PASS -- AN IMPROVED SYSTEM FOR COMBINING DRIS AND SUFFICIENCY RANGE APPROACHES TO PLANT ANALYSIS[1]

John Baldock and Emmett Schulte[2]

Introduction

The University of Wisconsin Soil & Plant Analysis **Lab (UW-Lab)** includes both the Sufficiency Range (SR) and the Diagnosis and Recommendations Integrated System (**DRIS**) interpretations in plant analysis reports. The UW-Lab added the DRIS to its routine plant analysis program in 1992. Soon after its introduction, the DRIS appeared to be diagnosing Ca as yield-limiting in many cases where the SR interpreted Ca as sufficient. The DRIS diagnosis of Ca as deficient also contradicted previous research which concluded that Ca was rarely limiting to crop production (Doll and Lucas, 1973; Simpson et al., 1979; McLean et al., 1983).

The authors began studying this DRIS-Ca problem in 1987 with funding from the Wisconsin Fertilizer Research Council and the Wisconsin Aglime Fund. The first of that study found that the DRIS Ca index was low in 45-55% of corn leaf samples taken prior to tasseling. Consequently, the authors recommended that corn be sampled only at the tasseling to silking stage (Baldock and Schulte, 1989). The initial study also found that the DRIS Ca index was low in 4 to 10% of the corn earleaf samples taken at the correct growth stage. Field studies conducted in 1989-1991 confirmed the earlier research findings that Ca did not limit corn grain yield in those cases.

Because the DRIS was often wrong about Ca, a correction was sought. However, other weaknesses were discovered that prevented a simple fix. Seeking a correction also made it clear that the weaknesses of the DRIS were strengths of the SR and vice-versa. Other workers have recognized the value of using DRIS and SR together (Kelling and Schulte, 1986; Jones at al., 1990). None have explained clearly how to combine the strengths and avoid the pitfalls of those two systems, however. Perhaps this is because the SR and DRIS often appear to be in agreement (Kelling and Schulte, 1986). However, a comparison of the two systems on 2781 corn earleaf samples submitted to the UW-Lab revealed that the two systems disagreed on at least one nutrient in over 60% of the cases. Thus, the two systems differ in theory and practice. Consequently, the authors have been developing a way to integrate the best parts of both systems.

---

[1] Research support from the Wisconsin Fertilizer Research Council and the Wisconsin Aglime Fund is gratefully acknowledged.

[2] Agricultural Consultant, AGSTAT, Verona, WI, and Professor, Department of Soil Science, University of Wisconsin-Madison.

The purpose of this paper is to introduce the prototype of such a system, which is called **P**lant **A**nalysis with **S**tandardized **S**cores (**PASS**). To accomplish that purpose, this paper outlines the essential features of the SR and DRIS, describes the PASS system and compares the performance of all three on several sets of plant analysis data.

The Sufficiency Range System

The SR system is an extension of the critical level (**CL**) approach. The CL approach determines the nutrient concentration below which yields decline. Usually, the CL corresponds to 90-95% of maximum yield on a yield versus nutrient concentration graph such as shown in figure 1a, although some use 100% of maximum (Munson and Nelson, 1990). The CL divides the range of nutrient concentrations into two regions such that concentrations below the CL are said to be deficient, symbolized with the letter D. A yield response is likely when nutrient levels are in the D range. Similarly, concentrations above the Cl are "sufficient" (S), and a yield response is unlikely.

The most basic form of the SR uses the CL and a second point, which is above the concentration for maximum yield, on the yield versus nutrient concentration graph where yields begin to decline. Nutrient levels above the second point are "high" (H). This basic SR divides the nutrient concentrations into three sections: S, D and H. Thus, the basic version, shown in figure 1b, is designated as SR3.

A more useful version of the Sr is obtained by dividing the deficient range into two sections. Nutrient levels that are only slightly below the CL are designated as "low" with the symbol "L". The "deficient" category is retained for very inadequate nutrient levels where nutrient responses are highly probable. This version of the SR sometimes includes another class for some nutrients that might become excessive or toxic under certain soil conditions or when applied at excessive rates. The "excessive" (E) class identifies situations in which increasing nutrient concentrations are likely to have a negative effect on yield. Thus, there are four or five categories in this version of the SR, termed SR5 in figure 5c. This is the form used at the UW-Lab (Bundy, 1992).

