Development and Testing of Preliminary Foliar DRIS Norms for Onions

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Abstract. The Diagnosis and Recommendation Integrated System (DRIS) was developed to incorporate the importance of nutrient balance into plant analysis. Yield and plant analysis data from five fertilizer trials conducted in the field during 2 years, using 'Granex 33' onions (*Allium cepa* L.), were entered into a data bank. The trials consisting of a $N^4 \times P^4 \times K^4 \times S^4$, a $N^4 \times P^4 \times K^4 \times \text{plant density}^4$, two $N^4 \times P^4 \times K^4$, and a $4N \times 6S$ factorial were conducted on sandy Ultisols in Georgia. Significant yield responses resulted from the addition of P and N. Leaf samples were analyzed for N, P, K, S, Ca, Mg, Mn, Zn, Cu, and B. Nutrient data were expressed in ratio form, and the population with yields $>45 \text{ Mg} \cdot \text{ha}^{-1}$ were used to calculate the DRIS norms. The proposed norms for N, P, K, Mg, and Cu were tested using published data from independently conducted field and greenhouse studies. By accurately diagnosing the most limiting nutrients, these norms successfully predicted yield responses to treatment. Preliminary norms for S, Ca, Mn, Zn, and B were determined but not tested.

Onions are grown extensively in the United States, with nearly 50,000 ha in production. However, there is some disagreement among researchers concerning the nutritional status necessary for good yields. Some researchers have proposed critical values or sufficiency ranges for the major nutrients (Table 1). Minimum nutrient concentration ranges proposed are 1.9% to 4.0% for N, 0.18% to 0.43% for P, and 1.7% to 4.5% for K. With such a diversity in the proposed values, more work is required for tissue analysis to be effective in revealing nutritional disorders in onions.

In the past decade, inadequacies in the critical value and sufficiency range approaches to plant analysis have been pointed out (Walworth and Sumner, 1988). Most critical value and sufficiency range approaches involve curve-fitting techniques using data from single-factor fertilizer experiments. The point at which no further significant yield increases occur is selected as the critical value; otherwise, a range plus or minus some percentage of a critical value is designated as the sufficiency range. While the single factor in question is varied, the researcher attempts to maintain all the other growth factors at their opti-

mum. This approach assumes that the effects of the treatments on the other factors will be neutral. Also, the optimum level for the other factors must be known beforehand. In estimating the nutritional status of a plant, the critical value and sufficiency range approaches consider each component separately and ignore nutritional balance.

The importance of elemental balance, as opposed to the mere concentration of K, Ca, and Mg, was first recognized in grapes by Lagatu and Maume (1924). In experiments on tung trees, the concept of elemental balance was expanded to include 12 of the essential plant nutrients (Shear et al., 1946). These authors stated succinctly: "All other factors being constant, plant growth is a function of the two variables of nutrition, intensity and balance." It was not until Physiological Diagnosis was developed by Beaufils (1957), later renamed the Diagnosis and Recommendation Integrated System (DRIS) (Beaufils, 1973), that the impact of elemental balance could be quantified. The DRIS approach, which uses nutrient ratios, has been reviewed extensively (Sumner, 1990; Walworth and Sumner, 1987). DRIS values have also been shown to be diagnostically superior to the critical value and sufficiency range approaches (Angeles et al., 1990; Elwali and Gascho, 1984).

Each nutrient ratio has two forms, e.g., N/P and P/N. Traditionally, the ratio that results in the most significant variance ratio between the low- and high-yielding populations is selected to be used in calculations (Beaufils, 1957). This procedure is intended to determine the norms with the greatest predictive precision. In an effort to increase the predictive precision of DRIS, other norm selection methods have been proposed. Davee et al. (1986) used four different procedures to pick

the norms to be included. There were no significant changes in the predictive ability of the norms selected by the procedures. Three selection methods were evaluated on Fraser firs [*Abies fraseri* (Pursh) Poeret], but again no significant predictive precision was produced (Rathfon and Burger, 1991).

We found insufficient data in the literature to establish an adequate database from which to calculate foliar norms for onions. Therefore, we conducted large, factorial fertilizer trials designed to provoke yield variability in the field. A similar approach to generating a DRIS data bank was previously carried out for sunflowers [*Helianthus annuus* (L.)] (Grove and Sumner, 1982). The purpose of our study was to create such a data bank from which preliminary foliar DRIS norms for onions could be calculated. The diagnostic value of the proposed norms was tested using data from independently conducted experiments reported in the literature.

