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Modern interpretation systems for soil and plant analyses in the United States of America

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Summary. Although over 3 million soil samples and over a half a million plant tissue samples are assayed in the some 450 soil-testing and plant analysis laboratories in the United States of America, both techniques are considerably under utilised by farmers. It has been estimated that <15% of the cropland is soil-tested each year and about 30–40% of farmers seldom soil test. Plant analysis is primarily used as a diagnostic tool, except for fruit and nut growers, many of whom test yearly in order to formulate fertiliser recommendations for next year's crop. Considerable standardisation of assay procedures and methods of reporting soil and plant analysis results have occurred in the last decade, although much has yet to be done. Laboratory accreditation and proficiency testing are current issues that will begin to impact the laboratories, while environmental issues will probably demand increasing testing by farmers to insure that fertiliser practices are not contributing to soil and water degradation. This paper reviews past, current, and future roles of soil testing and plant analysis in the U.S.A.

Introduction

It is difficult to generalise on how soil and plant analysis results are interpreted by the 450 soil-testing and plant analysis laboratories in the United States of America that provide a wide range of analytical services to farmers and growers. In a survey conducted by Jones and Kalra in the U.S.A. (1992), it was found that 83% of soil test results and 55% of plant analysis results included an interpretation and recommendation.

In the future, there will be a change regarding to whom and how recommendations will be made. Pending federal legislation related to the Clean Water Act would mandate soil tests for farms of sizable acreages and/or when a fertiliser purchase exceeds a certain quantity. Some States already require farmers to soil test for soil profile nitrate before applying nitrogen (N) fertiliser to soils in areas that are considered environmentally sensitive (such as the sandy soils in semi-arid regions of the U.S.A.). For this test, the requirements are clearly defined as to how and who does the test, and then how the results are to be interpreted. However, under the current pending federal legislation for the Clean Water Act the criteria for soil testing and interpretation are not specified.

It is also expected that those who will be making test interpretations and fertiliser recommendations will have to be certified. Currently, one form of certification, known by its acronym ARPACS, can be obtained through the American Society of Agronomy, the Soil Science Society of America, or the American Society for Horticultural Science. Another form of certification can be obtained from the National Alliance of Independent Crop Consultants. In 1993, a new certification program will begin, the Certified Crop Advisor. In order to become a Certified Crop Advisor, the individual must take a national examination as well as a State-administered one, have 4 years of experience past high school, and agree to follow a code of ethics. It will be interesting to see how the Certified Crop Advisor program will work in terms of who will become certified, and whether laboratories that provide soil test services will have on their staff a Certified Crop Advisor to make recommendations. Currently, only 7 States have implemented the Certified Crop Advisor program.

In a 1992 listing of the top 100 fertiliser dealers in the U.S.A. (Farm Chemicals, Voume 159, No. 12, 1992), 39% of these dealers provided their customers with soil-testing services and 20% provided customers fertiliser recommendations. That portion of the 20% who provided fertiliser recommendations are probably giving recommendations in the form of product-oriented materials in which the rate of application is based on meeting a specific crop requirement. These recommendations are not necessarily based on a soil test result. In the survey, there was no indication regarding plant analysis services that were offered or recommendations given based on a plant analysis.

In some crop speciality groups, such as citrus, sugarbeet, sugarcane, field tomato, and certain vegetable crops, crop consultants are hired to monitor the crop continuously with soil and plant tests, advising the farmer on fertiliser treatments required to correct observed insufficiencies. An increasing number of consultants who periodically scout for insects in crop fields have expanded their services to include nutritional evaluation based on collected plant tissue sample assays: samples taken when scouting for insects. The primary group that represents these crop consultants is the National Alliance of Independent Crop Consultants, an organisation that is rapidly growing in both members and influence.

The role of soil testing and plant analysis in crop management decision making is being driven by several factors including the economic challenge for greater production efficiency, and the environmental aspects of intensive crop production practices. Although not considered in this review in detail, crop product quality may be added to the list as larger quantities of waste products are land-disposed, waste products that frequently contain significant quantities of desirable nutrient elements such as N, phosphorus (P), potassium, calcium, etc., but also contain toxic elements such as cadmium, chromium, lead, etc. In addition, many waste products contain high concentrations of the heavy metals, such as copper (Cu) and zinc (Zn), and their contents are such that the waste product application rates must be carefully determined in order to prevent plant toxicities.

