ART. LII.—*On Soil Analyses and their Utility*; by EUG. W. HILGARD, State Geologist of Mississippi.

(Read at the Dubuque Meeting of the Am. Assoc. Adv. Sci., August, 1872.)

IN the *American Journal of Science* for September, 1861, Prof. S. W. Johnson published a criticism on the "Soil-analyses of the Geological Surveys of Kentucky and Arkansas," whose strictures, to a great extent eminently just, appear to have so impressed the scientific public in this country, that few if any soil-analyses have since then been made in connection with any state or national survey, excepting that of the State of Mississippi, where the work already begun was continued, either by myself, or under my charge, or recommendation, by others. Holding myself responsible for this departure from the generally adopted views, I propose in the present paper to discuss specially Prof. Johnson's objections, and to give my reasons for persisting in a course of research that has, more than once, secured for myself and my co-laborers the compassionate sym-

pathy of true believers. While I consider the work far from being as complete as it should be, and for that as well as other reasons its publication in detail may be delayed for some time ; yet I think what can now be said of sufficient importance to be brought before this meeting.

I propose, in this discussion, to maintain the mainly practical standpoint assumed by Prof. Johnson himself. I shall therefore leave out of consideration the performance of such exhaustive investigations of *all* the physical and chemical properties of the soil, as have been made in some cases, for special purposes, e. g., by Prof. Mallet, on some of the cotton soils of Alabama. If the investigation of each soil, to possess practical importance, requires from three to six months labor, we may as well, for practical purposes, consider such researches out of the question for the present. We want something analogous to the metallurgical assay of minerals, as distinguished from their complete ultimate analysis. So far, therefore, as the agricultural qualities of a soil may be inferred and approximately estimated by an experienced eye, I would relieve the chemist from the exact numerical determination, e. g., of the power of absorbing heat from the sun, the specific heat, the "water-holding" power, the capillary coefficients, etc. However necessary for theoretical investigations, I hold that for practical purposes, these laborious determinations may in most cases be dispensed with ; since from what has already been done, or what can be done with a few typical soils, we may infer the comparative magnitude of these coefficients with a sufficient degree of approximation.

The amount of labor bestowed on each soil by Dr. Peter, as reported in the Kentucky and Arkansas surveys, approaches very closely the limit beyond which the *immediate* advantages to be derived from such knowledge of soils as analysis may impart, would seem, to many, disproportioned to the expenditure involved. How very modest we are, truly, when a purely scientific object is involved, whose immediate practical application is not obvious at a glance ! In what other branch of technical science would it be thought admissible to proceed without obtaining such knowledge of the prime materials as chemistry may afford, even if *no* immediate application of this knowledge be foreseen ? Our public treasuries are constantly drawn upon for hundreds of thousands of dollars, in behalf of objects of at least questionable usefulness. Yet Prof. Johnson seems to have thoroughly satisfied our state geologists that they are not justified in giving the virgin soils of their respective States the benefit of such light as chemistry may even now confessedly afford : apart from the important general inferences which may fairly be expected to be drawn hereafter from the history of their cultivation. How are we to advance in our knowledge of

soils, if we abandon as hopeless the determination of their chemical character? Are the proofs that have been brought against the utility of soil analyses really of such a character as to justify so grave an omission? an omission, too, which in many cases cannot hereafter be supplied. Even in the comparatively youthful State of Mississippi, I have found difficulty in obtaining reliable specimens of some soils, whose great productiveness had led to their cultivation by the earliest settlers, over the entire area of their occurrence.

I question the propriety of this omission, and the justice of the *testimonium paupertatis* thus inflicted upon agricultural and analytical chemistry.

To define my position, I premise that—

1. I fully agree with Prof. Johnson as to the comparative uselessness of a single analysis giving the percentages of soil ingredients found, *in ordinary cases*. It is only when such analysis demonstrates the *great abundance*, or *very great deficiency*, of one or several primarily important ingredients, that, by itself, it conveys information of considerable practical importance. Note, that such cases are not altogether infrequent, even in virgin soils.

