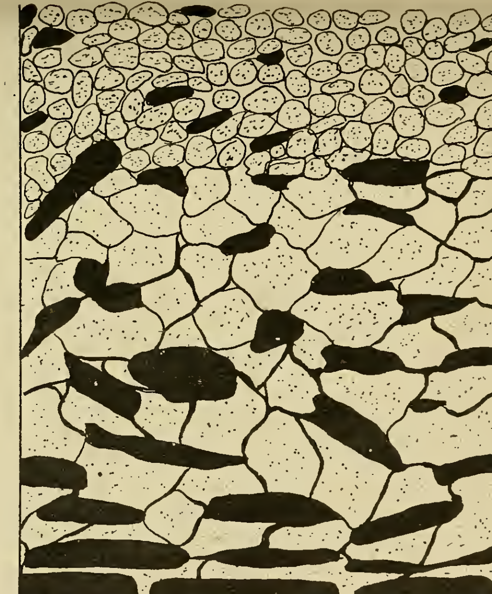


Fig. 2-- Schematic representation of the structural profile of a relatively shallow upland loam soil of acid-shale origin. Shaded areas are shale fragments. Lines represent primary structural cleavages, permeable to water. Dotted areas are aggregates; the more dots, the higher the permeability. Enclosed areas without dots represent large pores.

The subsoil is associated with strong but not extreme leaching. The soil should respond well to treatment in good rotations.

This profile is typical of such soils as Rayne, Clymer, and Wellston and is approached by deep phases of Muskingum and Gilpin.

large pores which will drain under low tension. Poorly aggregated clays and silty, single-grained layers over clay ordinarily hold water to the extent that definite mottling and "buckshot" are evident even on steep slopes. Highly silty surface layers probably do not develop from the clay-shale on upland slopes in West Virginia, but the condition is fairly common because of the alternation of clay-shale and silt-shale horizons in the parent rocks. These soils are mapped as Cavode and Wharton. Some Upshur and Brooke may develop structural profiles similar to that shown in Figure 1. Most of these soils will be mapped within the Meigs and Westmoreland soil complexes rather than as distinct types; all gradations into Gilpin are found. Many soils, both on the clay and silty shales, are too shallow to show much of a structural profile, but the structural gradation from rounded, stable granules to impervious clay is typical when the soil has developed from the clay. If lime is abundant in these subsoils, the structural units tend to be smaller and the permeability higher, resulting in a structural profile more like Figure 3, which will be discussed later. This is especially true of Brooke soils.

Figure 2 represents the bulk of the shallow shale uplands which are deep enough or have remained in place long enough to show a characteristic structure not governed by the parent shale. Permeability and aeration of the subsoil are favorable for water movement and root development. The subsoil structure is only weakly developed where the soil is shallow or is subject to frequent movement. In such cases the size, shape, and distribution of the shale and other stone fragments have a strong influence upon the normal physical constitution, and the true aggregates are more variable in size and shape, being mainly smaller and less well defined than the typical subsoil units shown in the Figure 2 profile. The frequent soil movement and the stone fragments ordinarily provide abundant looseness and aeration for plant roots.

The structural profile type shown in Figure 3 is drawn from studies of the Hagerstown series. It is extraordinarily favorable for air and water movement and root penetration. The surface aggregates are well-developed granules of favorable size and porosity. Below the surface 8 to 12 inches the aggregates become somewhat more angular and less porous; but they fit together loosely, leaving about the same volume of pores among the aggregates as characterizes the surface. There are no distinct horizon boundaries; all structural changes are very gradual. The aggregates become moderately

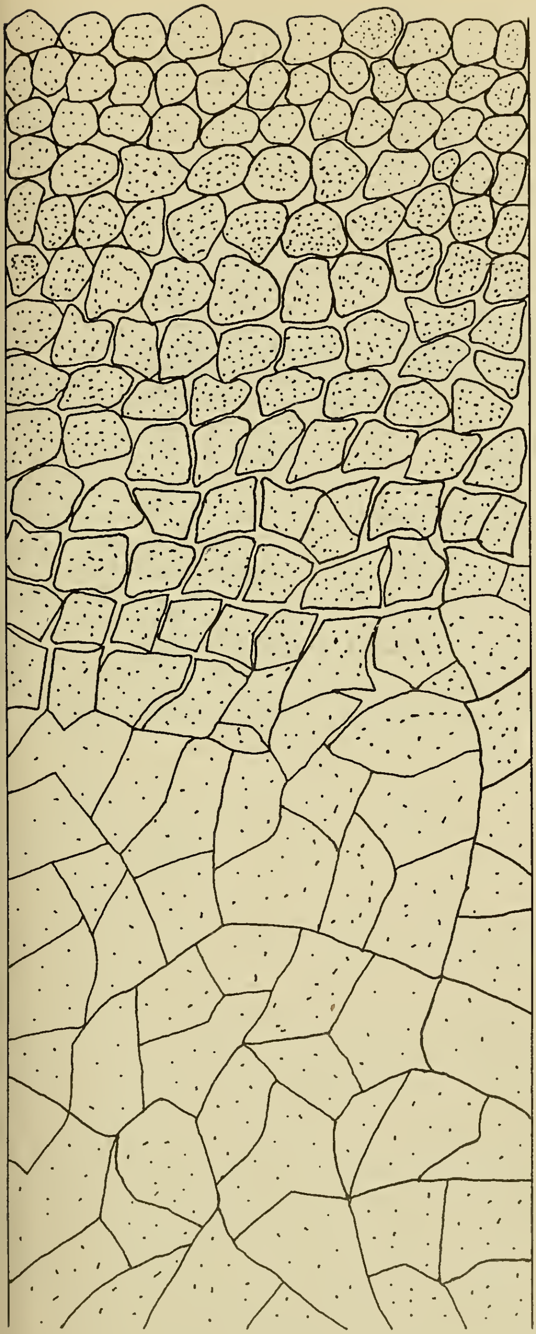


Fig. 3-- Schematic representation of the structural profile of a base-rich clay. The surface may be a heavy silt loam or a silty clay.

This profile is associated with soils of high productivity and rather strong resistance to erosion. Moderate treatment of the surface ordinarily permits rather intensive cultivation unless limestone outcrops or steep slopes interfere. Subsoil water and aeration are favorable, and deep-rooted crops grow exceptionally well.

This profile is typical of Hagerstown and deeper phases of Berkeley, Brooke, or Westmoreland. It is approached by some Frederick silt loam soils.

angular and tend to become larger and somewhat more closely packed with depth, but in the typical Hagerstown soil these changes are small. The subsoil clay is quite strongly fractured to indefinite depths depending on the distance to the parent limestone. In certain cases, especially where free carbonates are abundant, the lower material may appear even more thoroughly fractured than the middle subsoil at the 15 to 25-inch depths. It is believed, however, that the more characteristic condition is the gradual change with depth shown.

This soil seems favorable not only in appearance but in production of deep-rooted crops. Apple-tree roots have been shown to follow the structural cleavages to great depth (11), and the same deep penetration by alfalfa roots has been observed. The available water supply is large. There seems to be little reason to question the importance of this structure but it should be remembered that the Hagerstown and like subsoils not only have a favorable structure, but they show a favorable pH and saturation and abundant bases, and in some cases they may carry considerable available phosphorus. (See appropriate passages in the text.) It is difficult to say, therefore, that structure is the only or even the main reason for the deep root development. The fertility factors may be of equal importance. Or at least these various properties are all very closely interrelated and difficult to isolate.

Structural profiles of Figures 4 and 5 are apparently indicative of very strong leaching, low fertility, and high erodibility. They are known as "siltpan" or "hardpan" soils. A laminated pan is shown in Figure 4, the fully-developed, massive pan in Figure 5. The type in Figure 4 seems to develop only in silty material with few stones. It is typical of the Pickaway-Frankstown soils in the Greenbrier Valley. The real Frankstown as described has none of this development but much of the gently rolling area of the yellow-grey limestone soils of the area shows strong lamination in the lower subsoil corresponding with the appearance of some grey, yellow, and brown mottling. Similar, strongly laminated subsoil layers occur on the acid-shale uplands, where the soil is quite silty. These have been observed in both the Cookport and the Tilsit silt loams, although these types may have more massive pans as in Figure 5. The laminated pan should not be confused with the fine flakes found in silty surface or subsurface layers. The subsoil laminations are firm and somewhat harsh and vary in thickness from about 1/8 to 1 inch. This type of subsoil is not so compact as the massive pan, but it apparently represents an impediment to root developmen

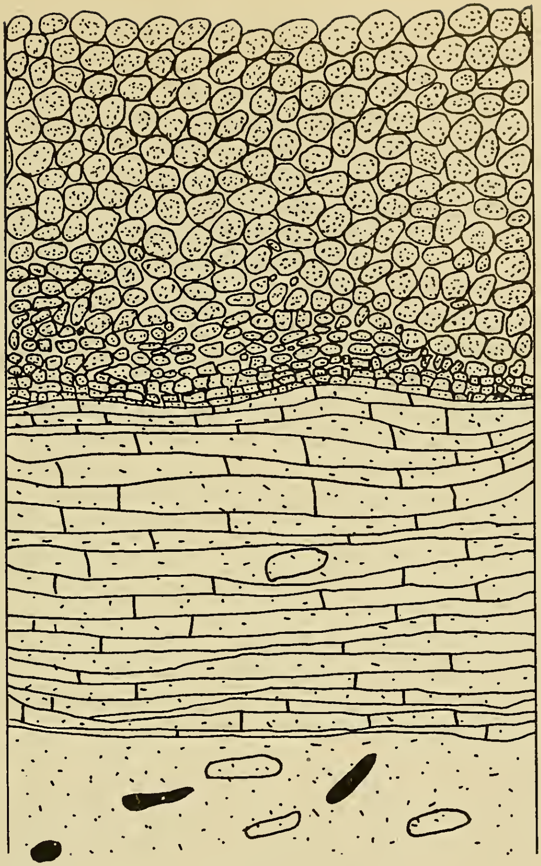


Fig. 4-- Schematic representation of the structural profile of a strongly leached silty soil.

The surface structure is not favorable for rapid water intake or for resistance to erosion. The laminated subsoil is only slowly permeable to water, but under cultivation the surface condition is normally limiting to infiltration.

This profile is associated with rather low fertility but moderate to good response to treatment. Erosion is likely to be severe under cultivation. Special precautions are needed to maintain organic matter and otherwise to protect the surface from rainfall and run-off.

Low subsoil fertility is likely to limit the success of alfalfa.

This profile is found in Frankstown-Pickaway areas in the Greenbrier and in better phases of Cookport, Tilsit, and Monongahela silt loams.

and is associated with a highly leached soil. This horizon is shown underlain by pervious silty material, which has been the case where it has been studied. The porous units in this layer are intended to represent the light-weight silt-stone or fine-sandstone fragments of the Frankstown-Pickaway or the permeable sandstone in the Tilsit and Cookport. It is believed that the high natural perviousness of this type of material delays or even prevents the development of the massive pan.

With the type shown in Figure 5 the pan, showing characteristically encased pores or small pockets of pores, overlies a clay. This is not an essential feature, but some of the most strongly developed pans occupy such a position, and this natural impediment, if present, is believed to hasten and intensify the typical pan formation. In such a case, there would seem to be little hope of ever improving the natural subsoil permeability, whereas with the laminated pan underlain by porous material, subsoiling or pan-breaking might offer some promise. It should be especially noted, however, that such physical development seems consistently associated with low fertility (see passages on acidity, bases, and potash), so that pan-breaking alone would seem to promise little reward at best. Deep placement of lime and fertilizer might be more beneficial than physical disruption of the pan.

In experiments with alfalfa at Morgantown, deep placement of lime and fertilizers resulted in a marked increase in deep root development, although the physical condition of the soil was uniform throughout. This suggests that the low fertility of pans may prevent root development regardless of the physical compaction.

Another feature of Figures 4 and 5, as shown, is the smaller surface aggregates, which decrease in size down to the pan horizon. This seems characteristic and causes these soils to be highly erodible, although the structure of the immediate surface may be influenced considerably by use. The subsurface layer contains mainly small sand or silt-sized units which sometimes approach the single grained type of structure. This rather floury layer probably permits only relatively slow water movement regardless of the lower subsoil.

