THE DIAGNOSIS AND RECOMMENDATION INTEGRATED SYSTEM (DRIS)

M. E. Sumner

Department of Agronomy
University of Georgia
Athens, GA 30602

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ABSTRACT

The Diagnosis and Recommendation Integrated System (DRIS) is discussed in terms of making diagnoses of nutrient requirements of crops based on both soil and tissue analyses. Details of how norms are developed and tested are presented together with examples of diagnoses.

INTRODUCTION

Over the past 20 years, the Diagnosis and Recommendation Integrated System (DRIS) originally called Physiological Diagnosis has been developed by Beaufils (1954, 1956, 1959, 1971, 1973) and successfully applied to rubber (Hevea brasiliensis) and maize (Zea mays). This system represents an holistic approach to the mineral nutrition of crops and is, in fact, an integrated set of norms representing calibrations of plant tissue composition, soil composition, environmental parameters and farming practices as functions of yield of the particular crop. Once such norms have been derived, it is possible to make a diagnosis of the condition of a particular crop thereby isolating those factors which are likely to be limiting growth and production. The optimizing of these factors creates conditions which are likely to increase the chances of obtaining higher yields and quality of the particular crop.

Subsequent work has resulted in the development of preliminary norms for the following crops: potatoes (Meldal-Johnsen, 1975), soybeans (Sumner, 1977a), wheat (Sumner, 1977b), pineapples (Langenegger & Smith, 1978) sorghum (Sumner, et al., 1982), alfalfa (Erickson et al., 1982), sunflower (Grove and Sumner, 1982), and sugarcane (Beaufils and Sumner, 1976).

Two of the most important advantages of the DRIS approach are its ability to:

(i) make a diagnosis at any stage of the crop's development and

(ii) list the nutrient elements in their order of limiting importance on yield.

These advantages which are unique to this approach increase the flexibility available to the soil fertility specialist because he is able to make diagnoses and corrective recommendations at will. In the case of annual crops, one is usually limited to making recommendations at the beginning of the season mainly for logistical purposes as it is usually impractical to make corrective treatments after planting. However in the case of perennial crops such as sugarcane, this is not so and often is desirable and practical. Many AdvisoryService Laboratories use both soil and leaf analysis in making fertilizer recommendations. The critical or threshold value approach utilized in interpreting leaf analysis places severe constraints on the period during which leaf samples can be validly taken. The facility offered by DRIS of being able to take samples at any growth stage would be a distinct advantage to growers particularly those cultivating perennial crops.

To serve as a ready reference for those who are interested a complete discription of the Diagnosis and Recommendation System (DRIS) in respect of both leaf and soil interpretation will now be given.

THE DRIS APPROACH

The yield and quality of a crop are the resultants of the efficiency with which vital biochemical processes take place within the plant cells. These processes which result in the accumulation of dry matter (and thus yield) by the plant are dependent on various environmental cultural and genetic factors over which man may or may not have some degree of control. The interrelationships between these factors and the ultimate yield of a crop are illustrated in Figure 1.

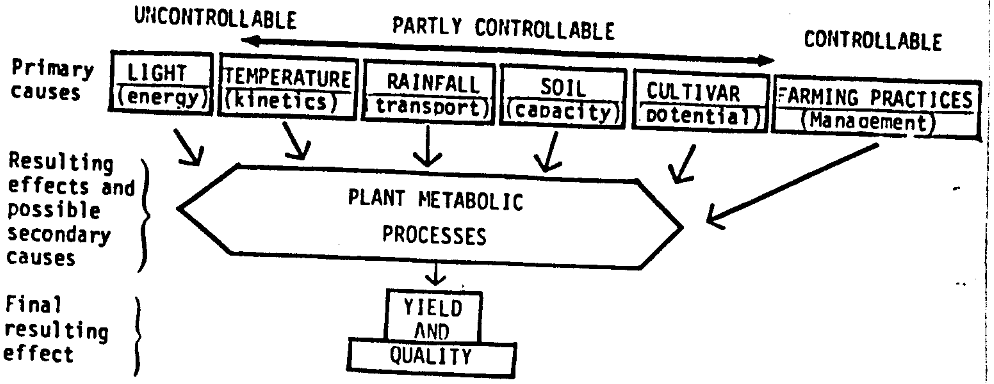


Figure 1. Schematic representation of the interrelationships between crop yield and quality, metabolic processes and external and genetic factors (after Beaufils, 1973).

The interrelationships illustrated in Figure 1 describe the system which needs to be calibrated in order to make meaningful and reliable diagnoses of the fertilizer and other treatments required to increase the chances of obtaining a higher crop yield or improved quality.

Farming practices are in a large measure controllable by man; nevertheless they can and do influence the nutrition of the crop and consequently the recommendations which are made. For example broadcasting or incorporating phosphate in the furrow at planting influences the crop differently and the method of application must be taken into account in making recommendations. Selection of a suitably adapted cultivar is essential to good results. Man has some control in this area in being able to breed disease resistant and adapted varieties and then select the cultivar best suited to a particular area. The special needs of a particular cultivar must be taken into account in making recommendations. As far as soil is concerned man can change some of its chemical properties rather easily by addition of fertilizers but the physical properties are much more difficult to alter. Thus in making recommendations, one must bear in mind the physical limitations to growth which a particular soil presents. This, in turn, will dictate the level of fertilization which will be economic. The remaining environmental factors (light, temperature and rainfall) are not controllable in a field situation. Nevertheless they must be taken into consideration because in many field situations they are, or ultimately become, the most limiting factors in relation to crop productivity. The DRIS approach attempts to calibrate as many of these interrelationships as are capable of qualitative or quantitative expression.