There are three major advantages of the SR system:

- It is simple to use: "D" or "L" denote where yield responses to increased applications of fertilizer are likely.
- The indices are independent; that is, the level of one nutrient does not affect the classification of another nutrient.
- The norms (or cutoff points) are relatively easy to develop from yield versus nutrient concentration graphs.

There are four major disadvantages of the SR system:

- The scale is not continuous. If a sample is "low,'" it is not clear if it is slightly low or very low, which could make a big difference in yield response.

Figure 1a. Critical level

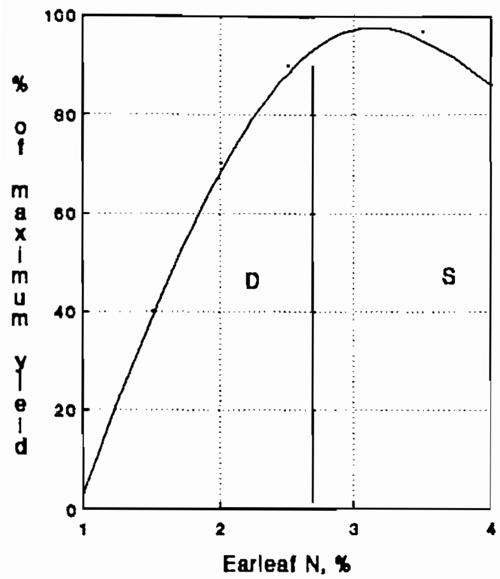


Figure 1b. SR3

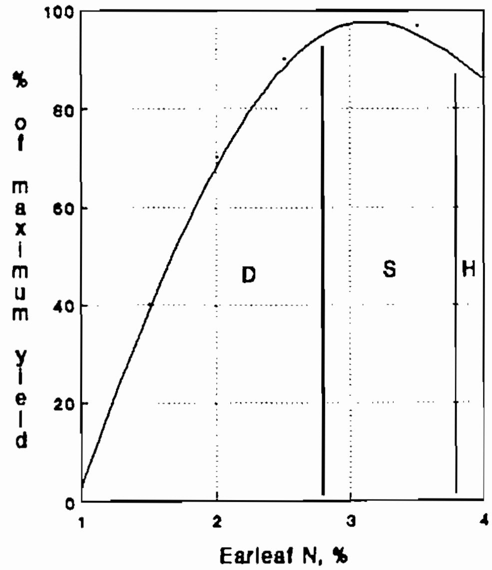


Figure 1c. SR5

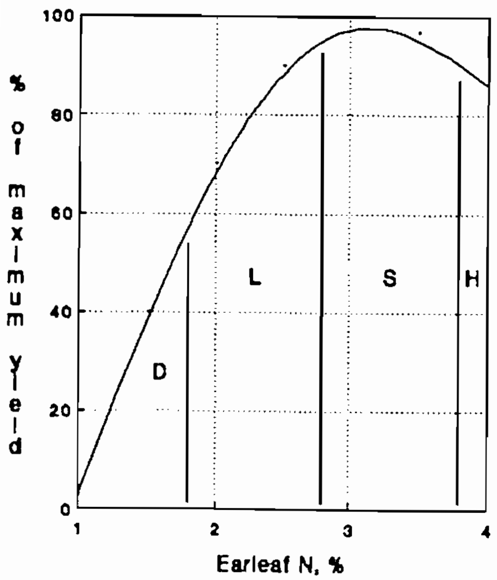
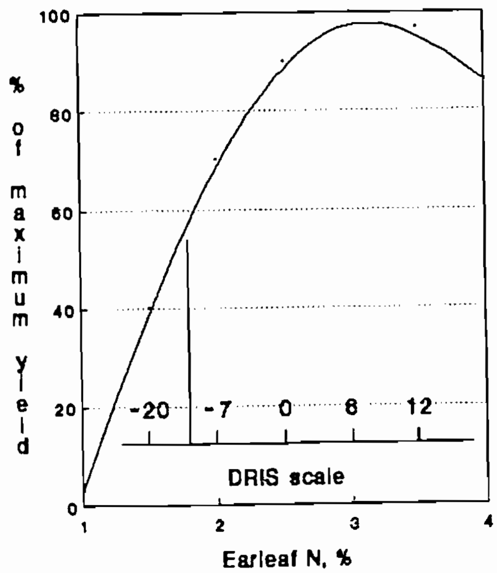