There are various intermediate stages between the permeable subsoil shown in Figure 2 and the massive pan. In the case of much gravel, as shown in Figure 2, and also in sandy or loamy soil material there is little likelihood of the lam-

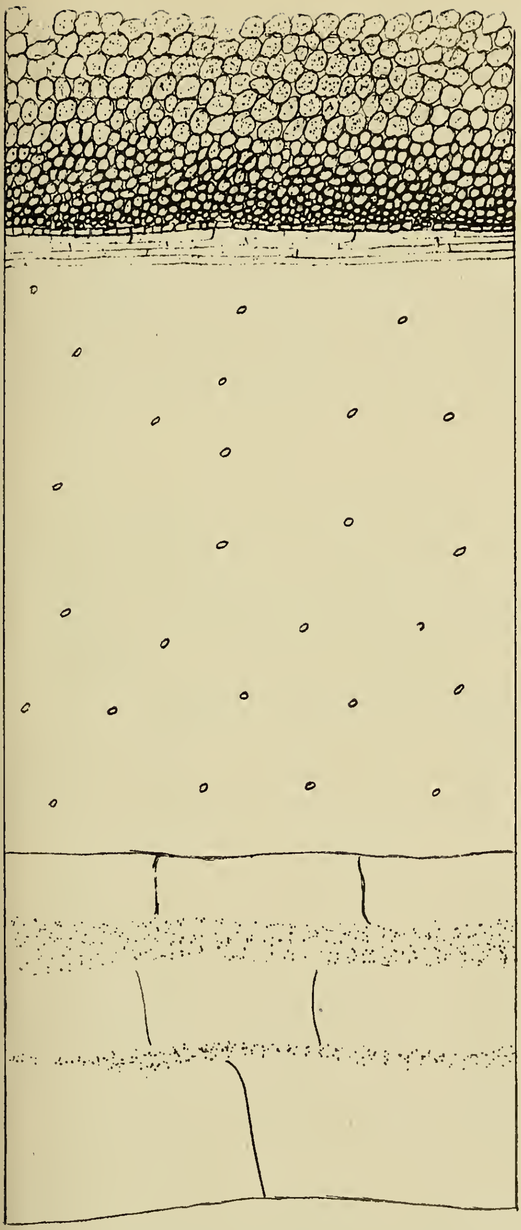


Fig. 5-- Schematic representation of the structural profile of a very strongly leached silty or fine sandy soil with a subsoil "silica pan."

This profile is associated with all of the undesirable features of Fig. 4, intensified, and is less responsive to treatment. It occurs mainly on slopes of 5 percent or less, but is very erosive under cultivation even on gentle slopes. This soil requires the protection of close-growing vegetation most of the time. It is unsuited to alfalfa and not well suited to corn.

Monongahela terraces and Cookport or Tilsit ridgetops typify the essential features shown. The clay-sand substrata are found on terraces; shale parent material occurs on the uplands.

inated stage as shown for silty profiles. The intermediate stages apparently are characterized by the coalescing of the normal nutlike aggregates into less distinct and more compact units. This is accompanied by the appearance of some brown, grey, and yellow mottling and can serve as an index of strong leaching. Much of the Rayne silt loam as mapped in West Virginia seems to typify this condition, grading into Cookport as the pan and mottling become pronounced. The pan seems to reach its maximum development immediately above the parent shale in these soils. The mottling apparently is largely a matter of strong but variable leaching of iron. This seems confirmed by the pale coloring, lack of iron concretions, strong acidity, and low base content of all such pans as well as by microscopic observations which reveal that much of the greyness is apparently from fine grains of clean quartz. The term "silica pan" seems appropriate for these horizons (25,31,50).

Summary of Soil Structure

Detailed observations of the structural condition of surface soils and subsoils can often serve as an index to soil permeability, erodibility, productivity, and general capacity for use. The size, shape, internal permeability, and hardness of the natural units into which a moist soil crumbles upon handling are the most important factors to consider in studying soil structure. Aggregates from crumb to small nut size are ordinarily most desirable in West Virginia soils. Rounded, porous aggregates are more desirable in surface soils than angular or blocky units. Visible porosity of the aggregates is associated with the more favorable structural types in surface soils but is not so essential in subsoils. Porous surface aggregates should be moderately firm and should not collapse into silt under pressure or water action. They should feel somewhat spongy or elastic. Very large aggregates in surface or subsoil ordinarily mean a tendency toward massiveness, which is unfavorable. Massive structure in surface soils suggests cloddiness, puddling, and poor seedbeds. Very small aggregates often indicate a tendency toward single-grained structure, which is also unfavorable. Surface crusting, high run-off, and severe erosion are characteristics of soils with small aggregates or single-grained structure. Subsoil pan layers indicate strong leaching and low fertility as well as high erodibility. Thoroughly fractured or fragmented clays indicate a high lime content. Blocky or massive clays are not necessarily related to any particular lime status, but the structure indicates low permeability and slow drainage. Well-formed, nutlike (sub-angular) subsoil units are found in mature upland soils of this region. Such soils

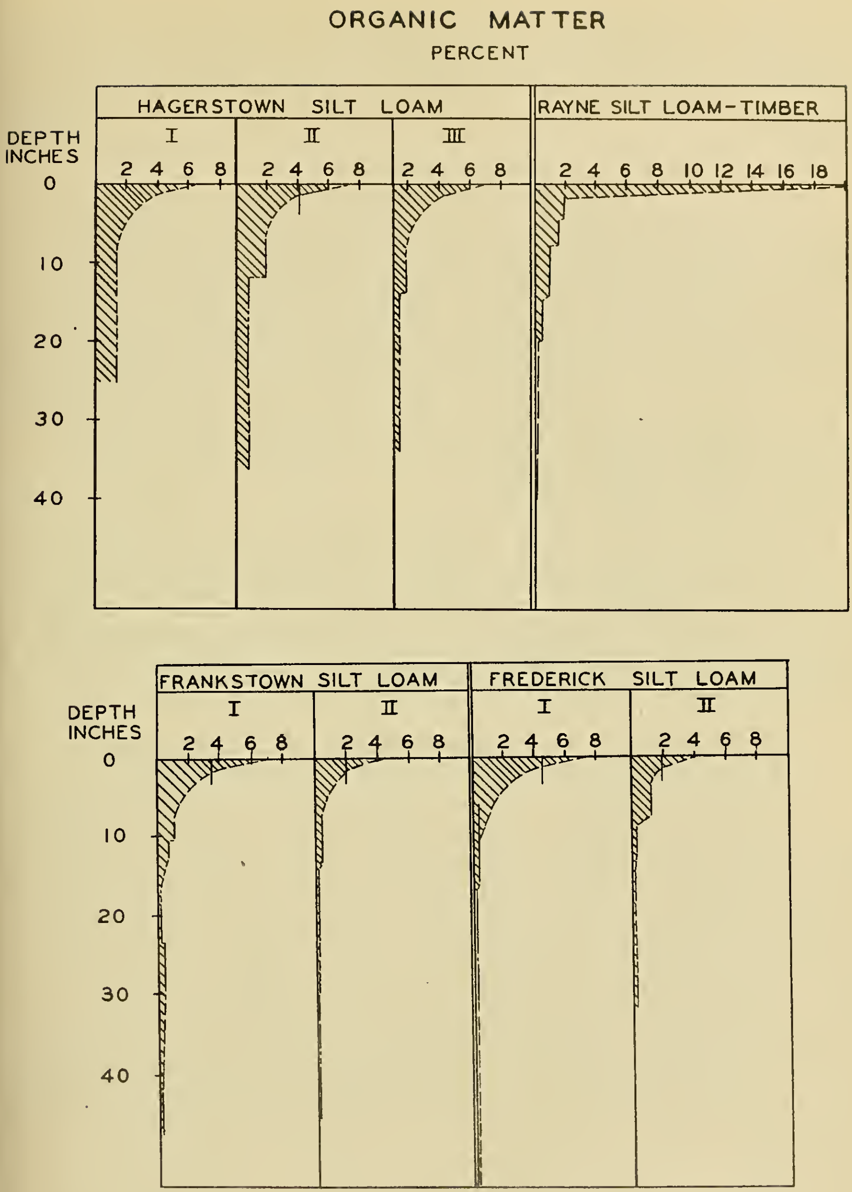


Fig. 6-- Organic-matter distribution in several typical soil profiles. Actual values obtained for a particular depth are indicated with solid lines. Dashed lines represent interpolations. At the surface an interpolation from 0 to 3 inches is shown corresponding approximately to the characteristic distribution shown in Table 1.

are strongly leached but are responsive to treatment. Younger upland soils have less distinct subsoil units, and their fertility is more closely related to the nature of the parent material.

ORGANIC MATTER

Attention has been directed to some relationships between organic matter and soil structure. In addition to these physical effects reflected in structure, organic matter is known to be closely correlated with total nitrogen and with the availability of nitrogen and other nutrients. These relationships afford some basis for considering organic matter as one of the best indices of soil productivity, although it is recognized that variations in the quality and the turnover of organic matter are factors which must be considered as well as the total amount.

In West Virginia only limited data have been published as to the amount and distribution of organic matter throughout the various soils and under various conditions within the state. A better understanding of the location of soil organic-matter reserves seems essential to any further study and interpretation of its properties and functions.

Distribution of Organic matter in Soil Profiles

It is not possible to show many clearly defined differences among soil types on the profile basis, but certain general features of profile distribution can be shown. Figure 6 shows the rapid organic-matter decrease with depth which is so important in understanding West Virginia upland soils. If the plow layer were removed, as by erosion, it is clear that the outstanding loss would be the organic reserve. With Hagerstown the subsoil reserve of organic matter appears considerably greater than with Frankstown or Frederick. The distribution shown for these latter two limestone soils is not unlike that for the upland sandstone and shale soils. Other data could be given, but the general picture would be the same.

The Frankstown and the Frederick soil profiles showing lowest organic matter in the surface are from areas known to have been cultivated, whereas the two higher profiles have not been cultivated in recent years, if at all. None of the three Hagerstown profiles has a record of cultivation.

The relatively high value for the 23 or 28-inch layer in one of the Frankstown profiles is believed to represent a fault in the method of determination, as discussed under "Method," because it does not appear reasonable and does not correspond with weight losses by these successive horizons on prolonged heating at 400°C.

One timber (mixed oak) profile is shown for comparison with pasture profiles. The extreme concentration in the immediate surface is typical of three profiles studied from timber areas. The leaf litter is not shown, although the distinction between litter and the surface soil is necessarily rather arbitrary. The amount and distribution below the immediate surface do not seem much different from the soils in pasture.

Among upland soils no other clearly significant differences between soil types have been established as yet. If terrace soils and bottom lands are included, it appears that the approximate extremes within the state can be established for pasture and cultivated lands. In a broad, flat lowland at the divide between the headquarters of Muddlety and Little Beaver Creeks in Nicholas County, black silty-clay soil occurs which is classified as Blago silty clay. It is apparently a "half-bog" soil (22,24) kept moist by seepage from the upland. A 6-inch surface composite from a hay field showed 17 percent of organic matter, whereas similar surface samples from adjacent hay land showed 11.2 and 11.7 percent respectively. On the Homestead land at Dailey, Randolph County, two 6-inch surface-soil samples that were similar in appearance to that from Nicholas County showed 11.0 and 10.9 percent of organic matter. Thus it seems that an average of 10 percent or more of organic matter is rather characteristic for this soil. The surface layer appears nearly uniform to a depth of 10 to 12 inches, where it grades through lighter colors into a highly mottled subsoil of grey, rust brown, and bluish grey. At 20 to 30 inches free water is evidently present most of the time because of the slowness of subsoil drainage or because of water under a hydraulic head in a permeable underlying stratum.

At the other extreme (exclusive of severely eroded areas), we can apparently place the low-altitude, light-textured terrace soils. For example, the Wheeling fine sandy loam at the Lakin Experiment Farm has an average organic content in the plow layer of about 1.2 percent. It varied from 0.65 percent to about 2.0 percent for 43 different plots recently determined, depending upon the cropping history and other factors. These values are for soil that is quite productive with the proper treatment and rotation of crops (27). Production is evidently maintained by a high turnover of organic matter rather than by building a large reserve to draw upon, although corn yield showed a rather close relation to increases in organic matter even within the small range covered. The sandy texture provides a desirable physical medium for growth even without much organic matter. The low altitude and relatively high average temperature at Iakin contribute to rapid destruction of organic matter and turnover of nutrients.