Plant composition which integrates the influences of the primary causal factors (Figure 1) gives the situation to be diagnosed. An attempt is made to explain this situation in terms of the primary causes reflected in soil composition and environmental and management factors. Depending on the extent to which the observed situation can be explained, the controllable factors such as nutrient elements and/or management practices required to remedy the situation can be determined. The quantities of nutrients to be applied are obtained from pre-established norms based on previous experimentation.

The situation which has to be evaluated in making a diagnosis is illustrated in Figure 2.

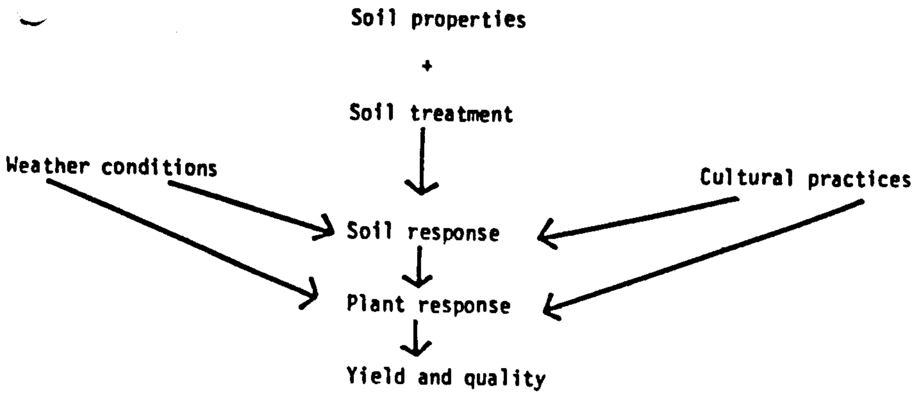


Figure 2. Schematic relationship between soil treatment, weather conditions, cultural practices and yield and quality of crop.

It should be borne in mind that a plant does not respond directly to a soil treatment. Rather the plant responds to the soil response to a soil treatment. For example in two situations in which the level of P is comparably insufficient in a sandy soil on the one hand and a heavy ferruginous soil on the other, the application of a given quantity of P will definitely result in different plant responses on the two soils. In the latter case the soil response to the treatment will be less in terms of increase in available P than in the former. Both weather conditions and cultural practices can influence the soil and plant responses. For example application of urea on the soil surface followed by dry weather conditions will result in considerable volatilization losses of N and consequently less N available for use by the crop.

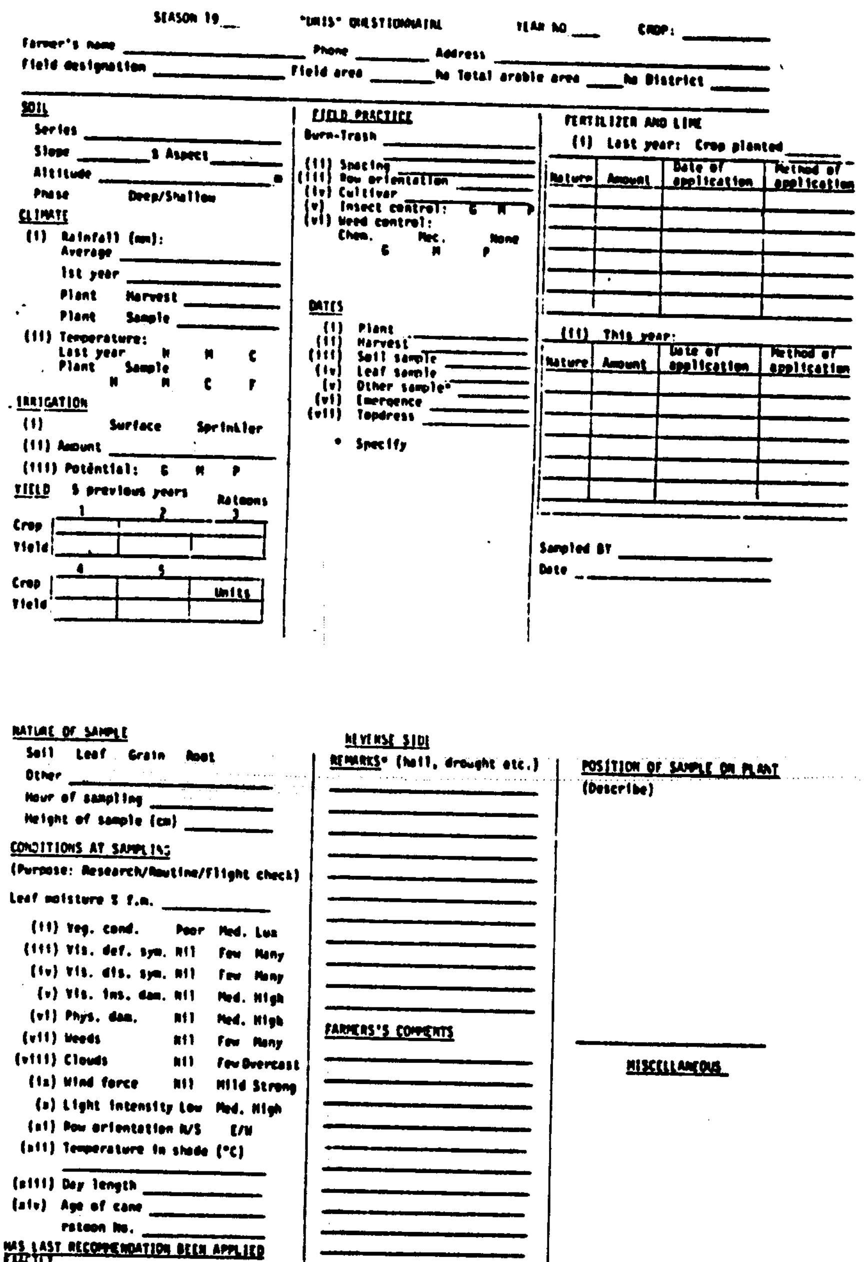
Bearing these considerations in mind any change in the conditions to which a crop is subjected is indeed a treatment and therefore the effects of both induced and natural treatments on crop productivity should be studied. Because these treatments can influence other factors in the whole dynamic plant/environment system as a result of a chain reaction-like mechanism, these interrelationships should be studied. Finally because any set of observations for a particular site represents only one sample from the whole population, all sets of observations should be studied irrespective of their origin, location or conditions at sampling.