Materials and Methods

Fertilizer application. Data used to develop the foliar DRIS norms were taken from five factorial fertilizer trials conducted in the field from 1988 to 1990. In 1988–89, field experiments were undertaken in Chatham County, Ga., on an Albany fine sand (thermic, Grossarenic Paleudult). The experiments consisted of an $N^4 \times P^4 \times K^4 \times S^4$ factorial with complete confounding in units of 64 (Expt. 1); and two $N^4 \times P^4 \times K^4$ factorials with complete confounding in units of 16 (Expts. 2 and 3). Each plot in Expts. 1–3 was later split. The main treatments included 84, 168, 336, and 672 kg N/ha as calcium nitrate; 39, 79, 157, and 315 kg P/ha as triple superphosphate; 41, 83, 166, and 332 kg K/ha as potassium chloride; and, in Expt. 1 only, 0, 34, 68, and 136 kg S/ha as gypsum. Each field received an initial application of micronutrients to supply Mn, Zn, Fe, Cu, B, and Mg at 5.6, 3.4, 4.5, 3.4, 1.7, and 56 kg·ha⁻¹, respectively. Phosphorus and S, along with 20% of the N and 33% of the K, were broadcast before planting and rototilled to a depth of 20 cm. Onion seedlings ('Granex 33') were transplanted on 13–15 Dec. 1988, 10 cm apart in rows 36 cm apart, resulting in a plant population of 22 plants/m². The remainder of the N and K was broadcast in three equal amounts on 4 Jan., 18 Jan., and 8 Feb. Also on 8 Feb., split applications of gypsum were applied to a randomly selected half of each plot in Expt. 1. On 1 Feb., split applications of triple superphosphate were applied to a random half of each plot of Expts. 2 and 3. Each split treatment of gypsum and phosphate was equivalent to the initial S or P treatment rate for the whole plot. Tissue samples were collected on 8 Mar. 1989. All plots consisted of raised beds 1.5 × 4.5 m. Onions were harvested on 20 May.

Experiment 1 was repeated in 1989–90, except that a planting density treatment was substituted for the nonsignificant S treatment and is referred to as Expt. 4. Due to a lack of significant yield response to K in the previous year, the K levels were adjusted to 0, 83, 166,

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Table 1. Proposed critical values and sufficiency ranges for onion tissue.

Nutrient					Plant part ^z	Growth stage ^y	Type expt. ^s	Source
N	P	K	Ca	Mg				
Nutrient in dry matter (%)								
2.5–3.5	0.25–0.40	2.5–5.0	1.5–3.5	0.30–0.50	YMB	MG	S	Piggott (1986)
3.0–3.8	0.27–0.40	2.0–3.4	0.9–1.7	0.18–0.38	YMB	B	G	Pankov (1984)
4.0	0.43–0.45	4.5–4.6	ND ^w	ND	YMB	B _{2.5 cm}	F	Painter (1977)
2.7–3.0	0.30–0.40	2.5–2.7	ND	ND	T	B	F	Bishop et al. (1972)
1.9–2.3	0.18–0.30	1.7–2.1	ND	ND	W	3m	G	van Lierop et al. (1980)

^zYMB = youngest mature blade; W = whole plant; T = tops.

^yB = bulbing; 3m = 3 months; MG = mid-growth.

^sS = survey; G = greenhouse; F = field.

^wND = not determined.

and 332 kg·ha⁻¹. Dolomitic lime was applied to the entire field at a rate of 1000 kg·ha⁻¹ and incorporated. The planting pattern used equidistant spacing with four population densities: 28, 36, 45, and 56 plants/m². All of the P, 10% of the N, and 50% of the K was applied and incorporated before planting. Onion seedlings were transplanted on 21 Nov. 1989. The remaining N was broadcast in three applications of 20% (3 Jan.), 30% (21 Jan.), and 40% (17 Feb.). The remaining K was applied on 21 Jan. Onions were harvested on 5 May 1990.

Also during 1989–90, a study was conducted in Tatnall County, Ga., on a field previously cropped to soybeans [*Glycine max* (L.) Merrill] on a Tifton loamy sand (thermic, Plinthic Kandiudult). The design was a N⁴ × S⁶ randomized factorial with two replications (Expt. 5). The levels of N were 56, 112, 225, and 450 kg·ha⁻¹ as calcium nitrate, and S at 0, 11, 22, 45, 90, and 180 kg·ha⁻¹ as gypsum. All of the S and 10% of N was broadcast and incorporated before planting, as previously described. The remaining N was broadcast in three applications of 20%, 30%, and 40%, as

described above (Expt. 4). Tissue samples were collected for both experiments on 19 Mar. 1990. Onions were harvested on 28 Apr. 1990.

