INTERPRETATION OF FOLIAR NUTRIENT ANALYSIS IN BEAN
--the Diagnosis and Recommendation System

by

Charles S. Wortmann

OCCASIONAL PUBLICATIONS SERIES, NO. 5

February, 1993

Correct citation: Wortmann, C.S. 1992. Interpretation of foliar nutrient analysis in bean -- the Diagnosis and Recommendation Integrated System. Network on Bean Research in Africa, Occasional Paper Series No. 5, CIAT, Dar es Salaam, Tanzania.

PREFACE

This document is part of a set of materials to promote the use of the Diagnosis and Recommendation Integrated System (DRIS) of interpreting foliar nutrient analysis results for beans (*Phaseolus vulgaris*). The document consists of two main sections: An Introduction to DRIS; and Instructions for Use of DRISBEAN Software. Also included in this set of materials is a reprint of a paper published in the Journal of Plant Nutrition which presents the results of research conducted on DRIS for beans. A program, DRISBEAN, is available on request for the calculation of the DRIS index values.

This volume is the fourth in a working document series that serves research on beans (*Phaseolus vulgaris*) in Africa. This publication series forms part of the activities of the pan-African bean research network, which aims to stimulate, focus and co-ordinate research efforts on this crop.

The network is organized by the Centro Internacional de Agricultura Tropical (CIAT) through three independent research projects, for the Great Lakes region of Central Africa, for Eastern Africa and, in conjunction with SADCC, for the Southern Africa region.

Working documents will include bibliographies, research reports and network discussion papers. These publications are intended to complement an associated series of Workshop Proceedings.

Support for the regional bean projects comes from the Canadian International Development Agency (CIDA), the Swiss Development Corporation (SDC) and the United States Agency for International Development (USAID).

Further information on regional research activities on common beans in Africa, and additional copies of this publication, are available from:

Pan-Africa Coordinator, CIAT, P.O. Box 23294, Dar es Salaam, Tanzania.

Coordinateur Regional, CIAT, Programme Regional pour l'Amelioration du Haricot dans la Region des Grands Lacs, B.P. 259, Butare, Rwanda.

PUBLICATIONS OF THE NETWORK ON BEAN RESEARCH IN AFRICA

Workshop Series

No. 1. Beanfly Workshop, Arusha, Tanzania, 16-20 November, 1986.

No. 2. Bean Research in Eastern Africa, Mukono, Uganda, 22-25 June, 1986.

No. 3. Soil Fertility Research for Bean Cropping Systems in Africa, Addis Ababa, Ethiopia, 5-9 September, 1988.

No. 4. Bean Varietal Improvement in Africa, Maseru, Lesotho, 30 January - 2 February, 1989.

No. 5. Troisieme Seminaire Regional sur l'Amelioration du Haricot dans la Region des Grands Lacs, Kigali, Rwanda, 18-21 Novembre, 1987.

No. 6. First SADCC/CIAT Regional Bean Research Workshop, Mbabane, Swaziland, 4-7 October, 1989.

No. 7. Second Regional Workshop on Bean Research in Eastern Africa, Nairobi, Kenya, 5-8 March, 1990.

No. 8. Atelier sur la Fixation Biologique d'Azote du Haricot en Afrique, Rubona, Rwanda, 27-29 Octobre, 1988.

No. 9. Quatrieme Seminaire Regional sur l'Amelioration du Haricot dans la Region des Grands Lacs, Bukavu, Zaire, 21-25 Novembre, 1988.

No. 10. National Research Planning for Bean Production in Uganda, Makerere University, Kampala, Uganda, 28 January - 1 February, 1991.

No. 11. Proceedings of the First Meeting of the Pan-Africa Working Group on Bean Entomology, Nairobi, Kenya, 6-9 August, 1989.

No. 12. Ninth SUA/CRSP Bean Research Workshop and Second SADCC/CIAT Regional Bean Research Workshop. Progress in Improvement of Common Beans in Eastern and Southern Africa, Sokoine University of Agriculture, Morogoro, Tanzania, 17-22 September, 1990.

No. 13. Virus Diseases of Beans and Cowpea in Africa, Kampala, Uganda, 17-21 January, 1990.

No. 14. Proceedings of the First Meeting of the SADCC/CIAT Working Group on Drought in Beans, Harare, Zimbabwe, 9-11 May, 1988.

No. 15. First Pan-Africa Working Group Meeting on Anthracnose of Beans, Ambo, Ethiopia, 17-23 February, 1991.

No. 16. Cinquieme Seminaire Regional sur l'Amelioration du Haricot dans la Region des Grands Lacs, Bujumbura, Burundi, 13-17 Novembre, 1989.

No. 17. Sixieme Seminaire Regional sur l'Amelioration du Haricot dans la Region des Grands Lacs, Kigali, Rwanda, 21-25 Janvier, 1991.

No. 18. Conference sur Lancement des Varietes, la Production et la Distribution de Semaines de Haricot dans la Region des Grands Lacs, Goma, Zaire, 2-4 Novembre, 1989.

No. 19. Recommendations of Working Groups on Cropping Systems and Soil Fertility Research for Bean Production Systems, Nairobi, Kenya, 12-14 February, 1990.