Another example of relatively low organic matter in light-textured terrace soils is obtained from experimental pasture plots on Monongahela fine sandy loam at Wardensville. The surface 1½ inches averaged about 2.4 percent for 24 composite samples, the 1½ to 3-inch layer, 1.4 percent. This would be about the same as the values for the Wheeling soil if the results were complete to plow depth. It is also about the same as the results for Holston silt loam for Wirt County in Table 1 and for three pasture soil profile samples from Holston loam, where the surface 6 inches had 1.6 percent, 1.3 percent, and 1.2 percent of organic matter, respectively. All of these results are for samples below 1000 feet in altitude.

It appears from these extremes that the practical range of organic matter is from 1.0 percent to about 10.0 percent. It would seem doubtful whether profitable cropping of any kind could be maintained under West Virginia soil conditions at an organic level below 1 percent. This low value, as indicated, would not be expected to give satisfactory results on any except certain light-textured soils, where a high degree of aeration of the surface layer is attained. Erosion would be difficult to control on such soil if it occupied an appreciable slope, and a rapid organic matter turnover from legumes or barnyard manure would be required.

The 10 percent value is only to be expected for an entire plow layer in the case of a relatively permanent water table close to the surface as described for Blago. It is approached by small areas of upland over perched water tables, particularly at high elevations.

Distribution of Organic Matter In the Surface Soil under Pasture Vegetation

Because of the importance of the immediate soil surface as the main root zone for shallow-rooted plants and new seedlings in pastures, and because of the important influence of this layer upon infiltration and erosion, some details of the

TABLE 1--COMPARISON OF ORGANIC-MATTER CONTENTS IN SEVERAL PASTURE SURFACE SOILS AT TWO DEPTHS AND UNDER DIFFERENT TREATMENTS

COUNTY	DEPTH OF SAMPLE (inches)	SOIL TYPES	SOIL TREATMENT**	YEARS SINCE TREATED	PASTURE HERBAGE	ORGANIC MATTER (percent)*
Monongalia	0 to 1½	Gilpin	None		Poverty grass & weeds	5.49
"	1½ to 3	Silt	None			2.72
"	0 to 1½	Loam	N P K L	8	Bluegrass & White clover	5.54
"	1½ to 3		"			3.06
Wirt	0 to 1½	Holston	None		Poverty Grass	2.34
	1½ to 3	Monongahela	"			1.48
	0 to 1½	Loam	N P L	6	Bluegrass &	2.82
	1½ to 3				White clover	1.62
Roane	0 to 1½	Upshur	None		Broomsedge	5.45
	1½ to 3	Silty	"			1.93
	0 to 1½	Clay	N P L	6	Broomsedge &	5.85
	1½ to 3		"		White clover	2.70
Putnam	0 to 1½	Zoar	None		Poverty grass	3.52
	1½ to 3	Silt	"			1.73
	0 to 1½	Loam	2 P L	3	White clover	3.78
	1½ to 3				& bluegrass	1.72
Hardy	0 to 1½	Litz	None		Poverty grass	3.87
	1½ to 3	Silt	"			2.06
	0 to 1½	Loam	2 P L	2	Poverty grass	4.14
	1½ to 3					2.15
Greenbrier	0 to 1½	Frederick	Variable	3	White clover,	4.79
	1½ to 3	Gravelly Loam			Bluegrass & Weeds	2.57
Monongalia	0 to 1½	Rayne-	None		Bluegrass	2.88
	0 to 1½	Cookport	P K L	7	Bluegrass	2.93
	0 to 1½ (Close-clipped)	Silt	Variable		Bluegrass	2.70
	0 to 1½ (Cut for hay)		"		Bluegrass	3.14

* Averages of composite samples from each of 4 replicated plots.

** N, P, K, and L refer to standard rates of application of nitrogen, phosphorus, potash, and lime, respectively.

normal distribution with depth in pastures are given (Table 1). The organic-matter content of the first $1\frac{1}{2}$ inches is seen to average twice that of the $1\frac{1}{2}$ to 3-inch layer. The $1\frac{1}{2}$ to 3-inch layer has 63 percent as much organic matter as the 0 to $1\frac{1}{2}$-inch layer for untreated Holston loam in Wirt County, whereas untreated Upshur clay shows only 35 percent as much at the $1\frac{1}{2}$ to 3-inch depth. The smaller difference with depth on the light-textured Holston and the greater difference on the heavy Upshur are probably related to the textural classes represented.

It is well to note from Table 1 that pasture treatment has apparently caused a slight increase in organic matter at both depths; but there is no indication that natural organic-matter differences among the various soils could ever be eliminated by treatment. That is, treated Holston loam shows only 2.82 percent after 6 years, whereas untreated Upshur Clay has 5.45 percent or almost twice as much organic matter. These differences seem rather characteristic of the soil types.

Table 1 shows also an apparent increase in organic matter at one location as a result of infrequent cutting of Kentucky bluegrass for hay compared with close clipping. This evidently results from increased root development, since higher forage yields were removed from the hay plots.

Effects of Climate and Cropping on Soil Organic Matter

The effects of rainfall, temperature, and cropping on organic matter and nitrogen have been subjected to considerable study (20). On the basis of the relationships which have been worked out between organic matter and these factors, it was expected that considerable variation would be found in West Virginia because of the wide climatic and cropping differences represented. From observation, it appeared that the Gilpin silt loam of Nicholas County and other associated areas at high elevations had more surface organic matter than the Gilpin of Wetzel County and associated low altitudes. A number of surface samples from these two counties afford a comparison which shows this difference and its magnitude (Table 2). The samples from both counties are confined to areas which appeared to have suffered from moderate to slight erosion. Meigs samples (a complex of Gilpin and Upshur) show essentially the same organic content as the associated Gilpin from Wetzel County, whereas the Gilpin from Nicholas is 35 percent higher. Total base and pH differences are included to show that there was a real basis for the distinction between the Gilpin and Meigs composite samples from Wetzel County.

TABLE 2--ORGANIC-MATTER COMPARISONS OF SURFACE SOILS

COUNTY	APPROX. ELEV.	SOIL TYPE*	pH	TOTAL BASES	NO. OF COMPOSITE SAMPLES	ORGANIC MATTER (percent)
Nicholas	2000	All upland	5.30	8.8	22	3.35
Nicholas	2000	Gilpin	5.16	7.6	16	3.13
Wetzel	700	All upland	5.24	12.7	26	2.26
Wetzel	700	Meigs	5.46	15.0	8	2.38
Wetzel	700	Gilpin	5.13	11.1	11	2.35

*All silt loams with slight or moderate erosion from tilled or tillable land.

It seems likely that the higher average organic-matter content of surface soils from Nicholas County compared with Wetzel County is to a considerable extent the result of lower average temperature and higher rainfall in Nicholas County. It is also possible that the factor of cropping is involved, since Wetzel has been farmed longer than Nicholas, but climate is probably the major factor of difference (49).

As an indication of the organic-matter differences to be expected from cropping, results with originally uniform soil in bin plots on the Agronomy Farm at Morgantown may be cited. After three years of cropping, the extreme organic contents of the surface three inches were 1.87 percent and 2.35 percent for continuous buckwheat and continuous Korean lespedeza, respectively. Various values are as follows:

	Organic Matter (percent)
Korean lespedeza (nothing removed)	2.35
Kentucky bluegrass and white clover (clippings removed)	2.31
Continuous corn (rye/vetch winter cover)	2.28
Corn, wheat, clover rotation	2.20
Continuous wheat	2.00
Continuous corn	1.92
Continuous soybeans	1.88
Continuous buckwheat	1.87

In the fourth year of cropping with 4-12-4 fertilizer at 500 lbs. per acre annually, the continuous corn yielded less than half as much as the corn with cover crop plowed under. In this case, the fertility balance of the soil growing continuous corn, with the organic matter depleted to less than 2 percent, was such that a very poor corn crop resulted, although the season was normal, the soil reaction was about pH 6, and the crop received 4-12-4 fertilizer as indicated. Where a rye/vetch cover crop was plowed under and the organic reserve was somewhat higher, the continuous corn produced a normal crop of about 40 bushels per acre.

It has been shown in Ohio (43) that higher organic matter levels characterize the surface soil under spaced trees in pastures than in adjacent open-pasture areas. Several Greenbrier County samples (0 to 3-inch depth) supplied by Soil Conservation Service District personnel show a similar relationship:

	AVERAGE ORGANIC MATTER		
TREE SPECIES	Under Trees (percent)	Open Pasture (percent)	NUMBER OF COMPARISONS
Black locust	3.78	2.80	8
Black walnut	4.23	3.51	6
Oak	3.83	3.08	2
Hickory	4.95	3.15	1
Apple	4.23	3.51	Composite from 6 trees

It is likely that the cooler micro-climate under the trees, together with the organic matter supplied by tree leaves, accounts for these differences.

ACIDITY, BASE SATURATION, AND BUFFERING

It is a useful concept to think of soils not only in terms of their acidity and base content but also in terms of their buffer capacities toward a base or an acid. If this approach is adopted, it is relatively simple to visualize the interrelations of lime requirement, pH, total bases, and percentage saturation with bases. Whether the soil is in its natural state of base saturation or has been shifted upward along its buffer curve by liming, or lowered by leaching and heavy cropping, the relationships are clarified by keeping the buffer curve in mind. For the curves shown in Figure 7, the zero point represents the pH when all exchangeable bases are removed. Natural soils at pH 4, 5, or 6 occupy varying positions on the right. If we consider pH 7 as the ultimate aim of field liming and hence as essential saturation, the buffer curve of any soil shows at a glance the base saturation, pH, exchangeable bases, and the base requirements to bring about

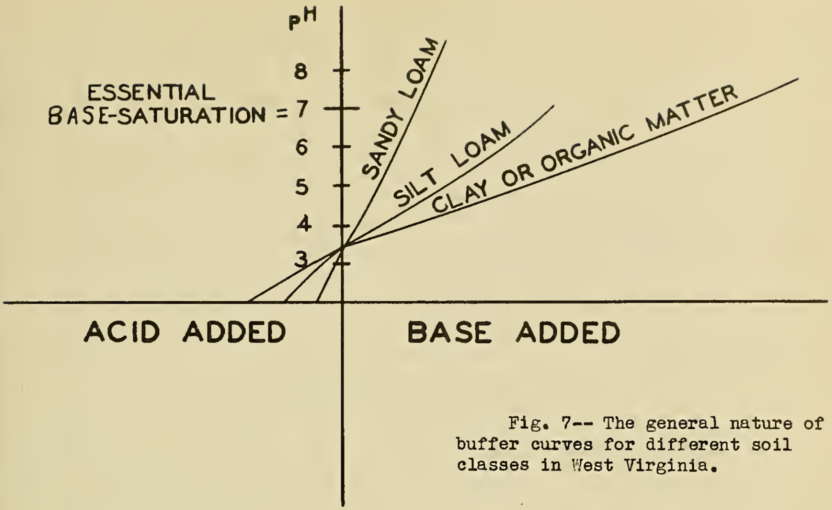
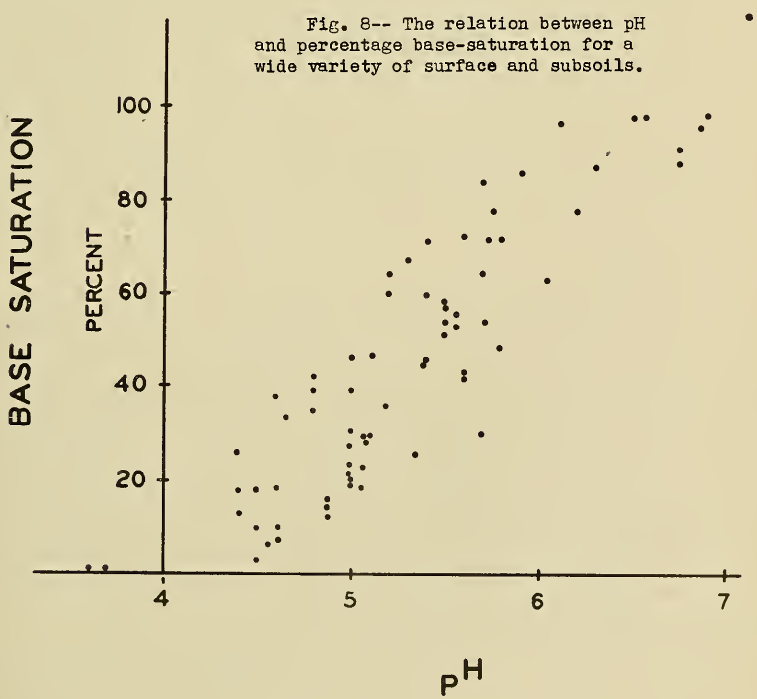


Fig. 7-- The general nature of buffer curves for different soil classes in West Virginia.