Figure 1d. Yield vs. DRIS N



- ☐ It does not rank the nutrients in order of deficiency, although SR5 can group nutrients by degree of insufficiency (D or L).
- ☐ It does not have an overall index to summarize the composite effect of the nutrient concentrations on yield.
- ☐ It is sensitive to plant maturity, so it can be used only at stages for which norms have been developed.

Description of the DRIS

DRIS was first proposed by Beaufils (1973), working with corn and rubber trees in South Africa. It was introduced and developed in this country by Sumner (1977, 1981). The standard DRIS is based on taking the ratio of all possible pairs of nutrients (e.g., N\P, N\K, ..., Mn/Zn), disregarding order. That is, either N/P or P/N, for example, may be used but not both. The sample ratios are compared to ratios that are "normal" for high-yielding crops, using a rather complicated standardization formula. The standard scores for each nutrient are averaged to get one index of availability per nutrient. Walworth and Sumner (1987) give one of the more complete accounts of the computations involved.

The DRIS index scale that results from those calculations is continuous and easy to understand. Zero is the optimum. Negative index values indicate that the nutrient level is below optimum; the more negative the index, the more deficient the nutrient. Similarly, a positive DRIS index indicates that the nutrient level is above the optimum; the more positive the index, the more excessive the nutrient is relative to "normal." Although the scale is continuous, an "in-balance" range is often established to avoid diagnosing deficiencies when the deviations from zero are actually due to lack of precision in sampling and testing. The "in-balance" range is usually -10 to +10 or -15 to +15. Figure 1d shows the DRIS scale for the same example used to illustrate the SR.

The DRIS also computes an overall balance index, which is the sum of the absolute values of the nutrient indices. It would be better named an imbalance index because the greater the difference between the sample ratios and their respective optimum, the larger the balance index becomes. Sumner (1977) showed that the DRIS balance Index was indeed correlated with yield.

There are four advantages of DRIS:

- o The scale is continuous and easily interpreted.
- o The nutrients are ranked from most deficient to most excessive.
- o The overall balance index provides a measure of the combined effect of the nutrient levels on yield.
- o It may identify some cases in which a yield response is obtained due to an interaction of nutrients.

There are also three disadvantages of the DRIS:

- o It is not a simple system computationaly.
- o The indices are not independent; that is, as a consequence of using ratios and taking their average the level of one nutrient can have a marked effect on the other indices.
- o Although it has been touted as being less sensitive to plant maturity, in practice it is often as sensitive to plant age as the SR system. One of the major causes of the DRIS Ca problem, for example, is its inability to compensate for plant maturity effects.

Description of the PASS System

The PASS system combines the advantages of the DRIS and SR systems. Thus, the PASS system has two sections, one based on an individual nutrient approach like the SR system, and the other based on nutrient ratios similar to DRIS. It uses one simple formula to put the nutrient indices in both sections on the same scale that the DRIS employs. That formula, equation 1, is also used for "standardized scores" in most statistics texts; hence the name for this system.

$$I_j = \frac{10(X_j - X_{n,j})}{SD_j}, \text{ where} \qquad \textbf{Equation 1}$$

I_j = the PASS index for nutrient j,
X_j = the concentration of nutrient j in the sample,
$X_{n,j}$ = the mean concentration of nutrient j in a high-yield population,
SD_j = the standard deviation for nutrient j in the high-yield population,
10 = a scaling factor to avoid decimal values, for
j = 1 to q nutrients.