2. I agree that an "average soil" is a *non ens*, except as referred, comparatively, to a *particular set of soils closely related in their origin*.

3. Also, that the claim of being able to detect the minute differences caused by cropping without return to the soil, is precarious, and perhaps beyond the power of our present analytical resources.

4. I further admit that, ordinarily, the analysis of soils long cultivated, and treated with manures, can give but little and very partial information as to the condition and composition of the soil; from the great difficulty, if not impossibility, of obtaining fair representative specimens.

5. Furthermore, that to designate soils by the names of the Cretaceous, Carboniferous or Silurian strata they may happen to overlie, is very loose practice; since in most cases they are derived from Quaternary deposits, which may or may not have been influenced in their composition by the subjacent rocks.

On the contrary I demur, in the first place, to the broad assertion that "it is practically impossible to obtain average specimens of the soil," as inapplicable to a very large class, especially of virgin soils, covering large areas with a uniformity of character corresponding to that of subjacent formations, from which they have been directly derived, by substantially identical and uniform, or uniformly variable, processes.

The importance of this exception is not, it is true, very obvious in the stony fields of New England (such as discouraged

Prof. Johnson in his vacation trip to Northern New York), or in fact, in any district where a great variety of formations has directly contributed toward forming the soil, and "chunks" of undecomposed minerals are diffused through it. In such cases, the analysis of the rock which has predominantly contributed to the mass of the soil proper, would be a more correct index of the prevalent characteristics of the latter, than if itself were taken in hand. And from such analyses we could at least deduce what ingredients, and in what form, it would certainly be *useless* to add to the soil.

But when we come to the great plains of the West and Southwest, whose soils are consistently derived from widespread Quaternary deposits, composed of materials almost impalpable save as regards siliceous sand; or even the rolling uplands of the Gulf States, whose subsoil stratum of "yellow loam" can only be diluted, but not otherwise changed, by the admixture of the underlying drift, leached long ago of everything soluble in carbonated water, or available to plants: the objection based upon the supposed impossibility of securing representative specimens, becomes obviously untenable; as I shall hereafter show from the close correspondence in the composition of soils, and especially *subsoils*, from widely distant portions of the State, derived from the same geological (Quaternary) stratum.

A word in regard to the "freaks and accidents" mentioned by Prof. Johnson as liable to make sport of the devoted analyst. Undoubtedly such errors must be ultimately provided against by multiplication of analyses (not necessarily of the same acre, but of other corresponding specimens, in the sense mentioned above); and while questioning the efficiency of a bird or squirrel in vitiating a properly taken sample of soil, I must admit the disastrous consequences which might result if a dog, cow, or horse were similarly concerned. No specimen of "virgin soil" can, of course, be obtained where such animals usually do congregate. But as a rule, it is not at all difficult to avoid such places; while the chance of accidentally hitting upon a sporadic animal deposit in the broad woods or prairies is singularly small, and is notably diminished by the circumstance, that an attentive observer (and none other should take soil specimens) will be able to distinguish such localities for years, by the peculiarity of their vegetation.

I will remark, however, that I consider the sampling of a soil with a view to securing a representative specimen, as a matter second in difficulty and delicacy only to the analysis itself; that I rarely have thought it worth while to analyze specimens sent by other than intelligent persons specially instructed by me; and even then have frequently had to reject them, from

their having obviously been taken at an improper locality, e. g., near a foot-path, by the side of a fence, on a partially denuded hillside or ravine, in the bed of a run, at the foot of a tree, etc.

The question of *depth* must, in my view, be left to be determined by the circumstances of each case, except in so far as the extreme depth to which tillage may cause the roots of crops to reach, must be within the limits of the samples taken. Of these, *one* should ordinarily represent what, under the usual practice of tillage, becomes the arable soil; another, the subsoil not usually broken into; a third will in most cases be useful to show what materials would be reached were the land to be underdrained. As a rule, I have taken no specimens of soil to a less depth than six inches, and as much deeper as uniformity of color reached—for obvious reasons. But in special cases, when important differences were suggested by the aspect of the soil and subsoil, they have been separately examined, at whatever depth the change of color might occur.