No. 20. Proceedings of the First African Bean Pathology Workshop, Kigali, Rwanda, 14-16 November, 1987.

No. 21. Soil Fertility Research for Maize and Bean Production Systems of the Eastern Africa Highlands -- Proceedings of a Working Group Meeting, Thika, Kenya, 1-4 September, 1992.

Occasional Publications Series

No. 1. Agromyzid Pests of Tropical Food Legumes: a Bibliography.

No. 2. CIAT Training in Africa.

No. 3 A. First African Bean Yield and Adaptation Nursery (AFBYAN I): Part I. Performance in Individual Environments.

No. 3B. First African Bean Yield and Adaptation Nursery (AFBYAN I): Part II. Performance Across Environments.

No. 4. Assessment of Yield Losses Caused by Biotic Stress on Beans in Africa.

No. 5. Interpretation of Foliar Nutrient Analysis in Beans--the Diagnosis and Recommendation Integrated System

No. 6. The Banana-Bean Intercropping System in Kagera Region of Tanzania--Results of a Diagnostic Survey

Reprint Series

No. 1. Bean Production Problems in the Tropics: Common Beans in Africa and their Constraints.

No. 2. Bean Production Problems in the Tropics: Insects and other Pests in Africa.

TABLE OF CONTENTS

INTERPRATION OF FOLIAR NUTRIENT ANALYSIS IN BEAN -THE DIAGNOSIS AND RECOMMENDATION INTEGRATED SYSTEM

Charles S. Wortmann

Regional Agronomist, CIAT,
Regional Programme on Beans in Eastern Africa
P.O. Box 6247, Kampala, Uganda

THE DIAGNOSIS AND RECOMMENDATION INTEGRATED SYSTEM (DRIS) FOR BEANS— BASIC PRINCIPLES

INTRODUCTION

Efficient nutrient diagnosis for crops generally requires the use of information from several sources. The diagnostic procedure most often begins in the field by observing symptoms expressed by the plants, and by observing the soil, parent material and other aspects of the surroundings. Information on cropping history and crop responses to applied fertilizers or amendments is often useful. Soil and plant tissue testing give useful clues to nutritional disorders. Often results of diagnostic trials or fertilizer response trials are available for the diagnosis and recommendation procedure. Whether little or much information from the above sources is available, achievement of improved efficiency in the diagnosis and correction of nutritional disorders requires improved interpretation of the available information.

In the past, tissue analysis interpretation has been based upon a comparison of analytical results to some standard values, variously called critical nutrient levels, sufficiency ranges or threshold levels (Beverly, 1991). While these approaches are easily applied, each nutrient is considered independently with no consideration of nutrient balances. Foliar nutrient levels are much affected by plant age (Walworth and Sumner, 1987) as well as interactions affecting nutrient uptake and distribution. The Diagnosis and Recommendation Integrated System (DRIS) was developed by Beaufils (Sumner, 1977) to cope with the difficulties inherent in interpretation of results of foliar testing.

BASIC PRINCIPLES OF DRIS

Introduction to DRIS

DRIS evaluates nutrient relationships and the adequacy of each nutrient in relation to the other nutrients using ratios (or products) between each pair of nutrients. Properly chosen nutrient ratios or products vary less with plant age than do dry matter concentrations of the nutrients.

Use of DRIS involves the comparison of each nutrient ratio from a tissue sample of interest to a corresponding ratio called the "norm". Norms are the standard values used to evaluate nutrient relationships. Theoretically, well-derived norms should be applicable to that crop regardless of where it is grown. However, norms derived under specific soil and climate conditions may be more appropriate for those environments.

Comparison of a sample's nutrient ratios to the norms is done by calculating function values, and the functions are then used to calculate index values (Walworth and Sumner, 1987 and Beverly, 1991).

Calculation of Function Values

Diagnostic values of means and coefficients of variation for nutrient ratios in a particular crop are used to calculate functions. Functions are calculated by using one of two formulas, depending upon whether the value in the tissue sample, e.g. N/P, is larger than or equal to (>=), or smaller than (<) the corresponding norm ($_{N/P}$).

1. If N/P >= $_{N/P}$, then $f(N/P) = 100[(N/P) / {}_{N/P} -1] * k/CV_{N/P}$

2. If N/P < $_{N/P}$, then $f(N/P) = 100[1 - {}_{N/P} / (N/P)] * k/CV_{N/P}$

The function value is measure of the deviation of the observed ratio value, i.e. of the tissue sample, from the norm value. The k value is an arbitrary number, usually 10, which is used to assure that function and index values are whole numbers. Dividing by the coefficient of variation (CV) for each form of expression gives more weight to those ratios with less inherent variability.