Independent nutrient index section. The independent nutrient section is like the SR in which an index is determined for each nutrient in the analysis. In contrast to the SR, however, a continuous index value is calculated with Equation 1 to replace the discrete categories denoted by D, S, or H in the SR. The indices calculated in this section are called the ***Independent Indices***, and they are symbolized by $\mathbf{N}_{Ii}$for N, $\mathbf{P}_{Ii}$for P, $\mathbf{Zn}_{Ii}$for Zn, etc. The scale for these independent indices is the familiar DRIS scale; that is, the optimum value is zero, positive indices indicate that the nutrient concentration is above the optimum, and negative values mean the concentration is below optimum. Due to sampling and other random errors, there is a range of index values that are considered close enough to optimum, namely -10 to +10. This range corresponds to one standard deviation below and above the mean (because of the factor 10 in Equation 1). Thus, Independent Index values below -10 are considered to be too far below the optimum, and a yield response to an addition of that nutrient is likely.

Predicting yield responses when they are unlikely has been a problem with the DRIS system. To help avoid that pitfall, the PASS Independent Indices are divided into two groups. One group includes those nutrients for which yield responses are likely and the other those nutrients for which yield responses are unlikely. The PASS system "likely response" section for corn includes N, P, K, S and Zn. The "unlikely response" section includes all of the other nutrients analyzed. If a nutrient is in the "unlikely response" section, it does not mean a response is impossible or that one would not try to correct an Independent Index value that was less than -10. But it does mean that verification of the predicted yield response is very important before spending very much money or effort in making such a correction.

Dependent nutrient index section. The dependent nutrient index section in the PASS system is like the DRIS because the pairwise nutrient ratios are calculated and compared to their optimum values. The are two major differences from the DRIS, however. First, only the nutrients that are in the likely response section are included. This restriction avoids some of the non-diagnostic shifts that are inherent in the dependent indices caused by extraneous variations in nutrients for which the plant requirement is low but uptake can be quite high. Second, the comparison to the mean or optimum value is made with equation 1 instead of the more complex DRIS formula. As in DRIS, each nutrient is involved in more than one ratio so it has more than one standardized score. The average of the individual scores are determined for each nutrient to obtain a single index. The resulting Dependent Indices are symbolized by $\mathbf{N}_{Di}$ for N, $\mathbf{P}_{Di}$ for P, $\mathbf{Zn}_{Di}$ for Zn, etc. These indices are also on the familiar DRIS scale and sum to zero as do the DRIS indices. However, it is necessary to establish an "in-balance" range because of their specialized use and interpretation in the PASS system.

Use and interpretation of the Independent and Dependent Indices in the PASS system. The interpretations and use of the PASS indices requires some explanation especially when the indices in the two sections do not agree. In the present stage of development, interpretation of the PASS indices has concentrated on separating the nutrients into three groups based on the likelihood of a yield response; that is, 1) very likely, 2) somewhat unlikely, and 3) very unlikely.

The diagnosis of being "very likely to produce a yield increase" is reached for any nutrient with an Independent Index less than -10. Of course, the farther below -10, the greater the probability of a yield increase if the deficiency is corrected. This decision is based solely on the Independent Indices because the Dependent Indices are best suited to identify the single most limiting nutrient and may miss some responses in multiple deficiency situations. The function of the Dependent Indices in the context of identifying the nutrients which are very likely to provide a yield increase are 1) to verify the diagnosis of the Independent Indices, and 2) to rank the deficient nutrients. The latter function is important in some academic studies, and occasionally it would be important for growers when capital was so short that not every deficiency could be corrected.

The diagnosis of being somewhat unlikely to produce a yield response comes from two sources in the PASS system. First, any nutrient in the "unlikely response" section that has an Independent Index less the -10 would be put in this category. Second, any nutrient for which the sum of its Independent Index and Dependent Index is less than -10 would be put in this category. The latter step should identify any of the so-called "nutrient interactions" that may lead to a yield response. Experience with the PASS system may lead to a third criterion that would put a nutrient in this category. That criterion would be an Independent Index between -10 and some lower value, for example -15. In that case, -15 would be used as the cutoff point below which the nutrient would be put into the "most likely to respond" group. The "very unlikely" to produce a yield response group is used for nutrients not assigned to another group.