Tissue sampling. Tissue samples consisting of the last matured leaf were collected at bulbing; composite samples of 10 leaves were taken per plot. Tissue samples were dried for 24 h at 80°C and ground in a Wiley mill to pass a 0.833-mm opening (20 mesh) screen. Samples were dry-ashed at 500°C, and P, K, Ca, Mg, Cu, B, Mn, and Zn were analyzed in a Li₂CO₃/HNO₃ buffer by arc-spark spectrophotometry. Total N content was determined by colorimetry on a flow-injection system after digestion by micro-Kjeldahl, and S by a sulfur determinator (model SC 132; Leco Corp., August, Ga.) (Isaac and Johnson, 1984). Onions were harvested, dried, and sorted by diameter (<5, 5–7.5, and >7.5 cm). Recorded yields were adjusted to reflect the market value difference between grades as follows: yield of bulbs <5 cm in diameter was multiplied by 0.5 and that for 5- to 7.5-cm-diameter bulbs by 0.8. Significant treatment effects

were determined by analysis of variance (SAS Institute, 1983). To determine significant differences, error terms in Expts. 1 and 4 contained three-way interactions, and Expts. 2 and 3 contained two-way interactions.

Calculation of norms. Using standard procedures (Beaufils, 1973), DRIS foliar norms and their coefficients of variation were calculated using the yield and tissue data from the experiments. The adjusted yields were separated into low- and high-yielding populations with 45 Mg·ha⁻¹ as the boundary. Ratios were selected to meet the requirements of a computer program developed in our laboratory for the calculation of nutrient ratios and are therefore not random (Lettsch and Sumner, 1983). This same procedure has been used successfully in previous work (Angeles et al., 1990).

The progressive diagnosis procedure was used to test the validity of the norms (Sumner, 1977). This process involves testing the proposed norms using published data from factorial fertility trials in which significant yield responses to treatments were recorded. Using the determined foliar data for each treatment, DRIS indices were calculated in the traditional way (Beaufils, 1973). An example of these calculations is presented below using the hypothetical nutrients A through N:

Table 2. DRIS foliar norms for onions from population yielding >45 Mg·ha⁻¹ (n = 173).

Expression ^z	Mean	cv (%)	Expression	Mean	cv (%)
N	3.68	16	Mg/K	0.09	69
P	0.37	29	S/K	0.12	47
K	3.10	36	Mn/K	35.75	60
S	0.36	57	Zn/K	10.60	50
Ca	1.37	34	Cu/K	6.62	114
Mg	0.24	33	B/K	3.78	53
Mn	100.14	49	Mg/Ca	0.19	42
Zn	30.21	48	S/Ca	0.31	85
Cu	16.74	70	Mn/Ca	76.86	48
B	10.62	43	Zn/Ca	25.00	70
P/N	0.10	36	Cu/Ca	12.53	62
K/N	0.85	39	B/Ca	8.93	67
Ca/N	0.39	37	S/Mg	1.74	78
Mg/N	0.07	41	Mn/Mg	492.91	79
S/N	0.10	54	Zn/Mg	151.28	72
Mn/N	28.66	53	Cu/Mg	77.18	72
Zn/N	7.82	45	B/Mg	49.56	58
Cu/N	4.83	73	Mn/S	331.70	55
B/N	2.83	40	Zn/S	95.95	52
K/P	9.34	50	Cu/S	59.33	89
Ca/P	4.23	53	B/S	32.00	42
Mg/P	0.69	40	Zn/Mn	0.34	52
S/P	1.03	50	Cu/Mn	0.18	63
Mn/P	312.28	70	B/Mn	0.12	51
Zn/P	88.00	52	Cu/Zn	0.66	83
Cu/P	51.05	86	B/Zn	0.38	41
B/P	30.12	40	B/Cu	0.84	67
Ca/K	0.54	78			

^zConcentrations of N, P, K, S, Ca, and Mg are expressed in percent dry weight, and those of Mn, Zn, Cu, and B in mg·kg⁻¹.

where, for example

where z is the number of functions included in the equation, the lowercase ratios represent the particular norm while the uppercase ratios represent the measured nutrient values and cv is the coefficient of variation (percentage). A function is added to the nutrient index calculation when that nutrient appears in the numerator of the function, otherwise it is subtracted. The equations for calculating the N, P, and K indices when provided with only N, P, K tissue data are presented below, using as an example

Table 3. Effects of N, P, and K fertilization on leaf composition, yield, and DRIS indices for onions from field data (Minotti and Stone, 1988).