Calculation of Index Values

The index value of each nutrient represents an integrated measure of its sufficiency compared to all other nutrients. The index value is the mean of all the function values involving that particular nutrient. The index consists of the sum of all functions where the nutrient of interest appears in the numerator, minus all the function values where the nutrient appears in the denominator, divided by the total number of function values involved. For example, the index values for N, P and K, when only these three nutrients are considered, are calculated as follows:

N index = [f(N/P) + f(N/K)] / 2

P index = [-f(N/P) + f(P/K)] / 2

K index = [-f(N/K) - f(P/K)] / 2

Interpretation of Index Values

Proper interpretation of index values is needed for meaningful diagnoses and recommendations. A negative index value does not necessarily represent a nutrient deficiency. Interpretation requires comparison of the index value for a nutrient with the values of other nutrients. The nutrient with the most negative index value is considered to be the most limiting nutrient. The most limiting nutrient may or may not be deficient, depending on the adequacy of soil moisture and other factors for crop growth.

Dry matter index values

A variation of DRIS is the incorporation of the sample nutrient concentration into the index calculation, treating the nutrient concentration as another ratio. Walworth et al. (1986) labeled this "Modified DRIS" or M-DRIS. Improved accuracy has been achieved with M-DRIS (Walworth et al., 1986), but it has the disadvantage of reintroducing the effect of sampling age on nutrient concentration into the diagnostic process which DRIS is meant to overcome.

DRIS FOR BEANS (Phaseolus vulgaris L.)

DRIS norms for beans were determined from a broad-based data set consisting of data from trials conducted in Colombia, Rwanda and Uganda on five different soil types (Wortmann et al., 1992). DRIS norms were calculated for N, P, K, Ca, Mg, Fe, Mn and Zn. The set of norms (Table 1) was tested for accuracy in predicting responses to applied N, P and K using data from on-farm fertilizer trials conducted in the Usambara Mountains of Tanzania and in central Uganda. DRIS was more accurate than critical nutrient levels in predicting responses to applied N, P and K. Diagnosis with DRIS was less affected by plant age than with critical nutrient levels. Accuracy of DRIS was similar to that of M-DRIS.

A BASIC computer program called DRISBEAN.BAS is available from the author of this paper for the calculation of index values for beans. It calculates both DRIS and M-DRIS values.

LITERATURE CITED

Beverly, R.B., 1991. A Practice Guide to the Diagnosis and Recommendation Integrated System (DRIS). Micro-Macro Publishing, Inc., ISBN 1-878148-003.

Sumner, M.E. 1977. Application of Beaufil's diagnostic indices to maize data published in the literature irrespective of age and conditions. Plant Soil 46:359-369.

Walworth, J.L., W.S. Letzsch and M.E. Sumner. 1986. Use of boundary lines in establishing diagnostic norms. Soil Science Society of America Journal 50:123-128.

Walworth, J.L. and M.E. Sumner, 1987. The Diagnosis and Recommendation Integrated System (DRIS). Advances in Agronomy 6:149-188.

Wortmann, C.S., J. Kisakye and O.T. Edje, 1992. The Diagnosis and Recommendation Integrated System for dry bean — determination and validation of norms. Journal of Plant Nutrition 15(11):2369-2379.

Table 1. DRIS norms for beans generated from a from a broad-based database.

	Norms	CV(%)
N/DM x 100	4.079	13.4
N/P	13.588	25.8
N/K	2.098	37.7
N*Ca	10.767	59.2
N*Mg	2.764	31.7
N*Fe	1370.780	59.9
N*Mn	1044.700	62.0
N/Zn	0.116	56.9
P/DM x 100	0.317	25.9
P/K	0.157	26.7
P*Ca	0.816	36.0
P*Mg	0.218	51.4
P*Fe	92.565	78.2
P*Mn	82.939	78.2
P/Zn	0.008	50.0
K/DM x 100	2.131	28.5
K*Ca	5.469	34.9
K*Mg	1.567	41.8
K*Fe	579.341	75.3
K*Mn	683.959	77.6
K/Zn	0.058	70.7
Ca/DM x 100	2.555	26.0
Ca/Mg	3.564	24.7
Ca/Fe	0.010	50.0
Ca/Mn	0.013	46.1
Ca*Zn	116.304	60.2
Mg/DM x 100	0.657	30.9
Mg/Fe	0.002	50.0
Mg/Mn	0.003	100.0
Mg*Zn	34.176	61.4
Fe/DM x 10^6	319.770	58.3
Fe/Mn	1.893	55.2
Fe*Zn	8581.772	80.0
Mn/DM x 10^6	250.469	60.6
Mn*Zn	12912.000	80.9
Zn/DM x 10^6	47.679	46.9

USING DRISBEAN -- INSTRUCTIONS

INTRODUCTION

DRISBEAN is a compiled BASIC program to aid in calculating DRIS index values for beans. It can run with any or all of eight nutrients, including nitrogen, phosphorus, potassium, calcium, magnesium, iron, manganese and zinc. Norms are not available and DRISBEAN cannot calculate index values for other nutrients such as sulfur, copper and boron.

DRISBEAN can run on either a floppy drive system or a hard drive system. DRISBEAN can receive data from the keyboard or from a disk file. The operator has an opportunity to select to receive the results either on the computer screen, in printed form or in a disk file.

RUNNING DRISBEAN

To run DRISBEAN, follow these steps.

1. Copy DRISBEAN.EXE to drive C if you have a hard disk or put the diskette in drive A if you have a one or two diskette system.