In the classical approach to soil fertility research, field experiments have been used to study the above interrelationships. However, field experiments have certain disadvantages in this regard, notably the relatively small number of factors which can be varied simultaneously and the local applicability of the data derived from a given experiment. In order to overcome these difficulties, Beaufils (1971, 1973) developed a scheme of experimentation which has culminated in the Diagnosis and Recommendation Integrated System. Before developing the basic tenets of this system and describing how the norms are derived, a word of definition is required. According to the Oxford Dictionary, diagnosis is defined as 'a formal objective and reliable statement concerning a given situation' or "the determination and identification of the nature of a diseased condition by investigation of its symptoms and history." This is the initial aim of DRIS to identify and set out the parameters of the problem but not to solve it automatically. The second phase is that of recommendation or remedy and bridging the gap between the two phases requires that other factors many of which are subjective such as the knowledge, experience and observational qualities of the specialist who makes the recommendation be taken into account.

ESTABLISHMENT OF NORMS

In contrast to the classical field experimental appraoch to soil fertility, the DRIS approach employs a survey technique representative of the industry for which norms are desired. In this survey, a large number of sites randomly distributed throughout the industry are selected. These sites can be both production fields or plots from existing field experiments. Each site is analogous to a plot in a field experiment so that the survey approach yields a large number of sets of observations which can be considered as constituent plots in a large "field" experiment replicated in time and space. At each site samples of soil and leaf tissue are taken for analysis and details concerning farming practices, weather variables, cultivar, irrigation, nature and amounts of fertilizer applied, etc., are recorded on cards as illustrated in Figure 3. The soil and leaf samples are analysed for a number of essential elements by conventional means. All this information constitutes a data bank and is stored in a computer in readily accessible form. Once a data bank of this nature has been formed, it enables one to study and calibrate the interrelationships illustrated in Figure 2 in the form of the following causal relationships:

(i) Soil properties $\rightarrow$ f_1 (plant response) $\rightarrow$ ϕ_1 (yield)
(ii) Weather conditions $\rightarrow$ f_2 (plant response) $\rightarrow$ ϕ_2 (yield)
(iii) Cultural practices $\rightarrow$ f_3 (plant response) $\rightarrow$ ϕ_3 (yield)
(iv) Soil treatments + soil properties + weather conditions + cultural practices $\rightarrow$ f_4 (soil response)
(v) Soil response + weather conditions + cultural practices $\rightarrow$ f_5 (plant response) $\rightarrow$ ϕ_5 (yield)



SEASON 19__ "DRIS" QUESTIONNAIRE YEAR NO ___ CROP: ________

Farmer's name ____________ Phone ________ Address ____________

Field designation ____________ Field area ________ ha Total arable area ____ ha District ______

SOIL

Series ____________

Slope ________ % Aspect ______

Altitude ____________ m

Phase Deep/Shallow

CLIMATE

(i) Rainfall (mm):
Average ____________
1st year ____________
Plant Harvest ____________
Plant Sample ____________

(ii) Temperature:
Last year H M C
Plant Sample
H M C F

IRRIGATION

(i) Surface Sprinkler

(ii) Amount ____________

(iii) Potential: G M P

YIELD 5 previous years

	1	2	Ratoons 3
Crop			
Yield			

	4	5	
Crop			Units
Yield			

FIELD PRACTICE

Burn-Trash ____________

(ii) Spacing ____________

(iii) Row orientation ____________

(iv) Cultivar ____________

(v) Insect control: G M P

(vi) Weed control:
Chem. Mec. None
G M P

DATES

(i) Plant ____________

(ii) Harvest ____________

(iii) Soil sample ____________

(iv) Leaf sample ____________

(v) Other sample* ____________

(vi) Emergence ____________

(vii) Topdress ____________

* Specify

FERTILIZER AND LIME

(i) Last year: Crop planted ______

Nature	Amount	Date of application	Method of application

(ii) This year:

Nature	Amount	Date of application	Method of application

Sampled BY ____________

Date ____________

NATURE OF SAMPLE

Soil Leaf Grain Root

Other ____________

Hour of sampling ____________

Height of sample (cm) ____________

CONDITIONS AT SAMPLING

(Purpose: Research/Routine/Flight check)

Leaf moisture % f.m. ____________

(ii) Veg. cond. Poor Med. Lux

(iii) Vis. def. sym. Nil Few Many

(iv) Vis. dis. sym. Nil Few Many

(v) Vis. ins. dam. Nil Med. High

(vi) Phys. dam. Nil Med. High

(vii) Weeds Nil Few Many

(viii) Clouds Nil Few Overcast

(ix) Wind force Nil Mild Strong

(x) Light intensity Low Med. High

(xi) Row orientation N/S E/W

(xii) Temperature in shade (°C) ____________

(xiii) Day length ____________

(xiv) Age of cane ____________
ratoon No. ____________

HAS LAST RECOMMENDATION BEEN APPLIED EXACTLY

REVERSE SIDE

REMARKS* (hail, drought etc.)