Fig. 8-- The relation between pH and percentage base-saturation for a wide variety of surface and subsoils.



a particular pH change. The slope of the curve at any point is an indication of the capacity of the soil to resist a change in its pH. If we know the soil pH we still need to know the nature of the buffer curve in order to predict the lime requirement, the base reserve, and other soil properties. The slope and the shape of the buffer curves of West Virginia soils are quite variable, but within the practical range from pH 4.5 to 6.5, most curves are essentially straight lines. The slope is ordinarily the most important consideration. Among normal soils the slope differences shown are not unusual, with the clay or organic soils requiring several times as much base as a silt loam to bring about a particular change of pH.

pH and Base Saturation

Considerable work has been done on the relation of pH to the base saturation of soils. In a recent summary of literature on the subject Pierre and Allaway (35) reached the conclusion that the bulk of the existing evidence indicated that percentage saturation was the most important factor in determining crop response relative to the bases of soils. In some of his work Pierre showed that percentage saturation seemed to have more significance than total bases or pH, and he indicated that, whereas pH and saturation were generally related, there were serious deviations from the relationship.

Robinson (40) showed that for 0 to 3-inch samples in West Virginia pastures, the pH correlated rather closely with percentage saturation and seemed to be more important than total bases in determining the stand of Kentucky bluegrass and white clover.

There are various evidences that the amount of base present and the ratio of different ions are also important factors (1), and in a recent study Mehlich and Colwell (28) showed that with montmorillonitic clay types, percentage saturation was dominant, whereas with kaolinitic clays the total amount of base was more important than the percentage saturation. They also showed that large amounts of exchangeable H^+ might be detrimental to plants at a constant degree of saturation of montmorillonitic clays. Both of these clay types are probably represented in West Virginia soils, and it may some day become practical to adjust lime recommendation in conformity with clay type as well as other factors.

Another factor regarding base saturation which has probably received insufficient emphasis is the role of organic matter. As decomposition progresses, various nutrients are released. One result is that base-saturation conditions throughout the soil become quite variable, so that regardless of the average condition there would be local areas where the plant could obtain nutrients, whether it be total amount, saturation, or other factors which dominated root intake. Thus it would seem that, where organic matter is the main base-exchange material as in as many West Virginia surface soils, there can be little doubt that both total amount of and percentage saturation with bases are important factors.

With these relationships in mind, soil pH was plotted against percentage base saturation, using acetate leaching at pH 7 as the standard of saturation. The results, summarized in Figure 8, show a fairly close correlation, although there are some rather wide variations where pH might give a seriously inaccurate indication of percentage saturation based on the average value.

Two points shown as having zero saturation were obtained by thorough leaching with dilute HCl and washing with distilled water. Electrodialyzed hydrogen clay with no bases, from the Hagerstown soil, shows an initial pH as low as 3.2, but it tends to come up to 3.8 to 4.0 on standing. With natural soils of the state a pH of about 4.1 seems more or less of an absolute minimum. This low value has been recorded for several samples not shown in this comparison. Values much lower than 4.0 seem to be a safe indication of acid mine water damage, which is a fairly common occurrence in the coal-mining sections.

Since so much importance is attached to percentage saturation by Pierre and others (34,35), and since it is not always convenient to determine total exchange capacity, an attempt was made to improve the accuracy of the pH/base saturation relationship by taking total bases into account. This was suggested by the fact that, at a particular pH value, soils with highest base contents usually proved to have the highest degree of saturation. By taking this into account in a purely empirical way, a graph is obtained (Fig. 9) from which the percentage saturation is read horizontally from the crossing of the vertical pH line and of the diagonal line corresponding to the base content. The accuracy of the chart is improved by subdividing the lowest diagonal into three textural groups. As an illustration, a soil with pH 5 and 15 m.e. of base by acetate leaching would have an expected saturation of 72 percent.

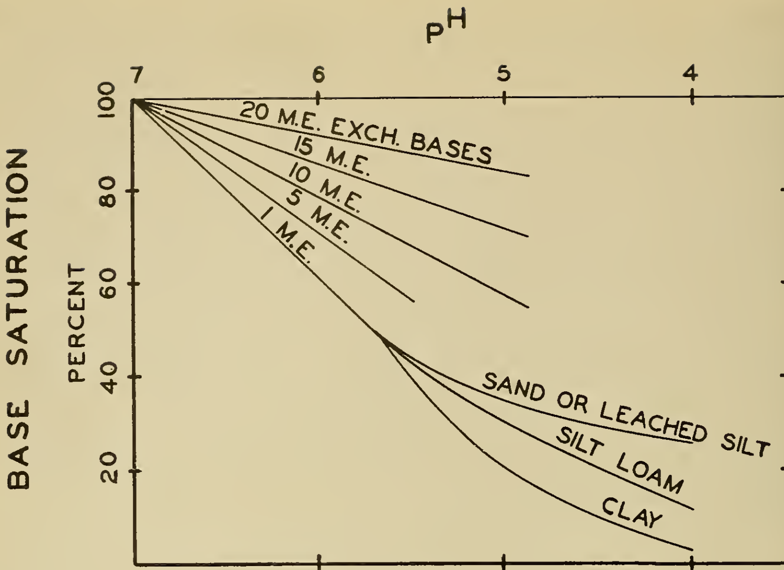


Fig. 9-- General relationships among pH, exchangeable bases, and percentage base-saturation for a wide variety of West Virginia surface and subsoils. By considering the exchangeable bases as well as the pH an improved estimation is obtained of percentage base-saturation.

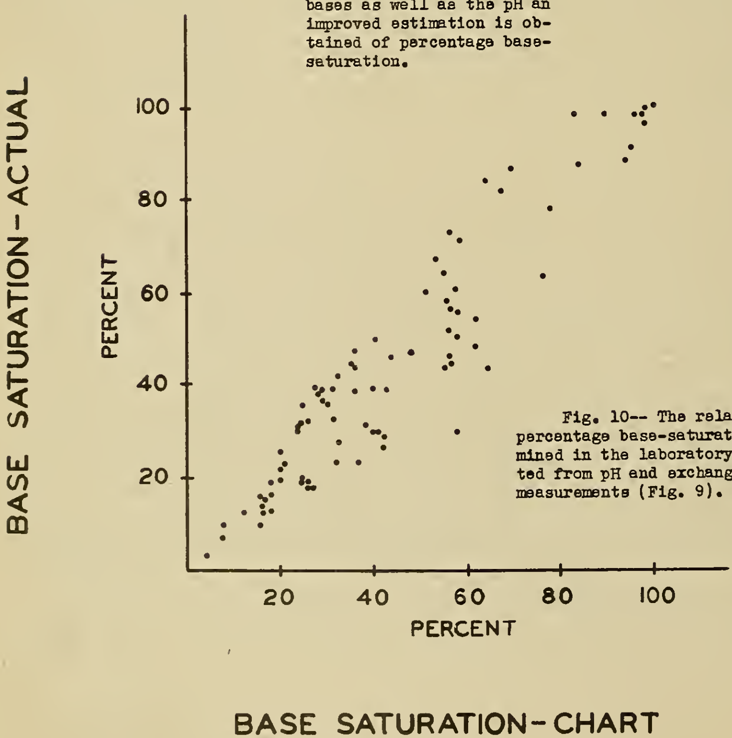


Fig. 10-- The relation between percentage base-saturation as determined in the laboratory and as estimated from pH and exchangeable-base measurements (Fig. 9).

Figure 10 shows the relation of saturation values predicted by the chart and actual values determined. It is obvious that this consideration of base contents and texture has provided an improved prediction of saturation. Considerable variation among samples is still evident, but the prediction of saturation appears satisfactory for most practical purposes, considering that such varied soil materials are involved in the comparison. It is likely that differences in the time of the year at which samples were taken and in the degree of dryness attained in the laboratory are responsible for some variations in pH, but it is to be expected that there are real differences in the strength or avidity of the soil acids which would prevent a perfect correlation under any conditions (34). Robinson (40) obtained a rather close correlation between pH and base saturation for 0 to 3-inch samples in West Virginia pastures without considering any other factor, but such close correlation would hardly be expected with the wide variety of surface and subsoils represented in the present results.

Now that some of the interrelations of soil acidity and bases for West Virginia conditions as a whole have been demonstrated, it seems appropriate to point out certain applications relative to different soils. First, in a very general way, it is possible to show some characteristics of particular soil types (Table 3). Base data by the Kappen method are used because they are more complete. A few of these results are conversions from acetate determinations by the equation given (Kappen values = 2.1 + (acetate values) x 1.3). Data by both methods are available for most samples, but nothing seems gained by using both values. It is recognized that this table may be criticized for not showing variations within soil types and for showing averages of all horizons within soil profiles, but the generalized picture seems justified if it is kept in mind that wide variations are included in some of the averages and that the results tabulated should be considered as a very general representation which might not apply to a specific case or even to an entire area.

In spite of the variations and overlapping of values, there are a number of distinct differences among soil types as shown. It is interesting that pH, percentage saturation, and total bases all correlate fairly well for many of the soils. Outstanding exceptions are generally associated with obvious textural or organic-matter differences. The Blago of Nicholas County has what appears to be a fair supply of bases, but the higher organic and high clay content result in a low pH and low saturation. The same is true of the Zoar, Tyler, Purdy group, which were quite high in clay on the average. With one

TABLE 3--SOME GENERAL AVERAGE DIFFERENCES IN ACIDITY AND BASES FOR SEVERAL SOILS INCLUDING ALL DEPTHS, UNLESS INDICATED

SOIL	DOMINANT TEXTURE IN PROFILE	NUMBER OF AVERAGE SAMPLED Locations	Horizons	pH	PERCENT** SATURATION	TOTAL BASES*	COMMENTS AS TO VARIABILITY
Hagerstown	Silt to clay	12	22	6.5	95	25.3	Relatively uniform
Frederick	Silt loam	2	8	5.2	46	12.0	Moderately variable
Frederick	Gravelly silt to clay	3	10	5.0		5.3	Relatively uniform
Frankstown (E. Panhandle)	Silt loam	2	8	5.8	65	11.0	Moderately variable
Frankstown-Pickaway	Silt loam (Greenbrier)	4	22	5.1	30	5.2	Moderately variable
Meigs Surface Composites	Silt loam	9	9	5.5	66(1)	14.9	Relatively variable
Gilpin Surface (Wetzel County)	Silt loam	11	11	5.1	60(1)	11.1	Relatively uniform
Gilpin Surface (Nicholas Co.)	Silt loam	16	16	5.1	42(1)	7.8	Relatively uniform
Gilpin	Shaly silt loam	5	12	5.2		10.0	Widely variable
Ashby	Silt loam	3	8	4.8	34	5.0	Variable with texture
Upshur-Meigs	Silt to clay	2	9	5.0***	70	15.9	
Calvin	Shaly loam	4	13	5.0	38	7.2	Widely variable
Rayne-Cookport	Silt loam	7	15	4.7	32	5.5	Relatively uniform
DeKalb	Fine sandy	2	4	4.4	21(1)	2.5	Uniform
Lakin****	Silt loam	1	6	5.5	66	7.2	Uniform
Holston-Monongahela	Loam to clay	4	16	4.8	35	4.0	Relatively uniform
Summers	Loam to silt loam	3	9	5.5***		16.4	Relatively uniform
Zoar, Tyler, & Purdy	Silt loam to clay	4	12	4.9	20	5.6	Moderately variable
Blago							
(Randolph Co.)	Silt to clay	1	3	5.6	63	12.0	Relatively uniform
(Nicholas Co.)	Silt to clay	1	4	4.6	22(1)	6.5	Relatively uniform
Fire Clays (Nicholas Co.)	Clay	2	2	4.7	12(1)	2.2	Uniform

* Total bases by the Kappen method. Expressed as m.e. / 100 grams.
** Most of these values are based upon acetate leaching. Those marked (1) are from buffer curves with $Ba(OH)_2$.
*** pH values probably relatively too low because determination was made after complete drying and storage.
**** Name not correlated.

Tyler subsoil sample, an extreme in unsaturation was reached. This sample, from 36-inch depth, was 72 percent clay (.002mm.) and only 2.7 percent saturated with base. It seems likely that these various clays were very acid when they were originally laid down, since none of the leached silts or sands has reached such a low degree of saturation by soil-forming processes.