2. Change to the drive and directory in which DRISBEAN.EXE resides and type

   DRISBEAN (enter)

3. The DRISBEAN illustration appears on the screen. Press **(enter)** to continue.

   (enter)

4. The following message appears on the screen to request the source of the input data.

   Select device to read input data
   1. keyboard
   2. file
   3. quit

To select the keyboard, type

1 (enter) (go to step 5 for procedure to continue)

To select a file on a diskette as the source, type

2 **(enter)** (go to step 11 for procedure to continue)

To leave DRISBEAN, type

3 **(enter)**

DATA ENTRY FROM THE KEYBOARD

5. If you selected keyboard for data entry, the program then requests a series of numerical values including the sample identification number, and the concentrations of the nutrients. Enter the values as requested. (For missing values, simply press **(enter)** and the calculations will be made without consideration of that nutrient.) For example

sample identification code
?**101** **(enter)**

Enter concentration of N (%)
?**3.45** **(enter)**

Enter concentration of P (%)
?**.45** **(enter)**

Enter concentration of K (%)
?**1.75** **(enter)**

Enter concentration of Ca (%)
?**1.32** **(enter)**

Enter concentration of Mg (%)
?**.57** **(enter)**

Enter concentration of Fe (ppm)
?**222** **(enter)**

Enter concentration of Mn (ppm)
? **(enter)**

Enter concentration of Zn (ppm)
?**30** **(enter)**

DRISBEAN then offers the opportunity to check the correctness of the data you have entered.

Is this correct? (Y/n)?

If you type

y (enter)

go on to step 6.

If the data is incorrect and you type

n (enter)

you will then be given a chance to select the variable to be corrected.

Enter variable to repeat (N, P, K, Ca, Mg, Fe, Mn, Zn,) or 'A' to repeat all?

Select the variable to be corrected, type **(enter)** and type the correct value.

In case of extremely low or high values you may be asked to recheck the extreme values, e.g., you may get a message as follows

Recheck, Mg is usually less than 4%

Is this correct? (Y/n)?

---

6. The program next offers the opportunity to select to receive the results on the computer screen, in printed form or in a file on a diskette. The computer must be connected to a printer and the printer must be ready in order to have the results printed.

Select Device to Receive Output Data
1 Screen
2 Printer
3 File
?

To select the screen, reply by typing **1** (go to step 7). To select the printer, reply by typing **2** (go to step 7). To select file on diskette, reply by typing **3** (go to step 8).

7. The output then appears on the screen (or it is printed if '**2**' is selected). At the bottom of the screen, you are offered the option to continue with data entry and analysis, or to quit DRISBEAN. Type **y** to continue and **n** to quit.

Sample Identification Code 101

Nutrient	Concentration	DRIS Index	M-DRIS Index
N	3.45	-18.11218	-17.47424
P	.45	9.484692	10.44659
K	1.75	-18.97962	-17.36032
Ca	1.32	-23.70741	-25.45343
Mg	.57	-8.04938	-7.605117
Fe	222	-2.220209	-2.982196
Mn	111	-18.40877	-18.74192
Zn	30	-17.50471	-16.79866

Do you wish to enter more data from the keyboard? (Y/n)?

If you answer **y**, the program will then return to step number 5 to ask for the sample identification code for the next sample.

8. If you select "file" to receive the output data, you are asked to enter the name of the file to receive the output.

"Enter output file name".

Reply by type filename (preceded by drive and directory if necessary) and **enter**, e.g.

a:output1.dat (enter)

9. You are given the option to enter more data from the keyboard.

"If you wish to enter more data, type 1. Otherwise type 2."

If you wish to enter more data, type

?1 (enter)

The program will then return to step number 6 to ask for the sample identification code and the nutrient concentrations for the next sample.

If you wish to quit DRISBEAN, type

?2 (enter).

DATA ENTRY FROM A FILE

10. DRISBEAN offers you the opportunity to receive the input data fro: a file on a diskette.

Select device to read input data
1. keyboard
2. file
3. Quit

?

To select file, type

?2 (enter)

DRISBEAN then asks for the input file name.

Enter filename
?

Reply by typing the name of the input file (include source directory if different from that in which DRISBEAN resides), e.g.

?a:basic1.dat (enter)

Now select device to receive the output data.

Select Device to Receive Output Data
1. Screen
2. Printer
3. File

Make your choice by typing 1, 2, or 3 and **enter**. DRISBEAN then does the calculations, produces the results and terminates the session.

CREATION OF INPUT FILES

DRISBEAN reads non-document ASCII files. Values are separated by commas. Commas not separated by numbers are read as missing values. Sample number must be included.