Overall balance index for the PASS system. There are 11 Independent Indices and 5 Dependent Indices in the PASS system for field corn. It would be convenient to combine those indices into a single number to summarize the overall degree of nutrient sufficiency and balance for a plant analysis sample. In the PASS system prototype, this is achieved by computing the sum of squares of the Independent Indices and dividing by one less than the number of Independent Indices. The simple sum of squares can be used because the optimum or mean value for each is zero. The advantages of using the sum of squares compared to the absolute value, which the DRIS uses, are 1) statistically it is the variance of the Independent Indices around their optimum values (zero), and 2) geometrically it is proportional to the square of the distance the sample is from the origin in q-space (where q is the number of nutrients in the analysis).

Estimation of the PASS system norms. There are two norms in Equation 1 to estimate for each individual nutrient and nutrient ratio in the PASS system: the mean ($X_{n,j}$) and the standard deviation (SD_j). In order to retain the key features of the SR and the DRIS scale, the means are not estimated in the usual fashion. Sin ce -10 corresponds to one standard deviation below the mean, the functional mean in Equation 1 is determined by

$$X_{n,j} = \text{critical value}_j + SD_j \qquad \textbf{Equation 2}$$

The critical values currently used in the PASS system for field corn are those published by Bundy (1992). When the critical values are not available or need to be verified, it is the authors' opinion that nutrient response studies would be preferable to survey data. One reason for the preference is the relative efficiency of nutrient response studies. Another reason is that nutrient levels can be designed to cover the important concentration levels. Both of those reasons can be seen from an example in which Walworth and Sumner (1987) presented a boundary line estimate of the leaf N concentration needed for maximum yield. Even though their chart contained 8,000 data points, the data are sparse in the regions that are most critical. Furthermore, it is more difficult to apply economic and environmental constraints to survey data than to data from nutrient response studies.

On the other hand, the standard deviations are best estimated from survey data because their function is to measure the variability within the population. The population should be a high-yielding one or the equivalent. In this prototype for the PASS system, an approximation to a high-yielding population has been used to estimate the SD_j for the Independent Indices and a few of the Dependent Indices by selecting all the leaf sample data analyzed by the UW-Lab for 1982-1986 that had a DRIS Balance Index of less than 100. That population would approximate a high yield population because the DRIS Balance Index is inversely correlated with corn yields (Walworth and Sumner, 1987).

The norms for the Dependent Indices were primarily those published for the DRIS by Elwali et al. (1985). When those norms were not in a convenient order, the mean was determined by inverting the published value. Because there is some skewness in the distributions, the standard deviations of the reciprocals are usually not equal. Consequently, standard deviations for the inverted ratios were estimated from the UW-Lab data described above.

Example of the PASS system. The current PASS prototype is constructed on a spreadsheet. An example of the spreadsheet with the PASS norms is presented in table 1. Note that the earleaf concentrations corresponding to the -10 to +10 levels of the PASS system closely approximate the end points of the sufficient zones for the SR5 system published by Bundy (1992). A more complete discussion of this example is given below .

Performance of DRIS, SR5 and PASS Systems on Plant Analysis Data

Ostensibly, the PASS system should perform better than the DRIS and SR systems because it includes the best features of both. Preliminary testing of the prototype PASS system has supported that hypothesis. Such testing must demonstrate that the system correctly identifies both deficient and sufficient nutrients.

Correctly identifying deficient nutrients. The indices for the SR, DRIS and PASS systems for the example in Table 1 are compared in Table 2. When the DRIS is properly applied (using -10 or -15 as the boundary between "in-balance" and "deficient", it does not diagnose any major nutrients as deficient. The SR diagnoses N and K as "low," but it does not provide any way to determine which is more limiting. The PASS system agrees with the SR that both N and K are "low." Moreover, both the Independent and Dependent Indices for those nutrients rank N as slightly more limiting than K. The yield responses that Elwali and Gascho (1988) reported verify this diagnosis. When 70 lb N/a was applied, the yield increased by 29 bu/a. When 70 lb/a of both N and k were applied, the yield increased by 51 bu/a. In this case, the SR% and PASS systems were able to identify nutrients that were substantially limiting yield, but the DRIS failed to identify them.