With soils of the character referred to, samples selected and taken with due care, and strict attention to thorough intermixture, both in the field and subsequently in the laboratory, I am unable to see why even two grammes may not correctly represent the characteristics of a 1000 acre tract. Not that every point of that tract would be likely to give the same percentage result, perhaps; especially as regards the surface soil, which might in places be more clayey or more sandy than the sample analyzed. Still, the *relative proportions of the soil ingredients, and their degree of availability*, would remain substantially the same; the wider range and readier penetration of roots in sandier soils, making up, within certain limits, for the smaller percentage of available ingredients in a given bulk, as compared with more clayey ones.

From the fact that the atmospheric surface water must, in its course, inevitably have a tendency to bring about such inequalities, by carrying forward the finer particles of the soil in larger proportion than the coarser ones; as well as from the greater influence of vegetation: we shall, in the series of analyses made a postulate by Prof. Johnson, expect to find a closer agreement between those of subsoils than those of surface soils. Such I find to be very decidedly the case; so much so, that I habitually look to the former as the most reliable index of a soil's distinctive character. To this there can be no legitimate objection, when, as in all the upland soils now under consideration, the surface soil is directly derived from the subsoil, and its depth is less than thorough culture would give to the arable soil.

As regards the analysis itself, I premise that I have always found even the most "chemically pure" reagents sold by dealers quite inapplicable to the purpose of soil analysis. From first to last, I have prepared or purified these myself; and, as regards the acids, especially hydrochloric, I have found it necessary to reject, as a rule, even the purest, after keeping it for a few weeks in a glass bottle. The same is true, and perhaps in an aggravated degree, of aqua ammoniæ. The severe ordeal of slow evaporation on a bright platinum foil will rarely be passed by ammonia a fortnight old; and still less frequently by hydro-sulphide of ammonium.

Armed with these, and a multitude of other precautions, usual and unusual, to secure the utmost possible accuracy; always treating the soil with the same large excess of acid of uniform strength, and precipitating all corresponding precipitates as much as possible from the same volume of liquid; using none but the best Bohemian glass, and platinum vessels, and filters specially extracted—operating, in short, as uniformly as the nature of the materials would permit: I confess I felt considerable confidence in the correctness of my results, until the experiments made in Bunsen's laboratory, on the solubility of glass vessels, gave rise to unpleasant doubts. On consideration, however, I found that the (sensibly constant) error so introduced would not, when allowed for, amount to more than the differences between two analyses of one and the same material, or vitiate in any serious degree the conclusions arrived at. Nevertheless, I shall hereafter, to the utmost possible extent, carry on all operations liable to introduce errors on this score, in platinum and porcelain vessels, as advised by Bunsen.

As regards Dr. Peter's failure to determine the amounts of soluble silice, nitric acid, ammonia, chlorine, and the degree of oxidation of the iron, I agree that the former is desirable, not only because, whether "essential" or not, some plants do habitually absorb it in very large quantities, and it might be best to let them have it; but also because it is a desirable index of the degree of decomposition which the soil silicates have undergone. I have therefore made this determination regularly, by boiling with solution of sodium carbonate. In a series of these determinations, an unmistakable relation between the soluble silice and the amount of lime in the soil becomes manifest; as might, indeed, have been foreseen.

As regards nitric acid, the consideration suggested by Prof. Johnson himself, viz., that its quantity must be exceedingly variable, within short periods, in one and the same soil, seems to me a sufficient dispensation from the laborious determination.