For example, take a case of 4 samples with the following nutrient concentrations:

Sample no.	N	P	K	Ca	Mg	Fe	Mn	Zn
	%	%	%	%	%	ppm	ppm	ppm
101	3.45	0.5	1.3	1.4	0.7	333	111	23
102	4.65	0.7	1.5	1.0		223	245	11
103	5.00	0.8	1.6	1.4	0.8			
104	4.76	0.7	1.1	1.2	0.5	342	143	33

The input file will appear as follows:

101,3.45,0.5,1.3,1.4,0.7,333,111,23
102,4.65,0.7,1.5,1.0,,223,245,11
103,5.00,0.8,1.6,1.4,0.8,,,
104,4.76,0.7,1.1,1.2,0.5,342,143,33

JOURNAL OF PLANT NUTRITION, 15(11), 2369-2379 (1992)

THE DIAGNOSIS AND RECOMMENDATION INTEGRATED SYSTEM FOR DRY BEAN: DETERMINATION AND VALIDATION OF NORMS

C. S. Wortmann
CIAT Regional Bean Programme in Eastern Africa, P.O. Box 6247, Kampala, Uganda

J. Kisakye
Kawanda Research Station, P.O. Box 7065, Kampala, Uganda

O.T. Edje
SADCC/CIAT, Regional Programme on Beans in Southern Africa, P.O. Box 2704, Arusha, Tanzania

ABSTRACT: The Diagnosis and Recommendation Integrated System (DRIS) of interpreting results of foliar analysis is an alternative to the Critical Nutrient Level (CNL) system. DRIS uses indices of ratios of nutrient concentrations and has been found to be more accurate in predicting nutrient needs for numerous crops than the CNL system. The objectives of this research were to estimate and validate DRIS norms for dry bean (*Phaseolus vulgaris* L.) determined from a broad-based data set. The previously recommended foliar CNL's of 3.0% N, 0.25% P, and 1.0% K were found to be too low to be useful in predicting responses to applied fertilizers in the test environments. Prediction based on levels of 4.7% N, 0.32% P, and 1.4% K was more accurate than with the lower CNL values. DRIS was more accurate than either set of CNL values in predicting responses to applied N, P, and K. Diagnosis with DRIS was less affected by plant age than CNL.

INTRODUCTION

Nutrient contents of foliar tissue are potentially useful indicators of the nutritional status of plants. Results of foliar analyses are commonly interpreted using a critical nutrient level (CNL) approach. Nutrient concentrations are, however, affected by physiological and environmental factors which influence plant growth. Plant age, relative availability of nutrients, stresses due to moisture deficiency and diseases, and rate of growth can affect nutrient concentrations in plant tissue.

An alternative approach to the interpretation of foliar analyses is the Diagnosis and Recommendation Integrated System (DRIS). Beaufils (1971) suggested the use of an integrated index of elemental concentration ratios to evaluate plant nutrient status. The assumption is that these ratios are less affected by factors other than nutrient availability than are the dry matter concentrations. Research on DRIS was reviewed by Walworth and Sumner (1987). In the review, evidence is presented for maize, alfalfa, and peach demonstrating less variation in nutrient ratios or products due to plant age as compared to the nutrient concentrations.

DRIS diagnosis is more accurate than CNL with varying stages of plant development, but more accuracy can be expected when sampling is done at the same growth stage as that from which the norms were estimated (Ammundson and Koehler, 1987, and Hallmark et al., 1988). DRIS has been found to be superior to CNL for diagnosis at diverse locations, but accuracy of diagnosis may be improved with locally calibrated norms (Escano et al., 1981 and Ammundson and Koehler, 1987). With soybean, however, Hallmark et al. (1990) reported better predictive accuracy with DRIS norms estimated from a broad-based data set than from a localized, narrow-based set. Walworth and Sumner (1987) listed 14 different crops for which DRIS has been found to be more accurate than CNL in the prediction of responses to applied fertilizers.

DRIS has not been applied to beans (*Phaseolus vulgaris* L.), although it is a potentially useful tool for the diagnosis of nutritional disorders. The objectives of this research were to estimate the DRIS norms from plant sample data collected from several tropical countries and to test these with results from on-farm trials conducted in Tanzania and Uganda. The efficiency of DRIS in predicting responses to applied fertilizers was compared to prediction using critical nutrient levels.

MATERIALS AND METHODS

Data were obtained from bean researchers in Colombia, Rwanda, and Uganda from various field trials conducted on five different soil types. A total of 1110 records were compiled. For the estimation of the norms, however, a minimum yield level was set at 1100 kg/ha and 306 cases were used to estimate most norms. These included 48, 87, and 171 samples from Rwanda, Uganda, and Colombia, respectively. For some trials, analyses were not done for secondary and micro-nutrients and fewer cases were used to estimate these norms (Table 1). In all cases, the sample leaf was the uppermost, fully expanded leaf on the main stem harvested at approximately the time of first flowering. Nitrogen was determined using Kjeldahl digestion with no pre-treatment. For the determinations of other nutrients, digestion was done in a mixture of nitric and perchloric acids (2:1). Potassium, calcium, magnesium, iron, manganese, and zinc levels were determined by atomic absorption spectrophotometry. Phosphorus was determined using colorimetry (standard methods described in Page et al., 1982).

Norms were estimated as described by Walworth and Sumner (1987). DRIS indices were calculated for N, P, K, Ca, Mg, Fe, Mn, and Zn. Modified DRIS indices (m-DRIS) were calculated which included the dry matter concentrations of the nutrients. These were compared to the DRIS indices as results of Walworth et al. (1986) indicate that inclusion of nutrient concentrations can improve the accuracy of DRIS, especially at high yield levels. Additional sets of norms were generated using data from Colombia only (181 cases), and the eastern Africa data (125 cases) to determine if it may be advantageous to have environment specific sets of norms.