The second case uses the nitrogen response data in figure 1. All earleaf concentrations

Table 1. An example of PASS calculations and indices with plant analysis data from Elwali and Gascho (1988).

Independent Index Section

Nutrient	Input	PASS Norms Mean	PASS Norms SD	Independent Index	
Corn yield response to these nutrients is likely.					
N, %	2.26	3.18	0.416	N_{Ii}	-22.0
P, %	0.31	0.30	0.046	P_{Ii}	2.9
K, %	1.62	2.19	0.439	K_{Ii}	-13.0
S, %	0.20	0.20	0.043	S_{Ii}	- 0.6
Zn, ppm	21.0	26.49	7.490	Zn_{Ii}	-7.3
Corn yield response to these nutrients is unlikely.					
Ca, %	0.44	0.425	0.125	Ca_{Ii}	1.2
Mg, %	0.21	0.250	0.090	Mg_{Ii}	-4.4
B, ppm	7.00	9.440	3.436	B_{Ii}	-7.1
Cu, ppm	3.00	5.640	2.640	Cu_{Ii}	-10.0
Fe, ppm	110	95.80	74.75	Fe_{Ii}	1.9
Mn, ppm	22.0	43.30	24.30	Mn_{Ii}	-8.8
Variance of Independent Indices					96.8

Interpretation of Independent Indices	
Below -10	Low
0	Optimum
Above +10	High

Dependent Index Section

Nutrient ratio	Ratio from input	PASS norms Mean	PASS norms SD	Ratio standard score
N/P	7.29	9.030	2.140	-8.1
N/K	1.40	1.460	0.426	-1.5
N/S	11.30	11.900	2.610	-2.3
N/Zn	0.108	0.118	0.045	-2.3
P/K	0.191	0.169	0.054	4.1
P/S	1.55	1.420	0.345	3.8
P/Zn	0.015	0.011	0.006	6.2
K/S	8.10	8.700	2.990	-2.2
K/Zn	0.077	0.071	0.048	1.2
S/Zn	0.010	0.010	0.004	0.1

$N_{Di} = -3.6$

$P_{Di} = 5.6$

$K_{Di} = -0.9$

$S_{Di} = 0.2$

$Zn_{Di} = -1.3$

Figure 2. Yield vs PASS N

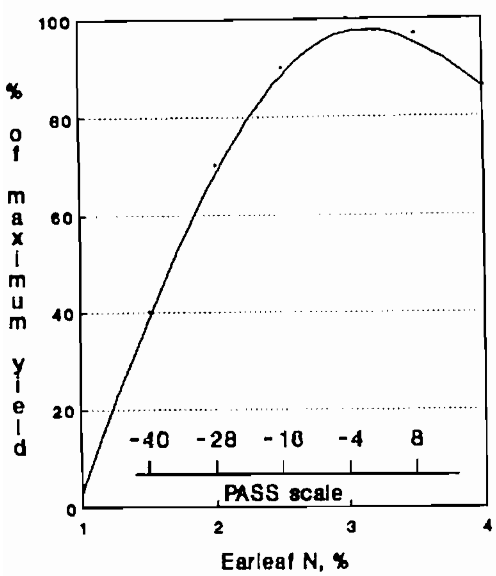


Figure 3. Balance index versus yield

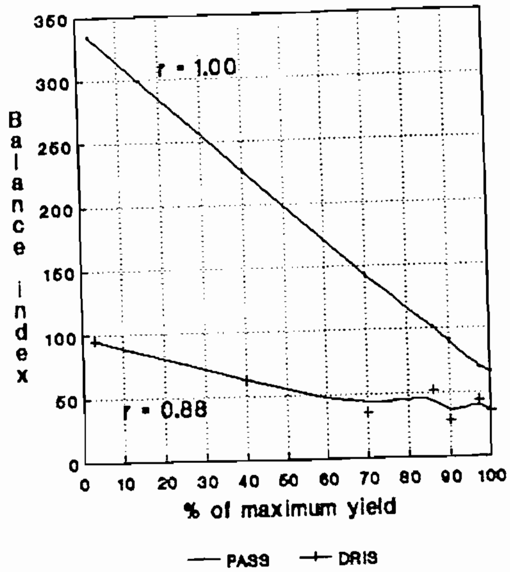


Table 2. Comparison of SR%, DRIS and PASS on plant analysis data of Elwali and Gascho (1988).