The same holds good, in a measure, for ammonia. Its quan-

tity varies continually in the soil, as it does in the atmosphere; its chief absorbers in the soil are "humus" and clay. Where these prevail largely, ammonia can scarcely be deficient as a nutritive ingredient to an injurious extent; albeit, more might doubtless be beneficially added. Moreover, the characteristic effects of ammonia on vegetation are sufficiently obvious (in "running to weed") to render its determination in virgin soils, laborious and even uncertain as it is, a matter of comparatively little *practical* consequence, however great might be its theoretical interest.

As for the determination of the degree of oxidation of iron, I confess I fail to see its practical bearing. When ferric oxide is present, plants surely can have no difficulty in reducing the modicum they need to a soluble condition. When ferrous oxide exists to any great extent, it indicates a want of drainage, and manifests itself both in the color of the soil and in the poisonous effect on vegetation. But farmers surely do not need the aid of chemical analysis to tell them that their soil needs drainage and aëration! A determination made to-day would be of no value to-morrow, if the soil had been plowed in the interval.

Finally, Dr. Peter *does* determine *chlorine*, in the treatment of soils with carbonated water; though it is not put down in the general analysis. However, the soluble chlorides, like the nitrates, are so constantly liable to variation and, as experience shows, so little likely to be deficient in the soil, that its omission would not be a serious practical objection.

A much graver defect is the failure to determine separately the organic matter ("humus") and the chemically combined water; and to this is owing, in a measure, the unsatisfactoriness of the analyses as regards information on the physical character of the soils. A large amount of water of hydration indicates, in ordinary cases, a correspondingly clayey soil, where heaviness in working may, or may not, be relieved by a large amount of "humus." The "volatile matter" item, however, gives us no information whatsoever on these vitally important points; and there is, unfortunately, no *simple* method by which the determinations in question can be effected even approximately. That they *should* form part of every soil analysis, is obvious, if only on account of the importance of "humus."

I have attempted to obtain a reliable scale of the different degrees of "heaviness" of soils, from the determination of their maximum absorption of hygroscopic moisture at ordinary temperatures. I find that at temperatures from about $+7^{\circ}$ to $+21^{\circ}$, the amount of aqueous vapor absorbed by a thin layer of soil exposed to a *saturated* atmosphere remains very nearly constant, being for

Very sandy soils, -----	1.5 to 2.0 per cent.
Loam soils, -----	5.0 to 8.5 “
Clay soils, very heavy, -----	12.0 to 15.0 “

there being, of course, all intermediate grades of hygroscopic power, as well as of “heaviness.” It appears that for this interval of temperature, the decrease of absolute absorbing power in the soil, resulting from the rise of temperature, is just balanced by the increased amount of vapor diffused in the air—not an unimportant circumstance, with regard to vegetable life.

There are, however, two soil ingredients which interfere seriously with the correctness of the estimate as to “heaviness,” derived from the coefficient of absorption, viz., “*humus*” and *ferric oxide*. Both of these are highly hygroscopic, yet both *counteract* the “heaviness” caused by excess of clay. Moreover, there is a class of soils (viz., fine siliceous silts) whose exceeding “heaviness” in cultivation is much complained of, yet whose absorbent power is very small.

When, as in the majority of cases, the surface soil has been directly derived from the subsoil, the disturbing effect of the “*humus*” may be sensibly eliminated by comparing, not the soils, but the subsoils, in this respect.* As to the ferric oxide, there are among about 200 Mississippi soils analysed but three or four whose agricultural qualities would have been seriously under-estimated by a reliance upon the coefficient of absorption alone.

But I do not for a moment admit, that in a material so complex both in its composition and mode of action any one or few data, whether chemical, physical, or agricultural, may be relied upon to characterize the soil; or, as Prof. Johnson expresses it, “to do violence to agriculture.” So far from this, I consider that a proper interpretation of the analytical results must take into consideration, not only all the chemical and physical facts observed on the specimen, but all that has been or can be observed *in loco*—the location, depth, derivation, relations to drainage, etc.; as well as all that is known concerning the qualities or peculiarities of the soil, both in its natural state and in cultivation. As Prof. Johnson says, it should “form part of a system of observations and trials; must be a step in some research; must stand, not as an index to a barren fact, but as the revelator of fruitful ideas.”