Low exchange capacities in DeKalb sandy samples provide another extreme, the samples averaging 21 percent saturated with only 2.5 m. e. of bases by the acid method. The pH values of 4.4 are the lowest shown, indicating a more strongly dissociated acid than most samples. The Lakin* soil, a loose, yellow, silty terrace in the Ohio Valley which has been considered as probably originating from wind-deposited material, is somewhat out of line with most samples. Its extreme siltiness is associated with a low exchange capacity and a rather high degree of saturation with only a moderate base content.

From any viewpoint, the Hagerstown soil as sampled is outstanding for its high bases, high pH, and high saturation. These samples have been limited to soil having rather uniform, typical reddish brown color, well-developed subsoil aggregation, and no gravel. These characteristics seem to typify the series in West Virginia and are consistently associated with strong basic properties.

The Frederick soil as mapped seems quite variable in bases. Some samples approach the Hagerstown, whereas others seem as strongly leached as level shale soils. The silt loam is believed to be much higher in bases and more uniform than the gravelly type, as indicated in Table 3. The grey subsurface layer which commonly occurs in the Frederick is highly silty with very low exchange capacity and very low bases. pH values as low as 4.8 have been obtained for cherty Frederick subsoil, indicating strong leaching for a limestone soil.

Frankstown silt loam from the Eastern Panhandle is shown separately from that in the Greenbrier Valley on the basis of results to date which seem to indicate a real difference between the two locations. This difference is partly accounted for by the large areas of Pickaway in the Greenbrier, but even the heart of the Frankstown area as mapped in the recent county soil survey (46) appears to be a more highly leached soil than the same type in the east, and this observation is

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*Name not correlated.

confirmed by the data in Table 3. The Greenbrier samples are designated as Frankstown-Pickaway on the basis that they seem intermediate between the two types as commonly described. In soil mapping, it is obvious that this intermediate soil would have to be classified into one or the other of the typical types.

One of the four Frankstown profiles from the Greenbrier was definitely better than the others, both in appearance and in base status, and could readily be classed with the Frankstown from the east. It was found near Frankford, where it seemed to represent a considerable area on several farms. If this profile were omitted from the averages, the base content of the remaining three profiles would be 4.5 m.e., the pH 5.0, and the saturation 27 percent. Base values down to 1.9 m.e. were obtained for lower subsoil, which is about as low a value as is ever obtained with the acid method. Such material evidently is mainly quartz sand and silt.

The Meigs surface samples from Wetzel County and two Upshur-Meigs profiles represent the only other soils with limestone influence, and they show the influence distinctly. Meigs, of course, is a complex rather than a distinct type, consisting of Gilpin (acid-shale) and Upshur (red clay-shale, mainly limey). The Upshur-Meigs profiles had obvious red clay-shale influences but were not typical Upshur. The lime influence is distinct, although some low pH values were obtained.

Gilpin surface samples afford an interesting comparison between Wetzel and Nicholas Counties. These same samples have been compared as to organic matter content. The base and saturation differences are almost as distinct as the contrast in organic matter. It appears that the organic exchange material from Nicholas County has a relatively low degree of dissociation of hydrogen compared with the exchange material of the Wetzel County samples. This is shown by the fact that the pH values are essentially the same, whereas the saturation is lower in Nicholas County. Another way of stating this would be that the Nicholas County samples show strongest buffering at relatively high pH values, which is consistent with Baver's (3) conclusions that most of the buffering by organic matter starts in the range of slight acidity and continues beyond neutrality. In certain other cases this does not seem to be true, suggesting that the type of organic matter must be considered.

Values obtained for Rayne and Cookport silt loams are so far rather consistent, showing a high degree of leaching and not much variation with depth in the profile. Several samples are from soil that is intermediate between the two; hence no distinction is possible.

Holston and Monongahela are shown together because of the comparatively small number of samples and the fact that two of the profiles sampled are believed intermediate between the two soil series and therefore not suited for drawing any distinctions. These soils are strongly leached although not extremely low in base saturation, suggesting that leaching does not readily lower the bases below a certain percentage saturation.

Gilpin, Ashby, and Calvin soil samples have shown great variation in base status, as might be expected from the variations in their parent rock. It would seem important in any localized area of interest to collect samples of the soil and the parent material of these soils to find out the reserve of bases. So far no observable rock characteristics have seemed consistently associated with the different base levels, but every effort is being made to find some useful field index to the base content. Rock and soil testing for lime, pH, and exchangeable bases appears to be the best approach at present. It would seem that such tests together with closer observations of soil depth would provide a valuable guide to the probable success of any deep-rooted crops. Ordinary soil-type distinctions in mapping cannot be expected to provide this needed information.

The samples of Summers soil were collected in Nicholas and Greenbrier Counties. The soil occurred at elevations approaching 3000 feet in close association with light-colored shale soils. The samples considered as Summers were exceptionally dark colored compared with the associated upland, and the dark color was recognized by farmers as having some association with soil productivity. The high bases shown suggest that the primary source of the fertility and dark color is the brown, rather soft shale or fine-grained sandstone from which the soil is derived. The lowest base value obtained was 11.0 m.e., which is relatively high compared with most other soils of the area. Potash apparently plays little part in the fertility of these soils because the exchangeable potassium is lower than the state average (Table 5.)

Acid/Base Distribution with Depth

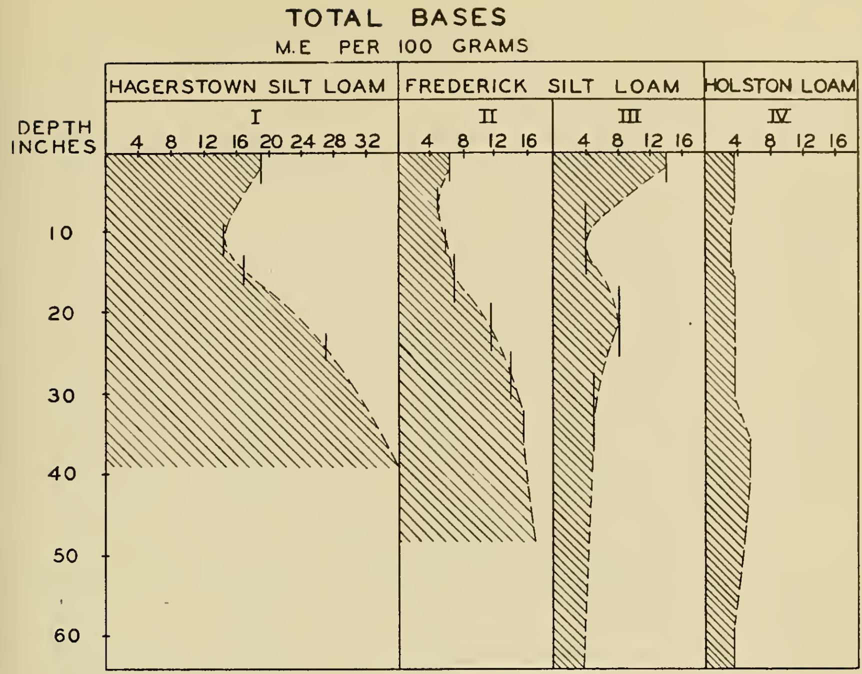
In addition to the general features associated with certain soil series or types, it is essential to recognize variations within particular soil profiles. The base contents of the profiles of certain soils are given in Figure 11. These appear typical of the main profile types in the state. Pertinent data on these same soils are given in Table 4.

No. 1, a Hagerstown silt loam profile from Greenbrier County, is not unlike other heavy-textured soils of strong limestone influence and is typical of other Hagerstown profiles studied. High base values throughout, with excess lime in the lower part of the profile, is characteristic. The values for the 9 to 12-inch layer are as low as any base values obtained for Hagerstown. Berkeley, Brooke, and limey Upshur soils show similar distributions of bases with depth.

Profiles 2 and 3 are Frederick silt loam from the Greenbrier. No. 2 is rather rich in bases, approaching Hagerstown, but neither the total bases nor the pH values are quite as high as for Hagerstown. A definitely leached zone corresponding to the grey subsurface layer typical of Frederick silt loam is evident. The increase in bases in the subsoil corresponds with an increase in clay, so that the pH and the degree of saturation stay about the same. It is easy to visualize that this profile could have been formed from a soil like the No. 1 Hagerstown by the natural progress of leaching.

No. 3 Frederick looked much like No. 2 in the field, but it is obviously more completely leached in the subsurface and subsoil, although the surface retains a high base content. The increased base content from 15 to 30 inches corresponds to a high clay layer, which is probably a real B horizon. The surface content of bases may be influenced by liming.

Profile No. 4 is marked by uniformity of bases and pH. The degree of saturation is more variable and increases with depth below the incipient hardpan at 25 to 30 inches. This seems typical of the various "hardpan" soils (Monongahela, Cookport). The profile shown is a highly leached terrace with very little reserve of bases either in the exchangeable or the primary mineral form. It is classed as intermediate between Holston and Monongahela because the color profile is more like Holston, although a recognizable "hardpan" is present.



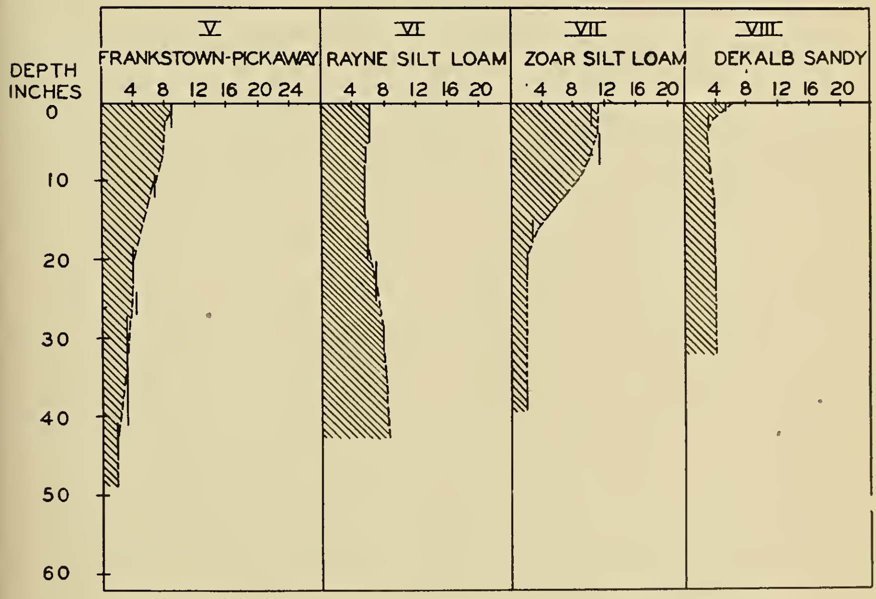


Fig. 11-- The distribution of bases with depth in several typical soil profiles. Solid lines represent actual determinations; dotted lines are interpolations.