____

FARMERS'S COMMENTS

____

POSITION OF SAMPLE ON PLANT
(Describe)

MISCELLANEOUS

Figure 3. Survey Information Card

The calibration of these causal relationships results in diagnostic indices which measure the magnitude of the deviation of the value of any particular parameter from its desirable range.

To develop a Diagnosis and Recommendation Integrated System for a given crop, the following requirements must be met whenever possible: (i) all factors suspected of having an effect on crop yield must be defined, (ii) the relationship between these factors and yield must be described, (iii) calibrated norms must be established, (iv) recommendations suited to particular sets of conditions and based on correct and judicious use of these norms must be continually refined.

1. Establishment of data bank

The first step is to define the parameters to be improved and those factors likely to affect them.

The second step is to gather at random all reliable data available from production fields and experimental plots so that a large number of sets of observations is available to form a data bank.

2. Calibration of internal or plant factors

The third step is to study the relationship between yield and internal parameters such as leaf composition using the following steps. (i) Each internal plant parameter is expressed in as many forms as possible, for example N(%), N/P, P/N, NxP etc. (ii) The whole population is divided into a number of sub-populations based on yield performance levels, for example, high, medium and low yielding sub-populations. (iii) The means of each sub-population are

are calculated for the various forms of expression. (iv) A X^2 test is used to confirm that the sub-populations conform to a normal distribution. (v) Variance ratios between yield sub-populations for all forms of expression are calculated together with the coefficients of variation (CV). (vi) The forms of expression for which the most significant variance ratios are obtained and for which the mean values for the populations are essentially the same are selected and related to one another in expressions with common elements. An example of N, P, K norms for corn leaves established in this manner is presented in Table 1.

Table 1. Corn leaf norms for N, P, and K.

Form of expression	Low yielding population (A)			High yielding population (B)			Variance Ratio
	Mean	CV	Variance	Mean	CV	Variance	
		%	S_A		%	S_B	$\frac{SA}{SB}$
N (% dm)	2.86	20	0.326	3.06	18	0.303	1.075
P (% dm)	0.30	20	0.0036	0.32	22	0.0050	0.720
K (% dm)	2.32	27	0.392	2.12	23	0.238	1.647**
N/P	9.88	18	3.158	10.04	14	1.996	1.582**
N/K	1.39	28	0.150	1.49	21	0.101	1.485**
K/P	6.94	29	4.000	6.74	22	2.222	1.800**
P/K	0.13	26	0.0011	0.15	24	0.0013	0.846
P/N	0.10	18	0.00032	0.10	16	0.00026	1.231
K/N	0.81	24	0.0380	0.72	22	0.0259	1.467**
NP	0.85	33	0.0792	0.98	32	0.0961	0.824
NK	6.59	34	5.040	6.45	34	4.910	1.026
PK	0.71	37	0.0675	0.68	36	0.0611	1.105

The norms selected are related to one another in a so-called DRIS chart (Figure 4). The point of intersection of the three axes corresponds to the mean value for the high yielding population for each form of expression. (N/P = 10.4, N/K = 1.49, K/P = 6.74).

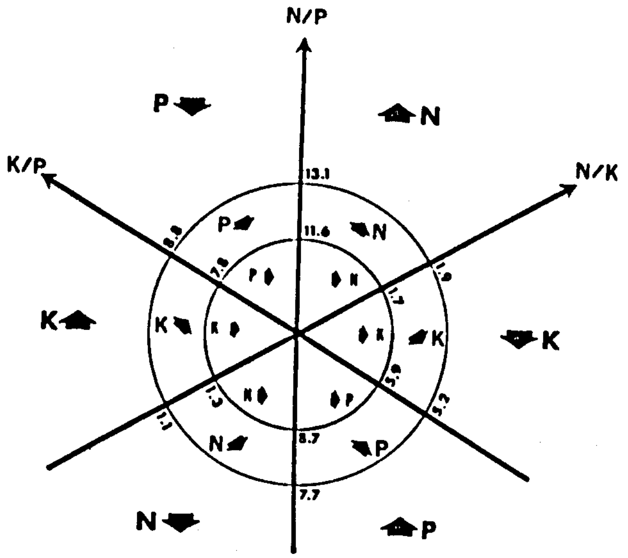


Figure 4. DRIS chart for obtaining qualitative order of requirement for N, P, K in corn.

This is the composition desired in order to increase the chances of obtaining a high yield. However this desired composition should not be considered as a single inflexible point but rather as a range encompassed by the inner of the two concentric circles in Figure 4. The diameter of this circle is set as 4 SD/3 (Beaufils, 1971) where SD is the standard deviation of the high yielding sub-population. This takes account of the variability in the population. A plant composition falling within the inner circle would be considered to be balanced and is denoted by a horizontal arrow (→). As one moves away from the central zone along any axis the degree of imbalance between the two elements increases. This zone of imbalance is divided into two subzones the first being a zone of slight to moderate imbalance. This is denoted by an arrow at 45 degrees to the horizontal (↙) (↘) and is encompassed by the outer of the concentric circles which has a diameter of 8 SD/3. Beyond this circle is a zone of marked imbalance denoted by vertical arrow (↓) (↑).