Such, precisely, has been my object from the beginning of my researches on the soils of Mississippi, for sixteen years past. Clearly, the difference between Prof. Johnson’s position and mine is one of degree only; yet this difference is not a slight

* In such cases, the surface soil is always more sandy than the subsoil.

one, since while, as before remarked, I have made, or caused to be made, some 200 analyses of soils and subsoils, his classic works on the growth and nutrition of plants do not contain so much as a tabular exemplification of the composition of various soils, as resulting from chemical analysis. If, then, "the probabilities of its uselessness in direct application to practice are so great," as Prof. Johnson seems to hold, I have committed a grievous error, and squandered the substance of the State.

I think that the considerations already adduced should plead measurably in extenuation of my course. But I will now state succinctly what services, in my view, soil analyses may fairly claim to be capable of performing, when conducted substantially in the manner, to the extent, and under the conditions defined above.

I take it for granted that, if in the determination of the mineral ingredients we were able to distinguish clearly from one another the portion immediately available to plants, from that which is in an unavailable form, we would go far toward accomplishing what was originally claimed for soil analysis; and this Dr. Peter attempted to do by treatment of the soils with carbonated water. It cannot be doubted, however, that plants, as well as agriculturists, have at their disposal much more powerful, or at least more *energetic*, solvents; and that, therefore, a determination of those ingredients which may fairly be considered practically within the reach of agriculture, must go deeper than does that with carbonated water.

Opinions may differ widely as to the proper strength and nature of the solvent ("*Aufschliessungsmittel*") to be selected. Hydrofluoric acid, or ignition with the alkaline earths, would evidently go too far; as no soil, probably, will ever yield up the whole of its nutritive ingredients to plants, and fertility is far from being proportional to the *whole* amount of potash, phosphoric acid, etc., contained therein.

When, however, a *partial* solvent of uniform strength is used in all cases alike, and its action continued for the same length of time, it may fairly be presumed that, *as between soils of similar origin*, the amounts so rendered soluble are, in a measure, proportional to the amounts of available nutriment present.

In using hydrochloric acid of the strength 1·11 to 1·12 sp. g., obtained by slow steam distillation of stronger or weaker acid, rejecting the first and last portions, I have in most cases found quite a satisfactory agreement between the results so obtained and the experience of cultivators as to the productiveness and duration of the respective soils; always *provided*, that the difference in the amounts of inert sand present, of specific gravity, of depth of soil, etc., were taken into account.

The proviso is important; but that with a proper local knowledge these allowances *can* be made, and that in most cases the information thus gained regarding the nature and treatment of the soil will be vastly more complete and reliable than the judgment of any number of "old intelligent farmers," my experience has fully convinced me; witness the egregious mistakes daily made by such in the selection of new lands. Moreover, a small minority only of farmers is likely to possess the requisite "age and intelligence"; and it is quite important that the multitude of those less fortunate should have the benefit of all the help science can give them.

I will adduce but one "odious example" of a widely prevalent error in reference to the character of a class of soils, that I have as yet been unable to eradicate, even from among the "old and intelligent;" who are unfortunately very much given to theorizing on inadequate premises. Our prairie soils are notoriously limy; they are also very "sticky"; and the mud takes the hair off the feet of cattle. *Ergo*, every "sticky" clay soil in the State is called, considered, and treated as a "prairie" soil, especially if the hardened clods adhering above the hoofs of cattle should carry the hair with them. If such soil is unthrifty, and rusts cotton, it is because "there is too much lime in it," which "scalds" the seedlings. In matter of fact, most of these soils are notably deficient in lime, so as to be most directly and immediately benefited by its application wherever it has been tried, in accordance with my suggestion. The lime here acts, probably, as much chemically as physically; the clay being rich in potash, as per analysis.* While the physical defects of these soils are doubtless the main cause of the crop failures, yet analysis has suggested a remedy which relieves, for the time being, from the necessity of the more costly improvements; lime being comparatively easy of access.