TABLE 4--ACID/BASE DATA FOR THE SEVERAL SOIL PROFILES SHOWN GRAPHICALLY IN FIGURES 11a AND 11b

HAGERSTOWN SILT LOAM

	TOTAL BASES m.e. / 100 gm.	pH	CLAY (percent)	BASE SATURATION (percent)
0 - 3"	19.0	6.4	18	91
9 - 12"	14.5	6.8	29	
12 - 15"	16.8	6.7		
22 - 25"	27.0	6.0	52	
29 - 35"	Free Lime		65	100

FREDERICK SILT LOAM

	TOTAL BASES m.e. / 100 gm.	pH	CLAY (percent)	BASE SATURATION (percent)
0 - 3"	6.6	5.8	10	48
3 - 6"	4.7	5.3	12	26
9 - 12"	6.0	5.2	27	46
12 - 18"	6.8	5.5	35	51
18 - 24"	11.5	5.4		
24 - 30"	14.5		56	
32 - 36"	15.4	5.4	58	

FREDERICK SILT LOAM

	TOTAL BASES m.e. / 100 gm.	pH	CLAY (percent)	BASE SATURATION (percent)
0 - 3"	13.4	5.6	9	55.6
6 - 15"	3.9	5.5	10	52
15 - 25"	7.5	5.2	43	64
27 - 30"	4.7	5.0	47	39
72 - 75"	3.5	4.9	39	36

HOLSTON-MONONGAHELA LOAM

	TOTAL BASES m.e. / 100 gm.	pH	CLAY (percent)	BASE SATURATION (percent)
0 - 6"	3.8	4.75	9	17
9 - 14"	3.5	4.9	13	35
15 - 21"	3.7	4.8	16	39
25 - 30"	3.7	4.7	17	30
35 - 40"	5.2	4.8	21	42
60 - 64"	3.5	4.9	11	51

TABLE 4--CONTINUED

FRANKSTOWN-PICKAWAY SILT LOAM

	TOTAL BASES m.e. / 100 gm.	pH	CLAY (percent)	BASE SATURATION (percent)
0 - 3"	9.0(Limed)	5.8	10	60
9 - 12"	6.6	5.2	30	
18 - 23"	4.0	5.2	41	
23 - 27"	4.2	5.0	43	20
27 - 41"	3.0	5.0	54	18.5
41 - 45"	1.9	4.9	14	21.5
RAYNE SILT LOAM				
0 - 5"	6.0	4.6	12	13
5 - 8"	5.5	4.6	17	17
8 - 14"	5.2	4.4	12	12.5
15 - 20"	5.7	4.5	29	14
20 - 25"	6.8	4.6	19	23
28 - 31"	7.8	4.6	34	29
ZOAR HEAVY SILT LOAM				
0 - 3"	10.2	5.6		43
4 - 8"	11.3	5.7		30
15 - 18"	2.6	4.9		15
19 - 22"	2.0	4.9		16
36 - 39"	2.1	4.6		7
DEKALB FINE SANDY LOAM				
0 - 1"	5.2	4.2	Low	15
$1\frac{1}{2}$ - 3"	3.0	4.8	Low	
21 - 24"	4.0	4.8	22	18

Profile No. 5 is from the Frankstown-Pickaway area of the Greenbrier. It shows some grey, brown, and yellow mottling in the subsoil but is not an extreme pan type. At 41 inches there is a definite break through the subsoil into a highly silty and fine sandy layer. The progressive decline in bases with depth indicates thorough leaching. The fact that no evidence of lime enrichment is encountered raises some question as to whether the soil developed from a strongly carbonated stone. If so, the leaching has been complete. Some lime is known to have been added to the surface, which is a good bluegrass/white clover pasture.

Profile No. 6 is Rayne silt loam from Monongalia County. It is a ridgetop soil of acid-shale origin. Leaching is strong through the entire profile, which is apparently typical of the upland shale soils of this area. They are leached through the structural A and B horizons and into what is ordinarily considered the C. In a number of deep cores from colluvial soils near Morgantown the profile was quite acid to depths of about 4 feet, below which it became less acid or neutral (17). This seems to be about the normal depth of leaching of upland soils in this vicinity. The leached layer below the structural B horizon probably constitutes a Y horizon as discussed under "Soil Depth."

Profile No. 8 was taken in oak timber where the soil has never been plowed. It is shown to illustrate the slight build-up of total bases in the shallow organic layer at the surface from a sandy substratum which is poor in bases. The build-up in total bases does not constitute an increase in pH or percentage saturation, because the bases are associated with a concentration of active organic matter. If this soil were put into cultivation, the decomposition of organic matter would be accelerated with a release of bases and other nutrients which might give one or two satisfactory crops. But after the small surface reserve was gone, there would be almost no fertility left. This is believed to be typical of the behavior and the history of many highly leached soils. The small surface reserve is mined and then the land is abandoned.

The distribution of bases with depth is an important consideration in any attempted reclamation of severely eroded soils. Subsoils with a fairly large supply of bases offer considerable promise of success, whereas strongly leached subsoils appear much more hopeless. This is especially true of clay subsoils, where in case of low bases the degree of saturation also is low. The fact that large additions of lime would be required is discouraging in itself, but there is the additional factor to consider that low base saturation is likely to be associated with low contents of other nutrients such as potash and various minor elements.

Soil tests seems to be the only way to evaluate the base status of many West Virginia soil profiles. The visible characteristics of mature or old soils or of young soils with free lime can be used to judge the acid/base status within reasonable limits; but among immature soils without free lime there are wide variations due to differences in the parent shale which are not necessarily reflected in the appearance of the soil profile. These differences can be readily detected by pH and total base determinations.

Clay and Organic Matter as the Sources of Base Exchange

It is well known that the base-exchange properties of soils depend to a large extent upon the clay and organic matter present. Both the factors of quality and quantity are involved. In the southern United States clays in general are known to be less reactive than in central or northern regions. Organic matter is also variable in quality. Differences in exchange and other properties are expected from this factor alone.

In order to determine something of the average exchange capacities associated with West Virginia soils relative to their contents of clay and organic matter, Figure 12 was prepared. Multiplication of the organic content by 6 seems justified by the study of various data throughout the state, suggesting that organic matter is roughly six times as active as clay in exchange properties. This would indicate that if clay (.002 mm.) has an exchange capacity of about 32 m.e. per 100 grams, then organic matter as determined would have a capacity of about 192. The points so far show a rather close relationship between exchange capacity and this combination factor in West Virginia soils. Deviations from the line are probably due to differences in quality of clay and organic matter (30), and even wider deviations are to be expected as more data accumulate. It is interesting to note that these varied soils fit the line as well as shown and that the points define a line which hits very near zero exchange for zero on the clay/organic matter scale. This tends to confirm that these soils have practically no exchange properties other than from clay and organic matter. By way of comparison four points are shown as open circles which were calculated from data given by Baver (2) for four Ohio soils. These points are all slightly high but conform to the straight-line relationship, suggesting that the 6 to 1 ratio for activity of organic matter to clay is about right but that the activity for the Ohio soils is slightly higher.

Even though Figure 12 is recognized as applicable only in a general way, it serves to demonstrate the approximate relative importance of humus* and clay in different parts of soil profiles. With most surface soils of 3 percent or more of organic matter it seems safe to assume that the exchange properties are dominated by the organic complex because most West Virginia surface soils are silt loams or loams with less than 15 percent and frequently less than 10 percent clay. In depleted or eroded soils or in subsurface layers clay or humus may dominate depending upon the particular conditions, whereas with subsoils the clay is clearly dominant. From this it seems worth suggesting that the aim in reclaiming eroded soils or even in maintaining high production levels may rest upon a certain ratio of organic activity to clay activity. With sandy or silty soils low in active clay, as already discussed under organic matter, it is possible to reconcile low humus content with high production by proper treatments and rotations. The same cannot be said in the case of heavy clays. Here the humus must be maintained at a higher level for satisfactory results.

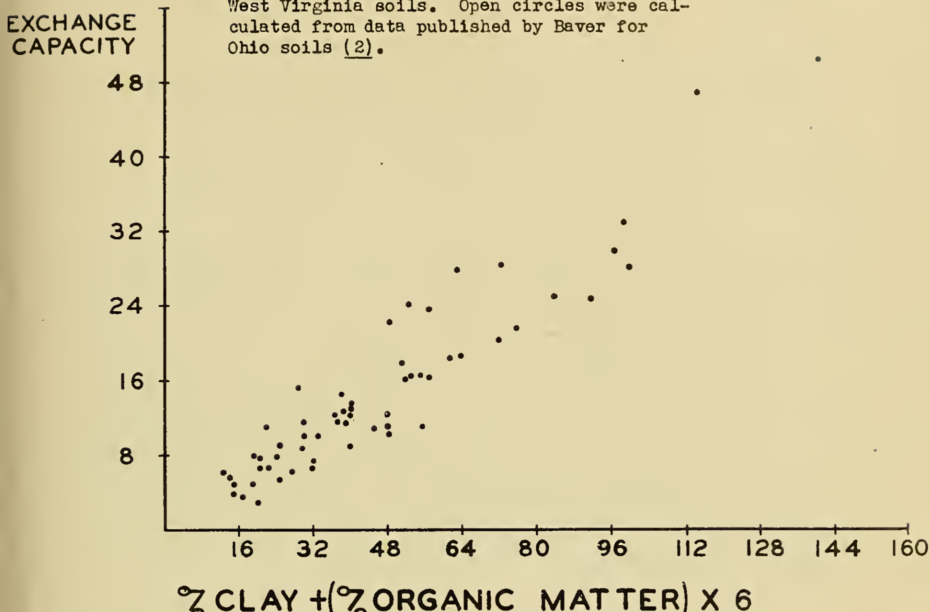
Organic Matter, Clay Content, and Exchange Capacity in Relation to Lime Requirement

As a general guide to the exchange properties of West Virginia soils it is possible to set certain limits which can be based upon observation in the field. These differences in exchange capacity are approximately proportional to lime needs to bring about a particular change in pH.

Surface Soils	Exchange capacity m.e. per 100 grams
1. Dark-colored	
a. Clay	20 to 50 (values above 30 are very uncommon)
b. Silty or sandy	12 to 25

*The terms "humus" and "organic matter" are used interchangeably.

Fig. 12-- The relation between exchange capacity and the multiple factor of clay + (% organic matter) x 6 for a variety of West Virginia soils. Open circles were calculated from data published by Baver for Ohio soils (2).



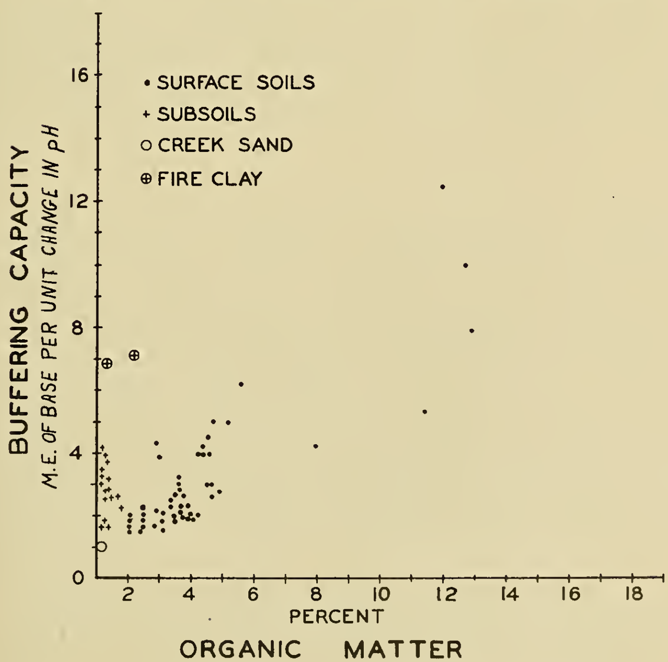


Fig. 13-- The buffering capacity of various West Virginia soils, showing the strong influence of organic matter among surface soils and the rather wide range among subsoils without regard to organic content.

2. Light-colored	
a. Clay	10 to 25
b. Silty	5 to 12
c. Sandy	3 to 6
Subsoils	Exchange Capacity
1. Clay	10 to 25
2. Silty	5 to 10
3. Sandy	2 to 5

A further illustration of the role of clay and organic matter is given by Figure 13. Clay as such is not shown, but the vertical range of the subsoil samples is largely a function of the amount and type of clay present. The vertical scale is an index of soil buffering based upon buffer curves of the soils toward $Ba(OH)_2$, as already described. Units on the vertical scale can be changed into pure $CaCO_3$ requirements for plow-layer depths by application of a factor of 1500, according to the standards established by Pierre and Worley (33). That is, 2 m.e. of base corresponds to 3000 lbs. of lime per acre 7 inches.

It is evident from Figure 13 that humus is ordinarily the dominant source of surface-soil buffering or lime requirement, whereas with subsoils the variation is due primarily to another factor, obviously clay. Some of the variability among surface soils is probably due to the quality of the organic matter as well as to differences in content of clay.

If organic matter data are recalled from the first part of this bulletin, it can be seen that great changes in buffering are to be expected with depth in the soil profile corresponding to variations in organic matter. The surface $1\frac{1}{2}$ inches in pasture may require as much lime as the next 3 inches to bring about the same change in pH. Subsoils compared to surface soils require less lime for a particular pH change unless there is a great increase in the clay content, because subsoils are so low in organic matter. With most of the shallow shale or sandstone uplands buffering is strongest in the surface soils, but if the surface soil is silty and the subsoil is a clay, the exchange capacity and the lime requirement per unit change in pH are likely to increase with depth. This is offset in some cases by an increased base content in the clay subsoil, as with Hagerstown, where the subsoil is essentially saturated. In such cases the strong buffering is a favorable factor because it represents a reserve of bases which can withstand heavy cropping and leaching losses.

In liming pastures it is sometimes noted that the pH change of the surface 3 or 6 inches averages less than expected. Determinations of exchangeable bases in several such cases have shown that the high organic content and strong buffering capacity of the immediate surface have caused most of the lime to be caught and held in the shallow surface layer, where the lime requirement on a plow-layer basis may approach a rate of 6 tons per acre for each unit of change in pH (as from pH 5 to pH 6).