System	N	P	K	Ca	Mg	S	B	Cu	Mn	Zn
	Nutrient concentration/index									
	%						ppm			
Conc.	2.26	0.31	1.62	0.44	0.21	0.20	7	3.0	22	21
DRIS	- 3	- 5	0	3	5	- 1	2	2	- 11	- 1
$PASS_{II}$	-22	3	-13	1	- 4	- 1	- 7	- 10	- 9	- 7
$PASS_{DI}$	- 4	6	- 1			0				- 1
SR	L	S	L	S	S	S	S	S	S	S

except N were set approximately 10% above their critical value so the systems could be compared. The resulting DRIS indices are shown in Figure 1d compared to the SR. If the usual cutoffs of -10 or -15 are used, the DRIS system will not diagnose N as deficient until a 40 to 50% yield loss has occurred; whereas, the SR diagnoses N as low as soon as the yield drops below 97% of maximum. Because the PASS system borrows the critical value from the SR, it also enjoys that nearly ideal cutoff point for this data (figure 2). The PASS system is better than the SR5 in this case because its continuous scale would predict the decrease in yield from97 to 84% of maximum when earleaf N concentration drops from 2.75% at the critical value to 2.3%. The PASS N_{II}parallels this decrease with a drop from -10 to -21. The SR5 index does not change; both earleaf N concentrations are in the "low" range. Also, the PASS balance index is perfectly correlated with yield, but the SR does not have such an index. Furthermore, the PASS system balance index fits the data batter than the DRIS balance index (figure 3).

Correctly identifying sufficient nutrients. To protect farmers' profits and the environment, a plant analysis system must avoid putting nutrients in the deficient category when they are, in fact, sufficient, and the crop will not respond to additions of that nutrient. An example from one of the Ca field studies is shown in table 3. The DRIS diagnosed Ca as most limiting, with an index of -17.The SR claimed that Ca and N were low. The PASS system Ca_{II} was -11, so it barely put Ca in the "somewhat unlikely" response category and agreed with the SR that N was a little low. The yields confirmed the PASS diagnosis that Ca did not limit yields. The untreated check yielded 145 bu/a, 1000 lb/a of calcitic lime 148 bu/a, and 1000 lb/a of dolomitic lime 147 bu/a, with an LSD of 16.9. (The lime rates are the totals for the year in which yields were measured and the preceding year.) Response to nitrogen was not tested. However, the other treatments received the same amount of N, and they tested in the 2.8 to 3.0% range, which indicates that N was adequate. This example not only demonstrates the superiority of the PASS system over the SR5 and DRIS, but also the utility of splitting the nutrients into the likely and unlikely response groups. The substantial random variability in earleaf concentrations can put a sample into the deficient category, so it is especially important to advise caution on nutrients for which yield responses are rare.

Table 3. Nutrient analysis of 27 July plant samples from a 1990 Ca trial.

	Nutrient concentration/index									
System	N	P	K	Ca	Mg	S	B	Cu	Mn	Zn
	%						ppm			
Conc.	2.59	0.27	2.10	0.29	0.24	0.20	13	8.1	100	22
DRIS	- 5	- 6	2	- 17	4	- 10	18	- 4	24	- 6
$PASS_{II}$	- 14	- 6	-2	- 11	- 1	- 1	10	9	23	- 1
$PASS_{DI}$	0	- 3	6			- 2				- 1
SR	L	S	S	L	S	S	S	S	H	S

Conclusions

Based on five years of research with plant analysis systems, the following conclusions have been reached:

- The SR has been highly underrated.
- The DRIS has been highly overrated.
- The SR and DRIS are more complementary than competitive; that is, the weaknesses of one are strengths of the other and vice-versa, as summarized in table 4.
- The PASS system combines the best features of the SR and DRIS into one system (table 4).