The effects of plant age on foliar nutrient contents were determined by sampling the uppermost mature leaf on the main stems of 2 bean cultivars at 3, 5, 7, and 9 weeks after planting (WAP). The cultivars, K2O and White Haricot, were grown in a randomized complete block design (RCBD) with 4 replications at the Kawanda Research Station.

The norms were tested for accuracy in predicting responses to applied N, P, and K using data from on-farm fertilizer trials conducted in the Usambara Mountains of Tanzania at Irente and Mabughai locations. The trials were complete factorials of two replications (RCBD). Fertilizer treatments were applied at the

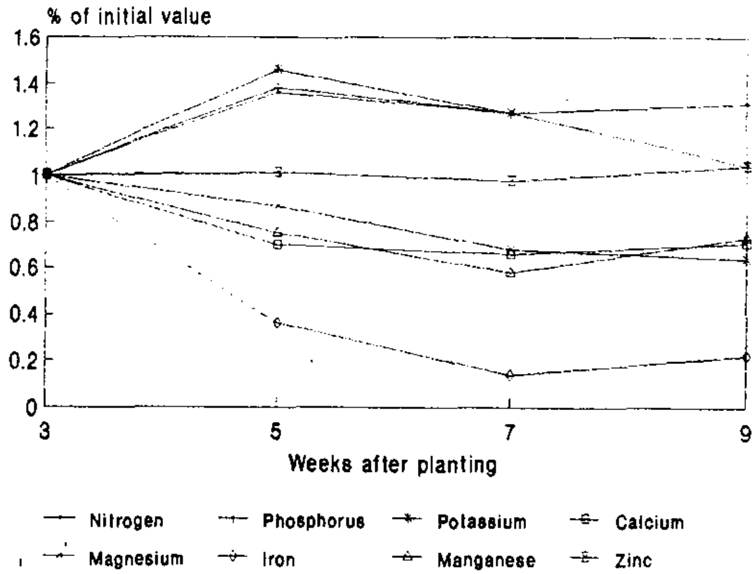

Fig. 1. Effect of plant age on foliar nutrient concentration

rates of 0, 30, 60, and 90 kg/ha N; 0, 60, 120, and 180 kg/ha P_2O_5; and 0, 30, 60 and 90 kg/ha K_2O. The norms were further tested using results of 16 on-farm diagnostic trials conducted in three districts of Uganda. The treatments were applied to 16-m^2 plots with 2 replications per farm. The treatments from the Uganda trials considered in the analyses were the unfertilized control, N, N + P, and N + K.

The efficiency of DRIS in predicting yield responses to applied fertilizers was compared to the efficiency of predictions from CNLs for deficiency in beans (Howeler, 1983). These were 3.0% N, 0.25% P, and 1.0% K. When these levels proved to be too low to give good predictive accuracy in these situations, the CNLs which gave the highest overall predictive accuracy were determined and compared to the DRIS indices. Also, the DRIS index values were determined for N, P, and K which gave the highest overall predictive accuracies with DRIS. Yield responses to fertilization were considered to be significant when the yield increase was the greater of 70 kg/ha, or 10% of the diagnostic treatment yield.

RESULTS AND DISCUSSION

Foliar concentrations of N, P, and K increased between 3 and 5 weeks after planting and thereafter gradually decreased (Fig. 1). Zinc concentration was not affected by plant age. Concentrations of Ca, Mg, Fe, and Mn decreased with plant age. Either elemental ratios or products can be used as DRIS norms depending on their relative stability. The effects of plant age on nutrient concentration in the leaves were used to determine whether ratios or products should be used as norms. The norms and their coefficients of variability are presented in Table 1.

The CNL of 3.0% for N deficiency was too low to be useful as a diagnostic tool for the Tanzania and Uganda sites (Table 2). A CNL of 4.7% N was most accurate. With DRIS, the N response-prediction accuracy, or the percentage of observed responses correctly predicted (Savory and Robinson, 1990), was 62% and higher than with both CNL 3.0% and 4.7%. Also, the overall- diagnostic accuracy was higher for DRIS than for either CNL. Greatest overall accuracy was achieved with DRIS with an N index value of -8, below which a response to applied N fertilizer was expected. N response-prediction was best at the Irente location where the DRIS values were more extreme.

DRIS was superior to CNL for P response-prediction accuracy and overall prediction accuracy (Table 3). CNL of 0.25% P was too low as an indicator of phosphorus deficiency in beans in these environments. CNL 0.32% P was the optimal level for high overall-diagnostic accuracy. DRIS predicted 65% of the responses to applied P and had an overall success rate of 61%. The CNL (0.32% P) system had an overall success rate of 56%. The optimum DRIS index value for predicting yield response to applied P was -12. Response prediction accuracy for P, as for N, was highest at the Irente location, but low for the Uganda trials.

A critical level of 1.0% K was inadequate for the diagnosis of potassium deficiency (Table 4). Increasing the CNL to 1.4% K improved predictive results. The K response-prediction accuracy of DRIS was superior to that of CNL, but the overall-diagnostic accuracy was slightly better than with CNL (1.4% K). DRIS predicted 74% of the yield responses that occurred due to applied K with an overall success rate of 71%. The optimum DRIS index value for predicting yield response to applied K was -30.