AVAILABLE PHOSPHORUS

After several hundred determinations by the standard Truog method and widespread tests made in the past, only one conclusion is possible--dilute-acid-soluble phosphorus is very low in practically all soils and subsoils of the state unless fertilizers have been added. The method is accurate down to about five parts of phosphorus per million of soil, which is generally considered too low for good growth of practically all crops except trees. About 20 parts per million ordinarily results in satisfactory yields unless there are other limiting factors. Robinson (40) indicated that 13 p.p.m. resulted in nearly maximum stands of bluegrass and clover, but responses in yield would be expected beyond that amount.

A very few exceptions may be noted to the low phosphorus rule, although their practical significance is uncertain. On the Homestead land at Dailey, 15 to 16 p.p.m. of soluble phosphorus was obtained at depths of 2 to 3 feet, and near Martinsburg in the Eastern Panhandle from 7 to 40 p.p.m. of phosphorus was found throughout two Hagerstown soil profiles in pasture, the average being about 15 p.p.m. This would probably be quite significant if it is widespread, but Hagerstown from the Greenbrier and from several other locations in the east have failed to show appreciable amounts. High soluble-phosphorus tests have also been obtained from subsoil samples in limestone areas near Wardensville and at Kearneysville.

In studying material from strip-mined dumps, high tests for soluble phosphorus have been obtained in a number of cases. If this were an absolute test for available phosphorus, it would be important because attempts are being made to reclaim this material for cropping. But plants growing on this same material in the field have been observed as having deficiency symptoms that look like phosphorus dificiency as shown in "Hunger Signs in Crops" (19), and greenhouse tests have shown a marked response to phosphorus. Thus it seems that the test used is not reliable as a measure of available phosphorus with this material.

It is believed that there may be one other serious complication in testing for phosphorus in the state. The chemical tests in use do not measure the organic phosphorus, which undoubtedly is important, particularly in soils having a high humus content. This leads to the general conclusion that phosphorus deficiencies as measured by test are ordinarily less severe if the soil contains large reserves or has a rapid turnover of organic matter.

In the analyses of soils reported in 1924 (12) a higher quantity of total phosphorus was shown for the limestone areas of the state and for the soils of generally higher productivity. Since total phosphorus may not be closely related to available phosphorus, this distribution of total reserves may be incidental to the associated soil fertility levels. The excellent response to phosphorus fertilizers on these soils with the relatively high reserves affords strong evidence that the low availability as indicated by the Truog test is a more realistic picture of the situation than are the total reserves. The quick response and generally higher fertility of the limestone soils is more likely traceable to such factors as the supply of bases, higher pH, superior physical properties, and greater soil depths. Even so, it seems worth keeping in mind that larger reserves of phosphorus are ordinarily present in these more fertile soils, and under certain conditions a part of this reserve may become available. The examples of high soluble-phosphorus tests mentioned apparently represent cases where the phosphorus reserve occurs in a more soluble form than in most subsoils. Similar variations have been reported for Iowa subsoils (47), but the solubility has not proved to be a very reliable index of availability to plants.

AVAILABLE POTASH

As with phosphorus, there is no absolute measure of potash availability in soils, but in contrast to phosphorus the normal reserves of potash are very large. Analyses of West Virginia soils (5,12,42) showed an average total of 28,000 pounds of potassium in the plow layer, compared with only 1100 lbs. of phosphorus. This amount of potash is 1.4 percent, or as much potash as we have organic matter in some soils; hence the high removal of potash by certain plants does not necessarily mean that potash fertilizer is needed at present. Neither does it mean that potash can be neglected as a fertilizer constitutent, for we know that limitations of availability may and do occur, although such limitations are undoubtedly less common than phosphorus limitations.

In studies thus far a few quick tests have been made, but all of the data presented are based upon quantitative determination.

A total of 136 duplicate determinations for surface and subsoils (Table 5) gave an average of 0.256 m.e. of K per 100 grams of soil.* This amounts to 200 lbs. of potassium or 240 lbs. of K_2O per plow-layer depth. This is considerably lower than the average of 0.38 m.e. obtained for 0 to 3-inch pasture samples by Robinson (Table 6), but 200 lbs. of available potassium per acre plow layer is a fairly abundant supply. It would be exhausted in a few years if not renewed, but it is known that there is a continual movement of potash from the non-available to the available form as the exchangeable potash is used up (14); and it has been demonstrated that plants can obtain some potash from sources other than the exchange complex, provided there are potash-bearing minerals in the silt fraction (38). The potash outlook for West Virginia soils as a whole is therefore moderately encouraging, although the immediately available supply may average only 0.7 percent of the total reserve.

There is wide variability with many low as well as high values for exchangeable potash. The highest obtained was 0.047 percent or 940 lbs. per acre for a dark-colored, heavy textured upland surface soil; the lowest was 0.002 percent or 40 pounds per acre for both a silty lower subsoil and for two leached, silty surface soils. On the average, surface soils are highest--0.35 m.e. for 44 surface soils as compared to 0.21 m.e. for 92 subsoils, but the average for subsoils is

*m.e. per 100 grams is converted to pounds of K_2O per acre by multiplying by 939.

TABLE 5--GENERAL SUMMARY OF EXCHANGEABLE-POTASH DATA

SOIL	NO. OF LOCATIONS	SAMPLES	EXCHANGEABLE K. m.e. / 100 gm. Av.	HIGHEST	LOWEST
All Profiles	45	136	0.256	1.24	0.04
All profile Surfaces	44	44	0.351	1.24	0.04
All profile subsoils	45	92	0.212	1.00	0.04
Holston-Monongahela	3	22	0.12	0.18	0.04
(Greenbrier) Frankstown-Pickaway	2	12	0.15	0.26	0.04
Lakin Silt	1	6	0.18	0.27	0.05
Calvin	3	9	0.18	0.29	0.10
DeKalb sandy	1	1	0.05		
Rayne	3	11	0.22	0.31	0.09
Frederick	3	13	0.33	0.86	0.08
Hagerstown	3	10	0.35	0.66	0.10
Litz silt loam	2	4	0.25	0.35	0.05
Zoar, Tyler, Purdy, Blago, Atkins	12	21	0.21	0.68	0.07
Calcareous slack-water terrace	1	5	0.21	0.24	0.17
Summers	2	5	0.19	0.28	0.09
Ashby, Gilpin, and other acid shales	7	15	0.43	1.00	0.09
Upshur Meigs	2	10	0.54	1.24	0.20
Profile average	45	136	0.256	1.24	0.04
Surface soils Corn plots*	5	20	0.12	0.18	0.08
Surface soils Orchard**	1	23	0.26	0.45	0.10

*Rayne, Clymer, and DeKalb soils--Bruceton Mills. Data supplied by E. H. Tyner, Department of Agronomy and Genetics.

**Frankstown--Eastern Panhandle. Data supplied by R. H. Sudds, Department of Horticulture.

not extremely low. Six samples from the Agronomy Farm at Morgantown average 0.265 m. e. or essentially the average for the state.

One other point should be mentioned concerning the averages given. The samples came from many different parts of the state, but the various soil types are not represented in anything like their proportion to the total area. Gilpin and Ashby, for instance, probably cover almost half of the state, but they represent only about one-tenth of the samples. In general the shale upland areas have potash supplies considerably above the average given, except where very strong leaching has occurred.

Relation of Available Potash to Organic Supply Matter

Surface soils average somewhat higher than subsoils in the present results, and even higher averages have been reported for 0 to 3-inch layers (Table 6), where the organic content is higher than in the entire surface soil. This, together with the fact that organic materials frequently contain relatively large amounts of potash, raises the question as to whether the two factors--exchangeable potash and organic matter--are generally associated in West Virginia soils. Figure 14 shows the relationship obtained with the present data.

TABLE 6--DATA FROM ROBINSON (40) FOR PASTURE SOILS
ALL 0 to 3" samples

SOIL	SAMPLES	EXCHANGEABLE POTASSIUM Average	Highest	Lowest
		m.e. per 100 grams		
DeKalb*	29	0.40	1.00	0.19
Hagerstown**	13	0.32	0.51	0.19
Upshur	4	0.58	0.95	0.22
Westmoreland	2	0.35	0.44	0.25
Elk	2	0.32	0.32	0.31
Pope	3	0.23	0.30	0.18

Average all soils--0.39.

* Included soils which have now been subdivided into several series, including Gilpin, Rayne, Clymer, *et cetera*.

**Probably includes some Frederick and Frankstown soils.

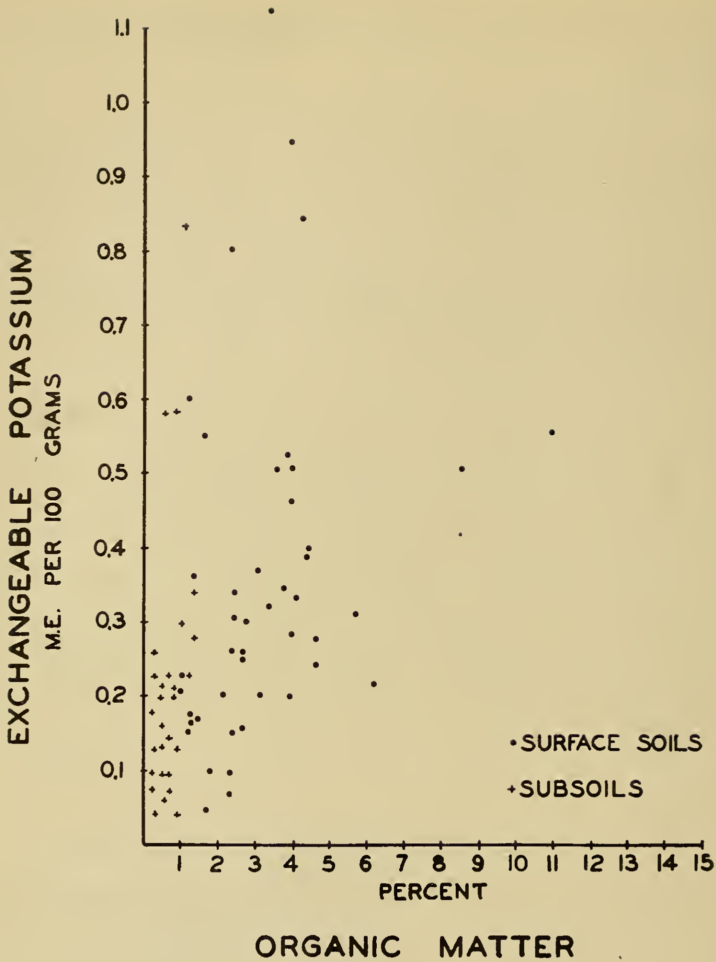


Fig. 14-- Exchangeable potassium values for surface soils and subsoils shown in relation to their organic contents. Surface soils seem to be relatively high in exchangeable potash if they are high in organic matter, but very wide differences occur both with surface and subsoils at low organic levels.

With both surface soils and subsoils there is a wide range of values at low organic contents, but it is clear that exchangeable potassium tends to increase with increasing organic content in surface soils. If the organic supply amounts to more than about 3 percent it appears unlikely that exchangeable potash will be very low, whereas, with the organic matter much below 3 percent, the available potash may be either very low or very high, much the same as in subsoils. This relationship suggests an answer to some questions regarding the response of pastures to added potash. As shown earlier, the organic reserve in ordinary pastures is quite high in the shallow surface soil, although the total plow layer may be rather low. Since bluegrass and white clover roots are concentrated mainly in this shallow layer, it is suggested that they ordinarily find abundant potash associated with the organic matter. With alfalfa or corn the deeper root zone would likely be much more deficient.

Available Potash Relative to Mineral Content, Soil Type, and Plant Response

Figure 14 showed wide variations in exchangeable potash which obviously bear no relation to the organic matter supply. These differences seem associated somewhat with clay content, the highest values for subsoils being invariably associated with rather high clay. But clay content as such is not a reliable guide, since certain of the heaviest clays showed low values, and even with some of the high values the total exchange of the clay may be so great that the degree of saturation and the availability will be lower than indicated. This follows from the fact that percentage saturation with potash may be important as well as the total exchangeable supply (14).