(a) Making a diagnosis

(i) Reading the DRIS chart

The way in which this chart is used to make a diagnosis will be illustrated by means of an example. Assume that the N, P, and K concentrations in a corn leaf sample on a dry matter basis are: 3.02%, 0.215%, 1.25% respectively which give: N/P = 14.0, N/K = 2.42 and K/P = 5.81.

Because an excess of one nutrient corresponds to a shortage of another in terms of balance, only insufficiencies are recorded by convention for the purpose of diagnosis which is done stepwise for each function. Identical diagnoses are obtained by considering either excesses or insufficiencies or both. Using the above data, the value of the function N/P lies beyond the outer circle in the zone of P insufficiency giving: (i) N P↓ K while the value of N/K also lies outside the outer circle in the zone of K insufficiency giving: (ii) N P↓ K↓ and that of K/P lies between the two circles in the zone of tendency to K insufficiency giving: (iii) $N \quad P\downarrow K\downarrow\searrow$. Once the three common functions have been read the remaining element is assigned a horizontal arrow. The final reading then becomes: (iv) $N\rightarrow P\downarrow K\downarrow\searrow$ which gives the order of requirement for N, P and K in terms of limiting importance on yield as: $K > P > N$. This does not necessarily mean that K is deficient and N excessive, but rather it should be considered as a relative ranking of the nutrients. As the plant is a dynamic system there is no reference point to which this can be referred on an absolute basis.

(ii) <u>Calculating DRIS indices</u>

The arrow notation used thus far can be quantified by calculating DRIS indices which measure the relative distances the values for a particular leaf composition are from the origin in Figure 4. The following equations are used:

$$\text{N index} = +\left[\frac{f(N/P) + f(N/K)}{2}\right]$$

$$\text{P index} = -\left[\frac{f(N/P) + f(K/P)}{2}\right]$$

$$\text{K index} = +\left[\frac{f(K/P) - f(N/K)}{2}\right]$$

where $f(N/P) = 100\left(\frac{N/P}{n/p} - 1\right)\frac{10}{CV}$ when $N/P > n/p$

or $f(N/P) = 100\left(1 - \frac{n/p}{N/P}\right)\frac{10}{CV}$ when $N/P < n/p$

in which N/P = the actual value of the ratio in the leaf under consideration

n/p = the mean value of the ratio for the population of high yielding plants

CV = coefficient of variation for the population of high yielding plants.

The other terms, f(N/K) and f(K/P), are derived in a similar way. The mean values of the ratios and coefficients of variation for the population of high yielding plants are presented in Table 1.

The DRIS indices have positive and negative values which sum to zero as they measure the relative balance among N, P and K. The order of plant requirement is given by the most negative index indicating the most required and the most positive, the least required nutrient. In the example used in the chart reading above the indices would be $N = 27$ $P = -10$ $K = -17$. These equations can be extended to a generalized form to encompass all essential elements (Beaufils, 1973; Sumner, 1981).

The above operations enable one to calibrate the function:

Plant response $\rightarrow \phi$ (yield).

(iii) Effect of age of tissue on diagnosis

Beaufils (1954, 1973) has shown that if the data for the population of high yielding plants are used, the variation with age in nutrient elements expressed as a percentage of the value at a given point in time follows the pattern schematically represented in Figure 5.

The concentration of some elements such as N, P, and K decrease with age when expressed on a dry matter basis while others such as Ca may increase with age in certain crops. This effect of age of tissue on diagnosis is a factor that has always presented problems because of the so called "dilution effect". In a study of the relationship between age of tissue and form of expression of nutrient content Beaufils (1973) showed that for a high yielding population the effect of age could be severely reduced by selecting appropriate forms of expression. His results are presented in Table 2.

Table 2. Correlation coefficients for the relationship between age of tissue and form of expression of nutrient content.

Form of Expression		Correlation coefficient with age r	Degree of dependence on age r^2
Dry matter basis	N%	-0.639	0.41
	P%	-0.495	0.25
	K%	-0.742	0.55
Water content basis	N%	0.215	0.05
	P%	0.169	0.03
	K%	0.100	0.01
Fresh matter basis	N%	0.086	0.01
	P%	0.047	0.00
	K%	-0.185	0.03
Ratio basis	N/P	0.046	0.00
	N/K	0.256	0.06
	K/P	-0.117	0.01

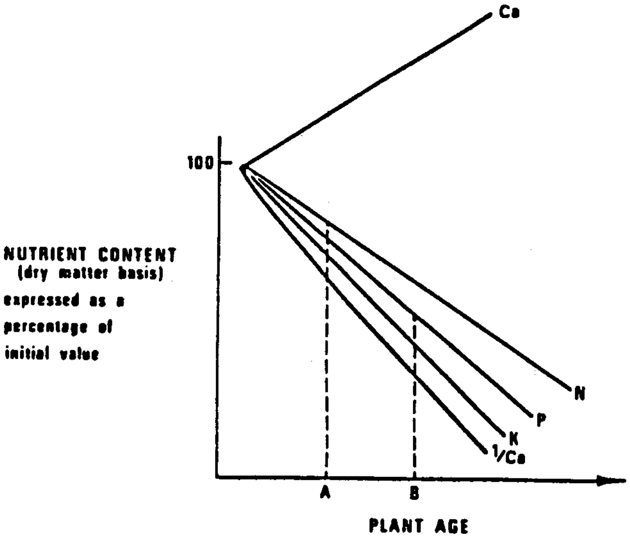


Figure 5. Diagrammatic representation of the variation in nutrient content of tissue with plant age. (Sumner and Boswell, 1981)