TABLE 1. DRIS Norms for Beans Generated from a Broad-based Database.

	Number of samples	Norms	CV(%)
N/DM x 100	306	4.079	13.4
N/P	306	13.588	25.8
N/K	306	2.098	37.7
N*Ca	227	10.767	59.2
N*Mg	227	2.764	31.7
N*Fe	88	1370.780	59.9
N*Mn	227	1044.700	62.0
N/Zn	227	0.116	56.9
P/DM x 100	306	0.317	25.9
P/K	306	0.157	26.7
P*Ca	227	0.816	36.0
P*Mg	227	0.218	51.4
P*Fe	88	92.565	78.2
P*Mn	227	82.939	78.2
P/Zn	227	0.008	50.0
K/DM x 100	306	2.131	28.5
K*Ca	227	5.469	34.9
K*Mg	227	1.567	41.8
K*Fe	88	579.341	75.3
K*Mn	227	683.959	77.6
K/Zn	227	0.058	70.7
Ca/DM x 100	227	2.555	26.0
Ca/Mg	227	3.564	24.7
Ca/Fe	88	0.010	50.0
Ca/Mn	227	0.013	46.1
Ca*Zn	227	116.304	60.2
Mg/DM x 100	227	0.657	30.9
Mg/Fe	88	0.002	50.0
Mg/Mn	227	0.003	100.0
Mg*Zn	227	34.176	61.4
Fe/DM x 10^6	88	319.770	58.3
Fe/Mn	88	1.893	55.2
Fe*Zn	88	8581.772	80.0
Mn/DM x 10^6	227	250.469	60.6
Mn*Zn	227	12912.000	80.9
Zn/DM x 10^6	227	47.679	46.9

TABLE 2. Summary of Predictions for Bean Yield Responses to Applied Nitrogen.

	Response occurred		No response occurred	
	Correct	Incorrect	Correct	Incorrect
		Mabughai, Tanzania		
DRIS	12	10	19	7
CNL (3.0%N)	0	22	26	0
CNL (4.7%N)	6	16	16	10
		Irente, Tanzania		
DRIS	16	5	13	14
CNL (3.0%N)	0	21	27	0
CNL (4.7%N)	19	2	4	23
		On-farm trials, Uganda		
DRIS	4	5	3	4
CNL (3.0%N)	1	8	7	0
CNL (4.7%N)	2	7	7	0
		Total		
DRIS	32	20	35	25
CNL (3.0%N)	1	51	60	0
CNL (4.7%N)	27	25	27	33

TABLE 3. Summary of Predictions for Bean Yield Responses to Applied Phosphorus.

	Response occurred		No response occurred	
	Correct	Incorrect	Correct	Incorrect
		Mabughai, Tanzania		
DRIS	19	14	9	6
CNL (0.25%P)	0	33	14	1
CNL (0.32%P)	17	16	9	6
		Irente, Tanzania		
DRIS	23	4	6	15
CNL (0.25%P)	13	14	14	7
CNL (0.32%P)	22	5	5	16
		On-farm trials, Uganda		
DRIS	1	5	10	0
CNL (0.25%P)	0	6	10	0
CNL (0.32%P)	0	6	10	0
		Total		
DRIS	43	23	25	21
CNL (0.25%P)	13	53	38	8
CNL (0.32%P)	39	27	24	22

TABLE 4. Summary of Predictions for Bean Yield Responses to Applied Potassium.

	Response occurred Correct	Response occurred Incorrect	No response occurred Correct	No response occurred Incorrect
		Mabughai, Tanzania		
DRIS	12	16	20	0
CNL (1.0% K)	4	24	20	0
CNL (1.4% K)	11	17	20	0
		Irente, Tanzania		
DRIS	31	0	3	14
CNL (1.0% K)	14	17	15	2
CNL (1.4% K)	26	5	7	10
		On-farm trials, Uganda		
DRIS	0	0	14	2
CNL (1.0% K)	0	0	16	0
CNL (1.4% K)	0	0	16	0
		Total		
DRIS	43	16	37	16
CNL (1.0% K)	18	41	51	2
CNL (1.4% K)	37	22	42	17

TABLE 5. Comparison of Norms Estimated from Africa and Colombia Databases.

	Africa	Colombia
N	4.349	3.891 **
P	0.279	0.344 **
K	2.078	2.167 ns
Ca	2.657	2.430 ns
Mg	0.561	0.775 **
N/P	16.422	11.620 **
N/K	2.463	1.844 **
N*Ca	11.464	9.912 **
N*Mg	2.432	3.171 **
P/K	0.150	0.161 **
P/Ca	0.725	0.928 **
P*Mg	0.155	0.295 **
K*Ca	5.358	5.605 ns
K*Mg	1.132	1.791 **
Ca/Mg	4.852	3.196 **

ns, ** Difference not significant or significant at the 1% level, respectively.

TABLE 6. Effect of Plant Age on Foliar Diagnosis of the Nutrient Requirements of Beans.