In many cases the variation of exchangeable potash within a soil type has been so great that no conclusion can be drawn as to potash status by soil types. An exception appears to be the Holston-Monongahela soils, which have shown only low values in 22 horizons sampled from 3 profiles. The average is 0.12 m.e. It is to be expected that these soils would show relatively strong response to potash treatment. Pasture plots on one of these sampled profiles, at Wardensville, showed moderate and rather variable response over the area (41*). On another, near Milton, the pasture showed little or no response to potash. Since these soils not only are low in potash

*Also unpublished data.

throughout but show less concentration of organic matter in the immediate surface than most other soils (Table 1), they would seem to represent an especially favorable condition for potash response. The fact that only variable response was obtained (41) seems to confirm the conclusion of Robinson (40) that potash limitations are not widespread on ordinary surface-treated pastures. But the conclusion obviously does not apply to other crops, and may not even apply to pastures if deeper-rooted pasture herbage is grown in place of bluegrass and clover, especially on soils low in potash like the Holston and Monongahela terraces.

Other highly silty soils without shale fragments have so far shown quite low potash values. Two profiles of the Frankstown-Pickaway catena from the Greenbrier averaged only 0.15 m.e. for 12 sampled horizons (Table 6). The surface soil of one profile showed only 0.08 m.e. The highest was 0.26. Another highly silty, stone-free profile, previously designated as Lakin silt loam, averaged 0.18 m.e. in all horizons, having only 0.05 m.e. in the surface soil.

Insofar as potash is concerned, these soils seem very much like the Holston and Monongahela, although they are unlike in other ways. It would seem that the difficulties with alfalfa experienced on the Frankstown-Pickaway in the Greenbrier may be related to this low potash supply along with the generally low base status of these soils already indicated. A low supply and general deficiency of potash has long been associated with the sandy soils of West Virginia and elsewhere, but this indication of exceptionally low values on the very highly silty soils has received less attention. It is noteworthy and possibly significant that examination of the fine sand fractions of these soils under a microscope has failed to reveal any appreciable quantities of muscovite or feldspars, two of the primary sources of soil potash. This suggests that highly silty soils may or may not be deficient in potash in West Virginia, depending to a considerable extent upon whether or not primary potash-bearing minerals are abundant in the fine-sand and silt fraction. If these are not present, the silt is mainly quartz, affording no nutrients. This matter of primary minerals appears to justify further consideration, for in the ordinary shale uplands the potash-bearing minerals seem rather abundant; and exchangeable as well as total potash is relatively high.

Among the acid-shale uplands three Calvin soil profiles show an average of 0.18 m.e. for 9 sampled horizons (Table

6). This average is quite low, and the highest value, 0.29, comes from a surface soil where the burning of litter may have had an influence, so it seems that the red shales which give rise to Calvin soils may be associated with potash deficiency, although the variability among these and other acid-shale uplands is such that no definite conclusions can yet be drawn. Results for Ashby silt loam (Table 6) vary from 0.09 to 0.56, the high values being associated with high organic matter. Gilpin averages somewhat higher, the extreme of 1.0 m.e. occurring in a shaly subsoil. These two soils are grouped together in Table 6 because their variability seems to leave little ground for separating the samples studied, and there is probably no reason to expect any characteristic difference.

Soils with strong limestone influence show moderately high exchangeable-potash contents, although Hagerstown and Frederick do not average as high as Gilpin, and quite low values were obtained for one typical sample of each. The Upshur-Meigs results shown are the highest, the extremely high values coming from a lime-rich profile over a partially red clay-shale. The second profile was more typical of Upshur in color and appearance and contained no free lime. Its exchangeable potash ranged from 0.20 to 0.35 m.e.

The slack-water terraces and associated bottom soils grouped together averaged rather low. Highest values were from the high organic Blago, and lowest for strongly-acid clay subsoil. One slack-water terrace soil with free lime below 40 inches is shown separately, but it is no higher in potash than the acid slack-water soils.

Fertility-plot experiments involving potash response on several soils seem to agree with the tentative conclusions which might be drawn from the chemical data. Alfalfa trials on various soils have shown good response on Holston, Frankstown, and Wheeling; fair response on some Hagerstown and DeKalb; but little or no response on Westmoreland or Meigs-Upshur. Alfalfa also responds well on Rayne-Cooksport soils on the Agronomy Farm at Morgantown. Corn response has generally been less pronounced, but in Preston County, farm trials seem to indicate considerable need for potash on soils containing from 0.08 to 0.18 m.e. of exchangeable potash per 100 grams in the surface horizon. The soils are predominantly DeKalb, Clymer, and Rayne and might be expected to show deficiencies. The exchangeable-potash values mentioned are quite low compared with many other soils in the state (Table 6).*

A large number of trials on Wheeling soil at Lakin indicate that the cropping system and use of manure are important in determining response to potash. In systems where plentiful supplies of manure were returned to the land, potash fertilizer had little effect. However, where no manure was used, crops gave good response to potash. This was particularly true on limed areas, where both legumes and nonlegumes have been increased in yield by the use of potash fertilizers.** Chemical tests for exchangeable potassium would not be expected to show all such differences as these which are associated with cropping and management.

Pasture studies, as already discussed, give some indication of response where potash is very low (Holston-Monongahela, some Rayne) but little indication of a widespread need for potash in bluegrass pastures. The need may become somewhat greater as more deep-rooted legumes and grasses are used in place of Kentucky bluegrass and white clover.

Greenhouse tests with several subsoils have shown much less response to potash than to phosphorus. Acid, shaly upland; clay derived from limestone, and slack-water clay materials have been involved in these tests.

DISCUSSION

In order to attain maximum profitable production over a long period it is necessary to make all of those factors influencing production as favorable as is economically possible. The factors for which data are presented are among the more important in West Virginia but are by no means the only factors to be considered. However, water and air relationships, soil structure, acidity and base content, organic matter supply, and content of available plant food must be favorable for the crops to be grown if the goal of maximum profitable production is to be achieved. There are two approaches to this problem--crops may be selected which will thrive under the conditions as found, or soil conditions may be changed so that the desired crops may be grown (23).

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*These data supplied by Dr. Edward H. Tyner, Department of Agronomy and Genetics, West Virginia University.
**Unpublished data.

Fortunately nature has provided plants for almost every soil and climatic condition known to man. It is therefore possible to select plants for the various conditions as they occur, whether these conditions be natural or the result of man's interference in nature's scheme. Actually, under the climatic conditions in West Virginia the mere protection of the soil and vegetation from abuse will usually result in adequate cover for the conservation of the soil and will at the same time provide some production. However, under many and perhaps most conditions the production thus obtained will be meager. Increased production can often be obtained by introducing crops which are adapted to the conditions. This fact has been responsible for the introduction and development of many plants which are adapted to a wide range of conditions. One example of this practice has been the introduction of the lespedezas into the agriculture of the southeastern part of the United States.

Unfortunately it has not been possible thus far to discover a sufficient variety of crops of the kind which satisfy the needs of agriculture under prevailing conditions of high acidity and low fertility. Some will serve a very useful purpose under certain conditions. Others may also be temporarily useful and for a time may prove to be the most profitable crops. But so far as is known at present there is no good substitute for favorable soil conditions.

The second alternative, i.e., changing soil conditions so that growth of better plants is encouraged, is usually the more desirable for long-time profitable agriculture. Under most conditions it is desirable to improve surface-soil structural conditions, air and water relationships, organic-matter supply, and plant-food content so that those crops can be grown which will give the maximum profitable production. To do this may require only a few simple practices or many different practices, depending on the soil.

It is evident from the data given that, although there is considerable variation within soils of the same series, there are even greater differences in certain properties between the different soil series. Certain soils appear to have many factors favorable for high production, whereas others are apparently lacking in several respects. For example, the Hagerstown soils have, in general, a favorable structure along with a high content of bases. Such soils will therefore be kept in a productive state by applying the plant-food elements needed, by keeping an active organic matter supply, and by using such practices as may be necessary to prevent loss of the surface soil by erosion. Since these soils are not so highly leached as many of the others, the need for added plant food is probably not so great. On the other hand, most of the other soils have less favorable structure, which in itself is a handicap, and lower quantities of bases. In addition some of the soils have less organic matter, less available plant food, and poorer air/water relationships, all of which must be dealt with in bringing the soils into a high state of productivity. Recognition of these variations between soils is of utmost importance both in planning and conducting experimental work and in planning for proper land use on the individual farm. Too often in conducting experiments in which the soil is one of the factors there has been a tendency to concentrate on a particular set of treatments being studied and to forget about the soil. As a result certain data are obtained which may have only very limited application because the soil on which they were obtained represents only a small area. For example, some experiments at Kearneysville showed good growth of alfalfa on a fairly acid soil. The reason for this was undoubtedly associated with the presence of lime in the subsoil, but tests of the surface soils did not show this. From this experiment, if other information had not been available, one might have concluded that lime was not necessary for alfalfa. Likewise, for some years different varieties of oats have been recommended for soils which had a plentiful supply of nitrogen than for the soils which are not so well supplied with this element. Hybrid-corn varieties, too, differ in their response to different levels of fertility, some being superior at high levels, whereas others, which are only mediocre at high levels of fertility, may be among the best at lower fertility levels. Other examples could be cited, but these are sufficient to establish the importance of the factor of soil fertility in relation to field response. From these it seems apparent that, in order to be able to interpret experimental results properly and, in fact, in order to secure experimental results which will be most helpful to farmers, it is necessary to conduct such experiments under a considerable range of soil conditions. Even when this is done there will still be many questions which will require additional research and proper interpretation for their proper solution. But the number and importance of the unanswered questions will decrease as our knowledge of the soils increases.

What has been said about planning experimental work is just as true in planning the management of the soils on the individual farm. Such problems as lime content, plant-nutrient supply, drainage, and physical condition must be considered in any program of farm planning. The relative importance of the various factors will vary with the soil. On some soils lack of lime and fertility may be dominant; on others drainage or erosion control may be of prime importance. Regardless of which factor or group of factors appears most important, all factors must be considered if the results are to be of permanent value and if crop production is to be most profitable.

For many years certain areas have been recognized as being good farming sections and other areas as being poor farming areas. In general the delineation of these areas appears quite exact and proper because, as has been said, certain soils have a more favorable combination of factors than others. Despite this general recognition there are poor farms in good areas and good farms in the poor areas. In the first case, the farmer has probably failed to recognize one or more of the factors limiting his production and as a result production has declined. On the other hand, the good farm in the poor area is usually an example of the farmer recognizing the important factors limiting production and then taking steps to eliminate these factors. As a result over a period of years the good farmer has been able to increase production and at least temporarily overcome the major factors limiting production. This fact should lend encouragement to other farmers who can do equally well if they will follow the principle of seeking out the limiting factors and then taking steps to correct the conditions limiting production. Agricultural workers, too, can often learn much about improved methods of soil management from a successful farmer.

SUMMARY AND CONCLUSIONS

Soil-profile samples were taken from a number of the more important soil series occurring in West Virginia. These samples were taken from sites carefully selected to be typical of the soil as mapped in the state. Determinations of texture, structure, organic matter, pH, buffer curves, exchange capacity, exchangeable bases, and acid-soluble phosphorus were made in the laboratory. Color was defined by field observation and by comparison with color charts.

Most of the surface soils were loams or silt loams with clay or clay-loam subsoils. Structural profiles are shown for certain groups of series, and the relationship of structure to movement of air and water, to soil erosion, and also to root penetration is pointed out. The distribution of organic matter in the soil profile is given for a number of series, and the effect of climate and past treatment on organic matter content is discussed.

The relationship between pH, percent saturation, and total bases is given for the major series. These show considerable variation within series as well as between series. Within the soil profiles certain series increase in base content and percent saturation (particularly Hagerstown and Frederick) others show little change, and some show increased acidity and decreased saturation with increasing depth. The relationship of this to growth of certain crops is discussed.

The relationship between exchange capacity, and organic matter and clay content is shown, and a general guide is given for evaluating this relationship.

The available phosphorus content was generally low, but a few subsoil samples have shown high contents of acid-soluble phosphorus. These do not seem necessarily to indicate high available phosphorus contents, as some of these soils have shown marked responses to phosphate fertilizers.

Exchangeable potash values range from low to high with an average of 0.256 m.e. of potassium per 100 grams of soil. Low potash values occur especially in highly leached terrace soils in sandy soils, in the silty limestone soils, and in old ridge top soils. Surface soils were usually higher in exchangeable potash than subsoils. High potash content was usually associated with high organic matter in the soil or with high clay content, but the reverse was not always true.

The relationship of the various factors to land use are discussed. In any program of research or farm planning, the chemical composition and physical make-up of the soil must be considered to make such programs most effective. By considering these, together with management on the farm, agricultural workers and farmers can make great progress in wise land use and increased agricultural production.

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