From the r2 values it is clear that the degree of dependence on age is markedly reduced when nutrient content is expressed on a fresh matter, moisture content or nutrient ratio basis. The reasons for this are simply arithmatic in nature. For example let us assume that two leaf samples (old and young) are taken. Let fresh matter = 100 and dry matter in young leaves = 20 and dry matter in old leaves = 25. If both leaves contains 1 part of N then:

	Old	Young	% Change with age
N% dry matter	4%	5%	25%
N% fresh matter	1%	1%	0%
N% moisture	1.33%	1.25%	6%

The precentage change in composition is therefore much greater on a dry matter basis.

When using the ratio form of expression the influence of dry matter accumulating more rapidly than the particular nutrient with age is greatly reduced. Thus

$$\frac{N}{P} = \frac{100N}{DM} \Big/ \frac{100P}{DM} = \frac{100N}{DM} \times \frac{DM}{100P}$$

This is the reason why the value of the ratio N/P for the population of high yielding plants will remain relatively constant with age and can therefore be used as a basis for diagnoses at any stage of development. The situation for those elements whose concentration in tissue increases with age can be handled simply by taking the reciprocal values thus inverting the line. When such elements are incorporated into the diagnosis element products are used instead of "ratios":

$$\frac{N}{1/Ca} = N\ Ca$$

Thus the DRIS approach utilizes both ratios and products (which are in fact also ratios) depending on the particular situation being considered.

To illustrate that consistent diagnoses can be made over a range of crop age the data in Table 3 are offered.

Table 3. Effect of corn crop age on DRIS diagnosis.

Age of Crop day	Leaf Composition			Form of Expression			DRIS Indices		
	N%	P%	K%	N/P	N/K	K/P	N	P	K
30	4.6	0.30	3.4	15.33	1.35	11.33	16	-32	16
60	3.9	0.26	2.4	15.00	1.63	9.23	19	-25	6
80	3.4	0.24	1.9	14.17	1.79	7.92	19	-18	-1
110	3.0	0.20	1.8	15.00	1.67	9.00	20	-24	4

The same order of requirement namely P > K > is obtained irrespective of the stage at which the crop was sampled. This is one of the most important advantages of the system.

(iv) Validation of DRIS norms

In order to test whether the norms established are capable of making valid diagnoses it is necessary to use independent experimental data preferably from factoral experiments in which yield responses were obtained to the particular nutrients under study. If the indices are able to predict the pattern of the behavior observed in the experiment confirmation would result. Such an exercise using the data of Lutz and Lillard (1973) will now be undertaken.

Table 4. Validation of DRIS corn norms for N, P, K using independent data of Lutz and Lillard (1973).

Treatment N	 P	Leaf Composition N	 P	 K	DRIS Indices N	 P	 K	Grain yield kg/ha
kg/ha		-------%-------						
160	0	2.62	0.205	2.42	1	-25	24	8961
280	0	2.70	0.195	2.44	5	-31	25	7753
168	25	2.73	0.265	2.11	-2	-5	7	11773
280	25	2.79	0.250	1.99	3	-8	5	11371
168	100	2.76	0.355	1.93	-11	15	-4	12655
280	100	2.76	0.345	1.86	-9	14	-5	13085

Beginning with the N_{168} P_0 treatment the DRIS indices diagnose that P is the most limiting of the three nutrients under consideration. Addition of P in treatment N_{168} P_{25} results is a decreased requirement for P with a concomitant yield increase but P is still the most limiting. Addition of further P in treatment N_{168} P_{100} results in a further yield increase with N now becoming most limiting. Addition of N in treatment N_{280} P_{100} gives a further increase in yield indicating that the indices can correctly predict the pattern of response in the experiment. If inappropriate treatments are made for example, applying N in treatment N_{168} P_0 where it was not called for resulted in a decrease in yield. The same was true for treatment N_{168} P_{25}. A response to N was finally obtained in the experiment but only after the P requirement had been satisfied, a trend correctly predicted by the DRIS approach.

Many other examples of the confirmation of validity of DRIS norms have been published (Beaufils, 1971, 1973; Beaufils and Sumner, 1976, 1977, Sumner, 1977a, b, c, 1979; Sumner and Beaufils, 1975).

3. Calibration of environmental or external factors

The third step is to study the relationship between yield and environmental or external factors such as soil composition, weather conditions etc., so that the most favourable condition can be determined in a particular case. To elucidate this relationship, four steps are necessary: (i) Each factor must be expressed in as many forms as possible (forms of expression). (ii) A scatter diagram of yield against each form of expression is plotted. (iii) visually guided by the spread of data, the external factor axis is subdivided into a number of classes (not necessarily of equal interval). The class interval boundaries are moved back and forth to generate the greatest number of classes whose mean values are significantly different from one another as determined by Fisher's t test. The class corresponding to the highest yield is the optimum for that form of expression. This process is repeated for all possible ways of expressing a given parameter (e.g. K ppm), K/P, K/Mg, etc. An example of the resulant calibration is present in Figure 6 for potatoes in South Africa (Meldal-Johnsen, 1975).