Crop age (weeks)	Leaf composition (%) N	P	K	Ca	Mg	Order of deficiency DRIS
			Cultivar K20			
3	3.64[1]	0.28	1.63	3.30	0.54	Mg < K = N = P = Ca
5	4.64	0.38	2.51	2.57	0.56	Mg < K = N = P = Ca
7	4.30	0.33	1.78	2.55	0.46	K < Mg = N = P < Ca
9	4.10	0.32	1.36	3.01	0.37	K < Mg < N < P < Ca
			Cultivar White Haricot			
3	3.06	0.23	1.21	4.41	1.00	K = Mg < Ca = N = P
5	4.45	0.35	1.65	2.85	0.79	K < Mg = Ca = N < P
7	4.23	0.34	1.83	2.54	0.57	K < Mg = Ca = N = P
9	4.67	0.37	1.59	2.45	0.60	K < Mg = Ca = N = P

[1] Underlined values are below the CNL's of 4.7% N, 0.32% P, 1.4% K, 1.25 % Ca and 0.30% Mg.

Inclusion of dry matter concentration of the nutrients (m-DRIS) in the indices did not affect the accuracy of prediction. The m-DRIS index values were generally nearer to zero than the DRIS index values, but the two sets of values were closely related and generally gave the same diagnoses.

The East Africa norms generally differed from those estimated from the Colombia data (Table 5). DRIS norms estimated from the two sets of data were compared with paired t-tests and found to differ for most nutrients, indicating that the accuracy of DRIS may be further improved by having different sets of norms for different bean production environments.

The order of nutrient requirements predicted by DRIS varies less due to differences in plant age than with the CNL approach (Table 6). DRIS determined N and P levels to be generally adequate, though the dry matter concentrations at 3 WAP were low, especially for White Haricot. DRIS generally found K to be the most limiting nutrient, but the results with CNL are not consistent. The two approaches gave different results, but the results presented in Tables 2-4 suggest that a more accurate diagnosis is expected from DRIS.

CONCLUSION

The critical nutrient levels determined for beans (Howeler, 1983) were found to be too low to have good predictive capacity in the test environments. Increasing the CNL's to optimal levels for these environments (4.7% N, 0.32% P and 1.4% K) improved predictive capacity but the results show that DRIS is a superior means for interpreting the results of foliar tissue analyses for beans. The consistency of DRIS predictions were less affected by varying plant age than were the predictions of CNL. DRIS may be further improved for beans with norms estimated for specific conditions.

ACKNOWLEDGEMENT

The authors are grateful to Dr. I. Kibirige Sebunya, Director of Kawanda Research Station, and to Mrs. T. Sengooba, former coordinator of the Uganda National Bean Program for providing the facilities needed for this research. The contributions of data by Drs. S. Beebe and J. Nolt to the database used for the estimation of the norms were appreciated as was the assistance of Dr. J. B. Smithson in the design and implementation of the trials in Tanzania.

REFERENCES:

1. Ammundson, R.H. and F.E. Koehler. 1987. Utilization of DRIS for diagnosis of nutrient deficiencies in winter wheat. Agron. J. 79:472-476.

2. Beaufils, E.R. 1971 Physiological diagnosis–A guide for improving maize production based on principles developed for rubber trees. Fertil. Soc. S. Afr. J. 1:1-28.

3. Escano, C.R., C.A. Jones, and G. Uehara. 1981. Nutrient diagnosis in corn grown in Hydric Dystrandepts: II. Comparison of two systems of tissue diagnosis. Soil Sci. Soc. Am. J. 45: 1140-1144.

4. Hallmark, W.B., C.J. deMooy, H.F. Morris, J. Pesek, K.P. Shao and J.D. Fontenot. 1988. Soybean phosphorus and potassium deficiency detection as influenced by plant growth stage. Agron. J. 80:586-591.

5. Hallmark, W.B., R.B. Beverly, M.E. Sumner, C.J. DeMooy, H.F. Morris, J. Pesek, and J.D. Fontenot. 1990. Soybean phosphorus and potassium requirement evaluation by three M-DRIS data bases. Agron. J. 82:323-328.

6. Howeler, R.H. 1983. Analisis del tejido vegetal en el dianostico de problems nutricionales. Centro Internacional de Agricultura Tropical (CIAT).

7. Page, A.L., R.H. Miller, and D.R. Keeney (eds.). 1982. Methods of Soil Analysis, Part 2 - Chemical and Microbiological Properities. Agronomy 9 (2nd ed.). American Society of Agronomy, Madison, WI.

8. Russel, M.P. and C.C. Sheaffer. 1986. Use of the diagnosis and recommendation integrated system with alfalfa. Agron. J. 78:557-560.

9. Savory, H.J. Jr. and D.L. Robinson. 1990. Norm range size effects in calculating diagnosis and recommendation integrated system indices. Agron. J. 82:592-596.

10. Walworth, J.L., M.E. Sumner, R.A. Issac, and C.O. Plank. 1986. Preliminary DRIS norms for alfalfa in the southeastern United States and a comparison with midwestern norms. Agron. J. 78:1046-1052.

11. Walworth, J.L and M.E. Sumner. 1987. The diagnosis and recommendation integrated system (DRIS). Adv. Agron. 6:149-188.