Table 4. Summary of the strengths and weaknesses of the SR, DRIS and PASS systems of interpreting plant analysis data.

Item	SR	DRIS	PASS
Scale for indices	Fair	Excellent	Excellent
Ranks sufficiency of nutrients	No	Yes	Yes
Has an overall balance index	No	Yes	Yes
Simple to implement	Yes	No	Yes
Indices are independent	Yes	No	Yes
Valid over range of maturities	No	No	No

References

Baldock, J.O., and E.E. Schulte. 1989. The DRIS calcium problem. Proc 1989 Fert., Aglime & Pest Mgmt. Conf. 28:36-43. Dept. of Soil Sci., Univ. of Wis.-Madison.

Beaufils, E.R. 1973. Diagnosis and recommendations integrated system (DRIS): A general scheme for experimentation and calibration based on principles developed from research in plant nutrition. Soil Sci. Bull. 1, Univ. of Natal, Pietermaritzburg, South Africa.

Bundy, L.G. 1992. Soil and applied nitrogen. Univ. of Wis.-Extn. publ. A2591, Madison.

Doll, E.C., and R.E. Lucas. 1973. Testing soils for potassium, calcium and magnesium. *In* L.M. Walsh and J.D. Beaton (eds.), Soil Testing and Plant Analysis. Soil Sci. Soc. Am., Madison.

Dumenil, L. 1961. Nitrogen and phosphorus composition of corn leaves and corn yields in relation to critical levels and nutrient balance. Soil Sci. Soc. Amer. Proc. 25:295-298.

Elwali, A.M.O., G.J. Gascho and M.E. Sumner. 1985. DRIS norms for 11 nutrients in corn leaves. Agron. J. 77:506-508.

Elwali, A.M.O., and G.J. Gascho. 1988. Supplemental fertilization of irrigated corn guided by foliar critical nutrient levels and diagnosis and recommendations integrated system norms. Agron. J. 80:243-249.

Jones, J.B., H.V. Eck and R.D. Voss. 1990. Plant analysis as an aid in fertilizing corn and grain sorghum. *In* R.L. Westerman (ed.) Soil Testing and Plant Analysis, 3rd ed. pp. 521-547. Soil Sci. Soc. Amer., Madison.

Kelling, K.A., and E.E. Schulte. 1986. DRIS as a part of a routine plant analysis program. J. Fertilizer Issues 3:107-112.

McLean, E.O., R.C. Hartwig, D.J. Eckert and G.B. Triplett. 1983. Basic cation saturation ratios as a basis for fertilizing and liming crops. II. Field studies. Agron. J. 75:635-639.

Munson, R.D., and W.R. Nelson. 1990. Principles and practices of plant analysis. *In* R.L. Westerman (ed.) Soil Testing and Plant Analysis, 3rd ed. pp. 359-387. Soil Sci. Soc. Amer., Madison.

Simpson, C.R., E.E. Schulte and K.A. Kelling. 1979. Soil calcium to magnesium ratios: Should you be concerned? Univ. of Wis.-Ext. publ.G2986.

Sumner, M.E. 1977. Use of the DRIS system in foliar diagnosis of crops at high yield levels. Commun. in Soil Sci. Plant Anal. 8:251-268.

Sumner, M.E. 1981. Diagnosis of sulfur requirements of corn and wheat using foliar analysis. Soil Sci. Soc. Am. J. 45:87-90.

Walworth, J.L., and M.E. Sumner. 1987. The diagnosis and recommendations integrated system (DRIS). *In* B.A. Stewart (ed.), Advances in Soil Sci., vol. 6, pp. 149-188. Springer-Verlag, New York, NY.

PROCEEDINGS OF THE TWENTY-THIRD

NORTH CENTRAL EXTENSION - INDUSTRY

SOIL FERTILITY CONFERENCE

October 27-28, 1993, Holiday Inn St. Louis Airport

Bridgeton, Missouri

Volume 9

Program Chairman and Editor:

Dr. Lloyd Murdock
University of Kentucky
Research and Education Center
P.O. Box 469
Princeton, KY 42445