Treatment ^z	Leaf composition (% dry wt)			DRIS indices			Yield (Mg·ha ⁻¹)
	N	P	K	N	P	K	
N ₀ P ₀ K ₀	2.75	0.40	2.69	-8	10	-2	54.2
N ₁₁₂ P ₀ K ₀	3.45	0.37	1.95	6	9	-14	62.8
N ₁₁₂ P ₀ K ₁₆₈	3.29	0.34	4.92	-10	-5	15	70.8
N ₀ P ₁₁₂ K ₀	2.81	0.60	2.79	-18	26	-8	48.4
N ₁₁₂ P ₁₁₂ K ₀	3.42	0.53	1.78	1	25	-26	63.9
N ₁₁₂ P ₁₁₂ K ₁₆₈	3.33	0.55	4.98	-18	9	9	72.2
N ₀ P ₀ K ₁₆₈	2.79	0.45	4.44	-19	8	12	53.3
N ₁₁₂ P ₀ K ₁₆₈	3.29	0.34	4.92	-10	-5	15	70.8
N ₀ P ₁₁₂ K ₁₆₈	2.60	0.67	4.78	-36	25	12	51.0
N ₁₁₂ P ₁₁₂ K ₁₆₈	3.33	0.55	4.98	-18	9	9	72.2
LSD _{0.05}							7.8

^zTreatments in kg·ha⁻¹.

the norms provided in Table 2 and values from the first line of Table 3:

ment level. The diagnoses were considered accurate if the next treatment containing the nutrient identified as limiting resulted in a yield increase. The inverse set of norms from the ones chosen for the program were used to calculate indices that were evaluated in the same manner.

Results and Discussion

The treatments in the field experiments were successful in inducing differences in yield and leaf tissue nutrient content. The highest yields exceeded 45 Mg·ha⁻¹, which is considered good by the industry. Leaf tissue nutrient content responded to fertilizer treatments, and the N and P applications resulted in significant yield responses. The split applications of S and P resulted in no significant differences. The total data set from which the norms were established contained 1038 observations, while the high-yielding subset contained 173. The norms and corresponding coefficients of variation are presented in Table 2.

To test the diagnostic precision of these norms, several studies in which significant yield responses resulted from treatments were selected from the literature. Using the tissue data provided, indices were calculated. The results of this procedure are presented in Tables 3–5 for various sets of data. Beginning with Table 3, the DRIS N index for the control treatment is -8, the most negative. Treatment N₁₁₂P₀K₀ resulted in a significant increase in yield, with K becoming the most limiting nutrient. When K was added, a further significant yield increase resulted. Nitrogen then becomes insufficient, but no higher N rate

existed. With treatment N₀P₁₁₂K₀ taken as the starting point, a requirement for N was suggested. The application of N resulted in a significant yield response and a K insufficiency. The addition of K produced another significant yield increase.

In a fertilizer test that included two single-factor experiments, the proposed diagnostic norms were also successful in predicting yield responses to applied P and Mg. The data presented in Table 4 are from a greenhouse study conducted in the former USSR (Pankov, 1984). In the study in which P was varied, yields increased up to treatment P₃₁, at which point P was no longer indicated as limiting. The next level of P resulted in no significant change in yield. In the same way, the Mg norm was successful in predicting yield responses to Mg applications.

By using the sufficiency ranges 3.0% to 3.8% N, 0.27% to 0.40% P, 2.0% to 3.4% K, 0.9% to 1.7% Ca, and 0.18% to 0.38% Mg developed by Pankov (1984) from single-factor greenhouse and field fertilizer trials, diagnoses identical to those using the DRIS norms were made for all the above studies. This success is not unusual in that nutrient intensity as well as balance can govern yield. So long as good values are used, sufficiency ranges can adequately detect nutrient limitations in the cases where nutrient intensity is more important than nutrient balance in governing yield. The DRIS indices calculated (Table 5) from the means of Pankov's sufficiency ranges show that, even though the means are below the DRIS concentration norms, they are in close balance. It is when the lower and upper extremes of these ranges are considered that inherent weaknesses in the sufficiency range approach become evident. When DRIS indices are calculated using a random combination of both lower and upper limits of these ranges, the possibility is demonstrated that a yield-limiting imbalance could exist within the confines of good sufficiency ranges. In this particular combination, the Mg index is -9, indicating that a Mg insufficiency could go undiagnosed, although the Mg concentration is within the sufficiency range when the mean of the range was used (Table 5).