Soil test interpretation

Methods of reporting soil test results and their interpretation are not standardised. This has been a source of concern and frequently has been cited as a reason farmers, in general, are distrustful of soil testing. This distrust arises from the fact that some farmers will split soil samples, sending separate subsamples to several laboratories for analysis and interpretation. If different test results are received in terms of the actual values given, the interpretation, and the recommendation, he becomes confused and distrustful of soil testing, even though there may be valid reasons for these differences. For example, 1 laboratory may express an elemental test result in pounds per acre (lb/acre), another in parts per million (ppm), another as equivalents (milliequivalents/l00 g). In addition, the philosophy used to develop a soil test recommendation will add variance the farmer may not fully appreciate. A fertiliser recommendation may include considerations for the potential yield goal, time and method of fertiliser application, and the impact that the concept of nutrient management will have when based on crop requirement needs with or without soil fertility considerations.

Not only are laboratories using a variety of terms and units for reporting the levels of the extractable elements, but there are some laboratories that report only a relative value that relates to its interpretation based on a sufficiency range concept. That is, the actual test result is not reported.

In addition to the actual value expressed in some unit, there may be a following letter or letters such as VL which means very low, L for low, M for medium, H for high, and VH for very high, etc. These designations establish an interpretative level which identifies what fertility level the soil test value represents. Unfortunately, there exist neither fixed values for the various categories, nor a consistent definitions of very low, low, etc. Although there is fairly good agreement on what consitutes a low soil test value for many of the essential fertiliser elements, there is considerable disagreement about what constitutes sufficiency (i.e. when no additional fertiliser is needed over that to satisfy the crop requirement). There is essentially no agreement on what constitutes an excessive or toxic soil test level. In fact, very few laboratories will identify a soil test level at a category other than high. For those laboratories that include a fertiliser recommendation as a part of the soil test service, there are those who never make a 'zero' recommendation; that is, some minimum amount of a fertiliser element is specified even though the soil test result for that element is considerably above the so-called 'sufficiency' level. Research is needed to identify at what soil test level no addition of that element as fertiliser is required, and any further increase in the soil test level could result in significant yield losses.

An example of the philosophy of recommending at a level that will both satisfy the crop requirement and add to the soil test level can be seen in the average P test levels that currently exist in many cropland soils in the U.S.A. In many of these soils, the soil test P level is well above the P fertiliser response level, and the percentage of soils testing low in P is <10% and the number testing high >50%. Even under these conditions, P fertiliser is still being recommended by many laboratories at rates that exceed the crop requirement.

Very few soils are being tested for micronutrient status, unless the crop–soil conditions are such that a micronutrient recommendation would be expected. In the past, it was common to recommend the use of a fertiliser that contained an added micronutrient or micronutrients that would be specified based on crop requirement, for example, boron being added to fertilisers applied to cotton or peanut crops grown on sandy acid soils, or Zn being added to maize grown on sandy and/or alkaline soil. However today, the trend is toward specific micronutrient recommendations based on the crop requirement and/or a combination of soil and plant test results. Unfortunately, micronutrient soil tests are being made when the method used is not suitable for the soil type, and/or the crop to be grown does not have a high requirement for that micronutrient.

Interpretation of plant analyses

Difficulties have been encountered in the use and interpretation of plant analyses, although the quantitative association between absorbed nutrient elements and

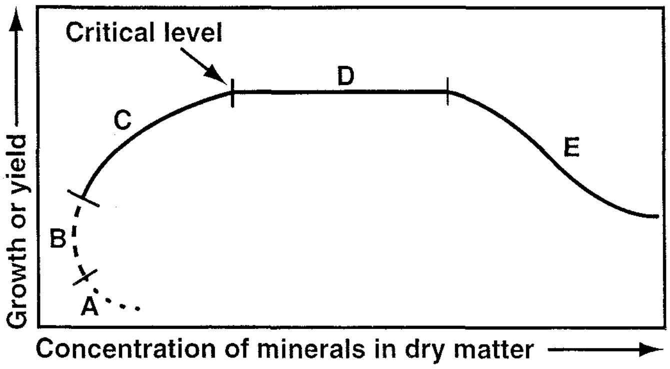

Figure 1. General relationship between plant growth or yield and elemental content of the plant (Prevot anf Ollagnier 1961). A and B, severe deficiency; C, moderate deficiency; D, luxury range; E, toxic range.

growth has been the subject of many articles. Questions raised at the 1959 Plant Analysis and Fertilizer Problems Colloquium (Reuther 1961) regarding the limitations of the plant analysis technique still apply today, such as the reliability of interpretative data, utilisation of ratio and balance concepts, hybrid influences, and changing physiological processes occurring at varying elemental concentrations. In addition, reliable interpretative data are lacking for chloride, for most of the nutrient elements in ornamental plants, for all plants during their early growth stages, and for identification of those concentrations considered 'excessive' and/or 'toxic'. It is also questionable whether the determination of iron (Fe) concentrations in a particular tissue can be used to identify Fe sufficiency (Chaney 1984; Jones and Wallace 1992).