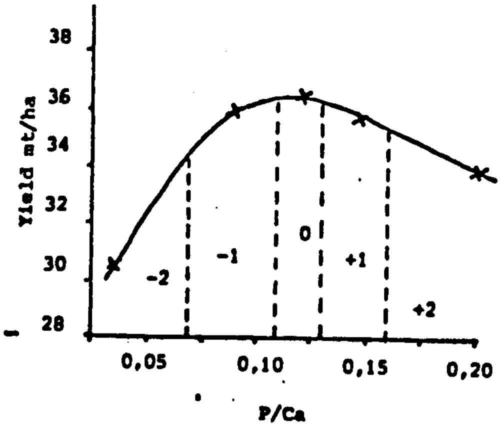


Figure 6. DRIS soil calibrations for potatoes.

Each class interval is assigned an integer the optimum being 0 while :ess is represented by positive integers and insufficiency by negative integers. A calibration as illustrated in Figure 5 will be obtained for each form of expression of the soil parameters.

To illustrate how a diagnosis of the limiting order of soil parameters on yield is made let us assume that for a given soil the following forms of expression were found to be in the class interval indicated below:

$$\frac{Ca}{CEC} = -1; \quad \frac{P}{Ca} = -1 \quad : \quad \frac{Ca}{Mg} = -2; \quad \frac{K}{Mg} = 1$$

$$\frac{P}{S} = +1 \; ; \quad \frac{Al}{P} = +4$$

Because CEC is an immutable property of a soil it serves as a constant basis and consequently must be considered as optimum. It is therefore assigned a value of zero (point of origin) in solving the above equations. Thus substituting CEC = 0,

$\frac{Ca}{0} = -1$ which means that Ca must

be one class interval more negative than the denominator which being 0 makes Ca = -1. Substituting this value in $\frac{P}{Ca} = -1$ give $\frac{P}{-1} = -1$ which means that P must be one class interval more negative than -1 that is P = -2. Continuation of this process leads to

CEC = 0, Ca = -1, P = -2, Mg = +1, K = 0, S = -3, Al = +2

which gives the following order of requirement:

$$S = -3 > P = -2 > Ca = -1 > K = 0 > Mg = +1 > Al = +2 \; .$$

This would indicate the need for single superphosphate and calcitic lime. This type of calibration for soil can only be used when CEC or clay percentage are available. These types of operation can be used to calibrate the other functions such as:

(i) Soil properties $\longrightarrow f_1$ (plant response) $\longrightarrow \phi_1$ (yield)

(ii) Weather conditions $\longrightarrow f_2$ (plant response) $\longrightarrow \phi_2$ (yield)

(iii) Cultural practices $\longrightarrow f_3$ (plant response) $\longrightarrow \phi_3$ (yield)

In other cases soil calibration can be handled in the same way as plant calibration discussed previously. The actual amount of fertilizer and lime to be added is obtained from a calibration of the indices in terms of amounts of these materials added in controlled experiments relative to soil and yield responses. This will be discussed later.

To illustrate that the soil norms developed in this way have diagnostic precision they will be used in conjunction with leaf norms in making progressive diagnoses on data from an NPKL factorial experiment with potatoes. (Table 5.).

Table 5

Diagnosis of limiting factor based on both soil and leaf parameters for potatoes.

Treatment NPKL		Soil Composition							Leaf Composition			Tuber yield kg/ha
		pHs	Al	P	K	Ca	Mg	CEC	N	P	K	
			meq/100g	--------ppm-------				meq/100g	-------%---------			
1111	Value	4.15	0.77	25	65	480	170	7.25	3.90	0.15	6.25	14913
	Index		+1	-2	0	0	+2	0	16	-45	29	
1211	Value	4.40	0.68	52	73	485	110	7.89	3.70	0.22	4.64	28081
	Index		+1	-1	-1	0	+1	0	8	-15	7	
1311	Value	4.30	0.83	64	40	500	71	7.85	3.70	0.31	3.43	30016
	Index		+1	+1	-2	0	0	0	7	1	-8	
1321	Value	4.50	0.70	67	70	490	115	7.99	3.90	0.28	4.65	33322
	Index		+1	+1	-1	0	+1	0	5	-7	2	
1322	Value	5.10	0.23	42	90	790	182	10.16	3.30	0.23	3.63	36218
	Index		0	-1	-1	+1	+2	0	7	-7	0	
1332	Value	5.20	0.18	49	133	835	139	11.00	3.70	0.24	5.18	41034
	Index		0	-1	0	+1	+2	0	5	-14	9	

Commencing with treatment 1111 tissue diagnosis indicates the need for P which is confirmed by the soil diagnosis which also indicates that Al and Mg are excessive. Addition of P in treatment 1211 results in a substantial yield increase indicating a correct diagnosis but insufficient P was supplied at the second P level. Both leaf and soil diagnoses indicate the need for P with soil beginning to show a need for K. Addition of further P in treatment 1311 results in K becoming most required in both leaf and soil with a concomitant yield increase. The addition of K in treatment 1321 results in a further yield increase but the diagnosis based on leaf and soil are now incongruent. The leaf indicates a requirement for P while the soil indicates that P is excessive and K is the most required. An incongruent diagnosis such as this usually points to a third factor being limiting. In this case it would most probably be soil acidity indicated by the low pH value and excessive level of Al. This would indicate the need for lime which when applied in treatment 1322 results in a yield increase with P still the most limiting in the tissue and P and K in the soil. The lime applied was dolomitic which has further aggravated the already excessive level of Mg. As there were only three P levels one has no choice other than to apply K in treatment 1332 which results in a yield increase with P still being the most limiting in both leaf and soil. If it were possible to add further P the likelihood of further improving yield would be good. Application of the nutrient combination resulting in the highest yield on the experiment (1332) could have been predicted from the diagnosis on the control which indicated the need for P and lime directly and that for K indirectly to offset the excessive level of Mg. The data in Table indicate that the soil norms do have diagnostic precision.