The DRIS indices calculated from experimental field data (Table 6), in which four levels of Cu were applied, point to Cu as the most limiting factor in the control. The next

where

Negative indices indicate relative insufficiency; relative excess is indicated by positive values. A diagnosis of the most limiting nutrient was made for each treatment combination beginning with the control, or the lowest treat-

Table 4. Effects of P or Mg fertilization on onion tissue nutrient content, yield, and DRIS indices from greenhouse studies by Pankov (1984).

Treatment ^z	Leaf composition (% dry wt)					DRIS indices					Yield (g/pot)
	N	P	K	Ca	Mg	N	P	K	Ca	Mg	
P _{3.9}	2.87	0.14	2.94	1.04	0.20	6	-25	10	1	8	180
P _{7.5}	2.80	0.18	2.67	1.09	0.20	3	-12	5	1	4	264
P ₁₅	2.77	0.24	2.62	1.20	0.21	-1	-4	3	2	1	310
P ₃₁	2.83	0.34	2.60	1.37	0.22	-4	3	0	2	-1	343
P ₉₃	2.80	0.53	2.59	1.38	0.22	-9	18	-4	0	-5	349
LSD _{0.05}											37
Mg ₀	3.06	0.41	2.52	0.95	0.10	6	20	4	-2	-28	261
Mg ₄	2.99	0.40	2.48	0.92	0.15	2	14	1	-6	-11	320
Mg ₁₂	2.94	0.34	2.53	0.88	0.20	1	7	1	-8	-1	410
Mg ₃₆	2.90	0.34	2.59	0.88	0.28	-2	4	0	-11	8	421
Mg ₁₀₈	2.83	0.31	2.50	0.76	0.42	-5	-1	-1	-20	27	415
LSD _{0.05}											42

^zTreatments in mg·liter⁻¹ substrate.

Table 5. DRIS indices calculated from the means and a combination of the lower and upper limits of the sufficiency ranges in percent dry weight for onions, as proposed by Pankov (1984). (Example demonstrates the possibility of nutritional imbalance within sufficiency ranges.)

Criterion	N	P	K	Ca	Mg
Mean of range	3.4	0.33	2.5	1.2	0.25
DRIS indices	1	1	-2	-2	2
Range extremes	3.0	0.40	2.0	1.7	0.18
DRIS indices	-3	10	-8	10	-9

level of Cu produced no change in yield while lowering the magnitude of the Cu index. With treatment Cu₂, a significant yield increase occurred and N became slightly more insufficient than Cu. The highest level of Cu resulted in no further significant yield response.

When we calculated indices for the same data with the alternate set of norms, similar results were obtained (results not shown). When significant yield increases were found, these norms predicted the same insufficiency. The DRIS onion foliar norms for N, P, K, Mg, and Cu have been shown through testing to have diagnostic precision and are suitable for use. It is probable that the S norms are also valid since the norms were calculated from results in which S was a treatment, but these could not be validated due to a lack of independent data. The norms for the remaining nutrients should be used with caution since they have not been verified nor were they derived from data in which these nutrients were controlled.

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Table 6. Effects of Cu application in the field on leaf composition, yield, and DRIS indices of onions calculated from the data of Mathur et al. (1983).

Treatment ^y	Leaf composition ^z								DRIS indices								Yield (kg/plot)
	N	P	K	Ca	Mg	Mn	Zn	Cu	N	P	K	Ca	Mg	Mn	Zn	Cu	
Cu ₀	2.80	0.45	2.84	1.72	0.33	88.2	43.1	4.09	-7	12	2	13	16	1	16	-53	5.72 a ^x
Cu ₁	2.50	0.51	2.55	1.62	0.31	84.5	37.1	7.47	-12	14	-2	7	9	-3	7	-21	5.73 a
Cu ₂	2.15	0.40	2.63	1.40	0.30	76.9	51.0	8.75	-17	7	-1	4	9	-5	19	-16	8.18 b
Cu ₃	3.07	0.40	2.71	1.39	0.30	84.4	53.8	14.65	-7	3	-3	0	5	-6	14	-5	7.21 b

^zN, P, K, Ca, and Mg concentration are in percent dry weight, and Mn, Zn, and Cu are in mg·kg⁻¹.

^yTreatment subscripts indicate increasing levels of soil Cu.

^xMean separation for yield by Duncan's multiple range test at $P \leq 0.05$.