Initially, single concentration values, such as critical (Macy 1936; Ulrich 1952; Smith 1962) or standard (Kenworthy 1961) concentrations, were sought. Today, those who interpret plant analysis results for diagnostic purposes prefer working with the full concentration range from deficiency to excess. Such interpretative data are obtained from response curves such as that described by Prevot and Ollagnier (1961) (Fig. 1). Others have drawn similar response curves with varying slopes within the deficiency range, such as that obtained by Ohki (1984) (Fig. 2). The slope and general configuration shown in Figure 1 are typical for describing the association between yield or plant response and a macronutrient concentration in the leaf or plant, whereas Figure 2 better typifies the association between yield and a plant micronutrient concentration.

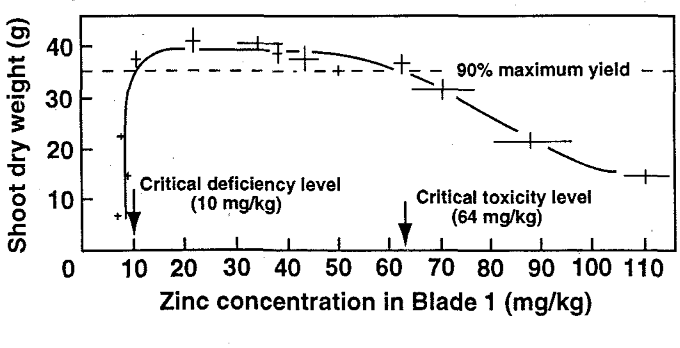

Figure 2. Relationship between zinc concentration in blade 1 of sorghum and shoot dry weight.

The C-shape of the left-hand portion of Figure 1 has been coined the 'Steenbjerg effect', and is the result of a combination of either elemental concentration or dilution, effects which have been discussed by Jarrell and Beverly (1981). Misinterpretation of a plant analysis result can occur if the interpreter is not familiar with the interactive relationship between element concentration and dry matter accumulation when there are no visual symptoms.

The steep left-hand slope shown in Figure 2 poses a significant sampling and analytical problem since a very small change in concentration results in a significant change in plant growth and/or yield. This is particularly true for elements like manganese (Mn) and Zn, where a concentration change of only 1 or 2 mg/kg in the leaf tissue can define either deficiency and sufficiency status.

In an ever-increasing number of instances, identifying the nutrient concentration in the excessive or toxic range is becoming as important as determining deficiency concentrations. Unfortunately, very little detailed information has been obtained on the full range of response from deficiency to toxicity.

A critical value is that concentration below which deficiency occurs. Being a single value, it is difficult to use when interpreting a plant analysis result if the assay concentration is considerably higher or lower than the critical value. Ulrich and Hill (1973) have suggested the interpretative use of the transition zone, the range in elemental concentration that exists between deficiency and sufficiency. Dow and Roberts (1982) proposed using critical nutrient ranges, which is the same concept as the Ulrich and Hill (1973) transition zone. The Y concentration range that lies within the transition zone is the range in which a 0–10% reduction in yield occurs, with the critical value at the 10% yield reduction point. Ohki (1987) has used this concept to define critical nutrient levels: the point at which a 10% yield reduction occurs as the critical deficiency level, and the point of toxicity as the critical toxicity level. The terminology proposed is new and has yet to be accepted.

Diagnosing a plant analysis result based on critical or standard values, or sufficiency ranges, requires that the plant part and time of sampling be identical to that described by the original source of the interpretative data. Because nutrient element concentrations in the plant can vary depending on plant part, stage of growth, genotype, and geographical location, these traditional techniques of plant analysis interpretation have their limitations.

There is another, fairly new concept of plant analysis interpretation called the Diagnosis and Recommendation Integrated System, referred mainly by its acronym DRIS, which was proposed by Beaufils (1971, 1973). The DRIS technique of interpretation is based on a comparison of calculated elemental ratio indices with established norms. The DRIS approach was designed to provide a valid diagnosis irrespective of plant age or tissue origin, to rank nutrients in their limiting order, and to stress the importance of nutrient balance.

DRIS is based on the principle of elemental interrelationships by determining, in order, those elements from the most to the least limiting. Beaufil (1973) surveyed international literature to obtain a plot of elemental leaf concentration *v.* yield, a distribution that is skewed. In order to normalise the distribution curve, the yield component is divided into low and high yield groups. Walworth *et al.* (1986) suggested that the data bank for determining DRIS norms should have at least several thousand entries, randomly selected, and that at least 10% of the population be in the high yield subgroup. It is also important that the cutoff value used to divide the low from the high yield subgroups be such that the data for high yield subgroup remains normally distributed. Using the mean for each element, the ratio and product among the elemental means are determined. The ratio or product selected for calculating DRIS norms is that with the largest variance. This maximises the diagnostic sensitivity.