Analogous cases are far from infrequent, both in this and in the adjoining States; and I have been led to attach special importance to the determination of *lime* in soils, from the (not unexpected) rule which seems to hold good very generally, viz., that, *cæteris paribus*, the *thriftiness* of a soil is sensibly dependent upon the amount of lime it contains; while, at the same time, in the usual mode of culture without return to the soil, the *duration* of fertility is correspondingly diminished, and its cessation is very abrupt wherever much lime is present.

It may be said that, after all, this is but what, from data already known, might have been expected. Granted; then, *a fortiori*, soil analysis, involving the determination of lime,

* See, for example, the article "Heavy Flatwoods Soil," in my *Miss. Rep.*, 1860, pp. 276, 279.

is of considerable use in determining the present and future value of soils.

In speaking of the "amount" of lime, I must be understood to refer, not so much to its absolute percentage, as to its quantity in comparison with that of potash, which, with phosphoric acid, is what all our fertilizers chiefly aim to supply. Their determination must, of course, be considered of prime importance, since their absence or extreme scarcity is fatal to profitable fertility; while, when they are present, even though *immediately* available for absorption to a slight extent only, we possess in lime, ammonia, etc., and the fallow, ready and powerful means for correcting their chemical condition.

Here again, the practical value of soil analysis is direct and indisputable. It is of no small interest to know whether the soil we intend to cultivate contains 0.75 per cent of potash and 0.25 of phosphoric acid, soluble in H Cl, or only the fifth or tenth part of these amounts. *One* will bear improvement of all kinds—will pay for underdraining, terracing, etc.; while the other, quite similar in aspect perhaps, would not, according to Liebig's testimony, ordinarily be capable of profitable culture.

Again, it is well known that the same species of plants may occupy soils of widely different quality and value. True, an attentive observer will in such cases see differences in the mode of development;* yet these are often such as to escape ordinary remark, and grievous disappointments frequently arise from this source, with new settlers especially. It is of no small importance to be able to *identify*, as well as to distinguish, soils resembling each other; and this, soil analysis can undoubtedly do, if there is any virtue in the law of probabilities even—admitting all that may otherwise be said against their reliability.

Even if no other direct benefits than those already mentioned could be attained by the chemical and mechanical analysis of soils (which I do not admit, and expect to prove otherwise hereafter); even if we leave out of consideration the addition to our general knowledge which may fairly be expected to result from extensive series of such investigations, carried out upon a uniform plan, whereby accidental errors (whether caused by "birds or squirrels," or analytical and other mistakes) will be eliminated; even thus, I contend that the practical and theoretical value of soil analyses is sufficiently great to justify whatever labor and expenditure may be bestowed upon them by state and national surveys; and that the neglect with which this branch of research has

* Miss. Rep., 1860, p. 203.

of late been customarily treated, is the more to be regretted as no probable amount of private effort can accomplish what must, of necessity, be done on an extended scale and with the *prestige*, voluntary assistance, and interest, not usually accorded to any but public enterprises. And with due deference to the author of the two volumes whose extraordinary merits no one appreciates more than myself, I call upon my colleagues in State surveys, especially in the West and South, to reconsider this subject before it is too late, and a legislative fiat declares their work to be "finished." It is true that the agricultural colleges must and will take up and continue, as far as possible, the investigation of the agricultural peculiarities of each State; but the special and local experience acquired by those conducting a field survey, as well as their opportunities for extensive and comparative observation, are unfortunately "not transferable," even to the finest quarto report. In order to attain their highest degree of usefulness, our agricultural colleges should teach, not merely general principles, together with a sufficiency of the handicraft of agriculture; but they should be enabled to point out to each student, with reference to his particular neighborhood, How Crops Grow, and How Crops Feed.

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