Other external factors can be calibrated as illustrated for planting date for corn in the Southern Hemisphere in Figure 7. The procedure is exactly the same as that used to obtain Figure 6. These data illustrate that there is an optimum range of planting dates either side of which there is a reduction in yield.

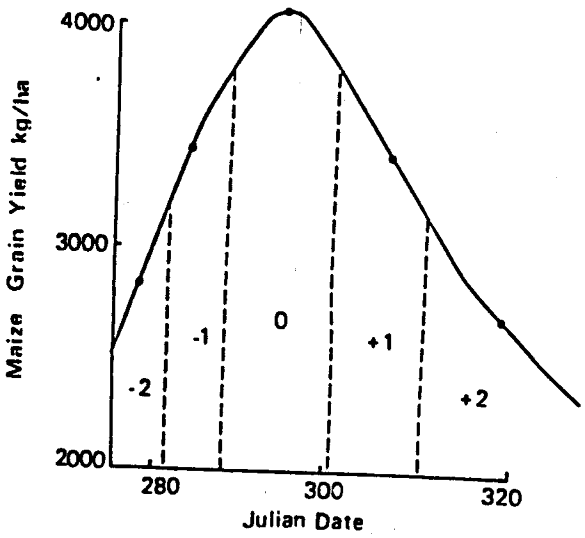


Figure 7. Calibration of planting date.

The actual quantity of fertilizer to be added to overcome a particular insufficiency is determined by the magnitude of the index. The indices are calibrated in terms of amount as illustrated in Table 6. The data from a factorial experiment are required for this purpose. The addition of X tons of dolomitic lime/ha results in changes in the indices as illustrated in Table 6 . Thus the Ca + Mg indices have changed by four class intervals in response to X tons of dolomitic lime. Thus one would require $\frac{X}{4}$ tons of lime to change the Ca + Mg indices by one class interval. In addition X tons of lime have caused an increased requirement for P which must be taken into account. The Al index has moved three class intervals which translates into $\frac{X}{3}$ tons of lime/class interval. Similarly Y kg P/ha has changed the P index by two class intervals and the Ca, Mg and Al indices by one class interval each. This Y/2 kg P/ha will be required to change the P index by one class

Table 6

Calibration of soil indices in terms of fertilizer requirements.

CALIBRATION OF SOIL RESPONSE

TREAT			INDICES			
NPKL	P	K	Ca	Mg	Al	$\mathrm{pH_s}$
000X	-3	-2	+1	+1	0	5.6
0000	-2	-2	-3	-3	+3	4.2
Differences	-1	0	+4	+4	-3	+1.4
0Y00	0	-2	-2	-2	+2	4.4
0000	-2	-2	-3	-3	+3	4.2
Differences	-2	0	+1	+1	-1	+0.2
00Z0	-2	-1	-3	-4	+3	4.1
0000	-2	-2	-3	-3	+3	4.2
Differences	0	+1	0	-1	0	-0.1

interval. For Z kg K/ha the K and Mg indices change by one class interval. Having proceeded with such a calibration as indicated in Table 6. one can then make a formulation based on a particular situation. Let us assume that a soil analysis gives the following situation which requires correction.

$$\text{CEC} = 0,\ P = -3,\ K = -2,\ Ca = -3,\ Mg = -3,\ Al = +3$$

The fertilizer to be added would thus be: 2(Z) kg K/ha, $3(\frac{Y}{2})$ kg P/ha, (both these applications change other indices thus now Ca = -3.75, Mg = -4.25, Al = +2.25), $[(\frac{3.75 + 4.25}{2})\ \frac{X}{4}]$ tons of dolomitic lime/ha.

4. Calibration of interrelationships between external and internal factors

As an illustration of this facet of calibration the influence of an external factor (plowing) on plant composition will be presented in Table 7. Plowing has a marked effect under these particular conditions on the nutrition and yield of the crop. The severe K insufficiency can be alleviated equally by both K addition and plowing. Thus in a field situation the farmer would have two options to consider. Thus under a no-till system more K than would be indicated by soil test would be required.

Table 7.

Effect of plowing (PL) and N P K treatments on leaf composition, DRIS indices and yield of corn at Arlington, WI (Schulte, private communication).

Treatment				Leaf Composition			DRIS Indices			Soil		Grain Yield
N	P	K	PL	N	P	K	N	P	K	P	K	
				%	%	%				ppm		kg/ha
0	0	0	1	2.25	0.273	0.58	33	50	-83	30	77	3477
0	0	0	0	2.61	0.403	0.29	95	190	-285	38	75	1342
1	1	1	1	2.53	0.243	0.82	25	19	-44	42	75	5246
1	1	1	0	2.45	0.332	0.49	41	85	-126	49	75	3538
2	2	2	1	2.88	0.266	1.11	19	10	-29	52	82	8130
2	2	2	0	2.51	0.299	0.87	15	33	-48	52	90	5368
3	3	3	1	2.93	0.261	1.70	8	-3	-4	60	105	8662
3	3	3	0	3.44	0.267	1.24	29	-1	-28	72	88	7259
4	4	4	1	2.93	0.292	1.91	1	0	-1	72	92	8357
4	4	4	0	3.47	0.288	1.52	19	-1	-18	87	112	7381

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