Although the DRIS method has been applied primarily for interpretation based on the major elements, DRIS indices have been generated for boron, Cu, Fe, Mn, and Zn. The emphasis on the major elements is based on the fact that the database for the major elements is considerably larger than that for the micronutrients. Therefore, the reliability of a micronutrient DRIS index would normally be expected to be less than that for a major element.

The DRIS concept of plant analysis interpretation has been compared with the more traditional techniques based primarily on sufficiency range interpretative values in established plant analysis programs for corn (Kelling and Schulte 1986), sweet cherry (Davee *et al.* 1986), and hazelnut (Alkosliab *et al.* 1988). In these studies, it was found that a DRIS-based interpretation was no better than that based on sufficiency range values. All agreed that both methods of interpretation have their advantages and work best when used together.

Jones and Bowen (1981) compared a DRIS interpretation with that obtained by means of a Crop Log diagnosis of sugarcane tissue. They found that the DRIS approach produced slightly more accurate diagnoses of nutrient deficiencies. This is in stark contrast to the statement made in Reuter and Robinson's book (1986) that '...in view of the apparent lack of physiological bases for a number of the key ratios and balances it (DRIS) uses, the current form of DRIS cannot be recommended for use in Australia.'

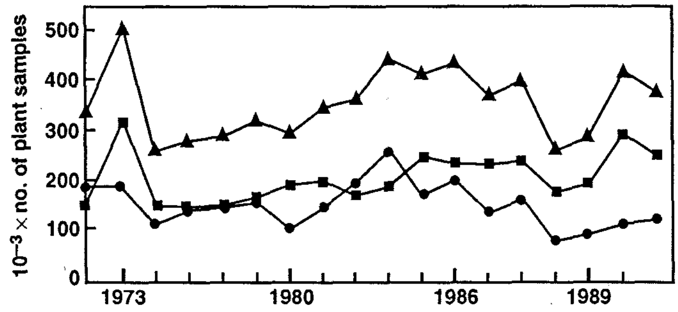

Fig. 3. Number of plant tissue samples analysed in the United States of America by government (■) and commercial (●) laboratories from 1971 to 1991. ▲ Total number of plant samples analysed.

It seems that DRIS works best at the extremes of the sufficiency range by pinpointing that element or balance of elements that is insufficient, and is least useful when plant nutrient levels are well within the sufficiency range. In most studies that have been designed to test the DRIS concept, users have found that DRIS is not entirely independent of either location or time of sampling, and that DRIS diagnosis can frequently be misleading and incorrect.

The DRIS concept has recently been evaluated by Walworth and Sumner (1987) and by Beverly (1991). Beverly (1991) gives a detailed procedure for calculating DRIS indices and lists DRIS norms for 31 crops.

A review of the various methods of plant analysis interpretation used in the U.S.A. is given by Jones *et al.* (1991), which includes plant analysis report forms from 3 plant analysis laboratories. In general, most laboratories use the sufficiency range concept for interpretation which may be combined with other interpretative values, such as critical values, DRIS indices and norms, or short- and long-term averages. The Oregon State University Plant Analysis Laboratory has recently dropped the inclusion of DRIS indices as a part of the interpretative data. The Georgia Soil Testing and Plant Analysis Laboratory uses only sufficiency ranges for interpretation (Plank 1989). Also, the Southeastern Regional Soil Testing and Plant Analysis Workgroup has recently published the plant analysis procedures that are used in that region of the U.S.A. (Plank 1992).

Cost and lack of an understanding of the value of a plant analysis may be major factors that still limit the wider use of the plant analysis technique for diagnostic and monitoring purposes. In past and current surveys conducted by the United States Department of Agriculture-Extension Service and the Soil and Plant

Analysis Council, the numbers of plant tissue samples assayed for farmers has not exceeded 500 000 (Fig. 3). Farmers need to be made more aware of the value of soil tests and plant analyses as a means of monitoring the nutrient element status of their soil–crop system, in order to ensure nutrient element sufficiency as well as to avoid applications of unneeded fertiliser.

Conclusions

Although both soil-testing and plant analysis services are in wide use in the U.S.A., and the techniques for analysis, interpretation, and formulating fertiliser recommendations based on these test results have been intensively studied, there is still considerable variability in methods of reporting results and their interpretation. Increased demands for testing will come with legislative programs to control environmental pollution and crop quality. Standardisation of methodology as well as interpretation may also occur, and this could have a significant impact of what laboratories will be required to do in order to provide soil and plant analysis services to farmers and growers. Currently, there is considerable effort to standardise analytical methods for the analysis of soil and plant tissue, but no organised attempt is being made to standardise the techniques used for interpretation and formulating fertiliser recommendations based on a soil test and/or plant analysis.

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