NUTRIENT CONCENTRATION RELATIONSHIPS BETWEEN THE FOURTH PETIOLE AND UPPER-STEM OF POTATO PLANTS[1]

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Abstract

Successfully evaluating the nutritional status of a crop during growth and development is dependent upon sampling an identifiable plant part. Consistently sampling a petiole of the same maturity in potatoes (*Solanum tuberosum* L.) is difficult. We evaluated the nutrient relationships between the upper-stem and the fourth petiole from Russet Burbank plants in field studies having N, P, K, Zn or Mn variables. The upper-stem was obtained by excising the stem below the sixth leaf and removing all leaves and the terminal meristem. Petole NO_3-N, P, K, Zn and Mn concentrations were from deficient to sufficient. The NO_3-N, P and K concentrations were similar in the fourth petiole and upper-stem, while the Zn concentration was 40% higher in the upper-stem. Calcium, Mg and Mn concentrations were lower in the upper-stem than in the fourth petiole. Copper and S relationships were not adequately defined. The fourth petiole's NO_3-N, P and K diagnostic concentrations now used to monitor plant nutrient status can also be used for upper-stem samples. Zinc diagnostic concentrations should be increased, while Ca, Mg and Mn concentrations should be adjusted downward in the upper-tem. Additional data are needed to refine the Ca and Mg relationships, and to establish relationships for Cu, S and other essential nutrients. A significant advantage of using the upper-stem is the elimination of the petiole selection problem when sampling.

Compendio

La evaluación exitosa de las condiciones de nutrición de un cultivo durante su crecimiento y desarrollo depende en tomar la parte correcta de la planta. El muestreo permanente de un peciolo con igual estado de madurez en el cultivo de papa (*Solanum tuberosum* L.), es difícil. Se evaluaron las relaciones entre la parte superior del tallo y el cuarto peciolo de plantas Russet Burbank en estudios de campo que tenían aplicaciones variables de N, P, K, Zn o Mn. La parte superior del tallo fue obtenida seccionando al

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mismo por debajo de la sexta hoja y eliminando todas las hojas y el meristema terminal. Las concentraciones de NO_3-N, P, K, Zn y Mn estuvieron entre deficientes y suficientes. Las concentraciones del NO_3-N, del P y del K fueron similares en el cuarto peciolo y en la parte superior del tallo, mientras que la concentración del Zn fue 40% más alta en la parte superior del tallo. Las concentraciones de Ca, Mg y Mn fueron menores en la parte superior del tallo que en el cuarto peciolo. Las relaciones entre el Cu y el S no fueron definidas adecuadamente. Las concentraciones de diagnóstico de NO_3-N, P y K en el cuarto peciolo utilizadas ahora para el seguimiento del estado de nutrición de las plantas, puede también utilizarse para las muestras de la parte superior del tallo. Las concentraciones de diagnóstico del Zn deben ser incrementadas, mientras que las de Ca, Mg y Mn deben rebajarse en la parte superior del tallo. Se requiere de información adicional para refinar las relaciones del Ca y del Mg y para establecer las relaciones para el Cu, S y otros nutrientes esenciales. Una ventaja significativa en el uso de la parte superior del tallo es la eliminación del problema de la selección del peciolo en el muestreo.

Introduction

Soil and plant chemical analyses are common management tools that can improve fertilizer use efficiency and crop yields. Soil analyses identify preplant nutrient availabilities, fertilizer requirements, soil pH and salt problems. Plant analyses are used to determine the causes of poor plant growth and effectiveness of preplant fertilization applications. Increasingly, they are being used to help manage a crop's nutritional status during growth to achieve high yields and quality, particularly for a high cash value and intensively managed crop like potatoes (*Solanum tuberosum* L.). Efficient nutrient management becomes more important if the potential environmental impact of a nutrient is also considered.

Accurate sampling techniques, analytical methods and interpretations based on research results are required for any diagnostic test to be effective. Many factors must be considered in the diagnostic process, *e.g.*, crop, variety, plant part sampled, growth stage, field variation, etc. Samples must represent the whole plant and the sampling area. A specific plant part is generally used because its nutrient concentration reflects the nutrient available to the plant from soil and fertilizer sources. The nutrient concentration in the plant part must also relate to crop growth and yield up to a "critical concentration", reflecting the nutrient's metabolic relationships in the plant. It is also desirable that the difference between the deficiency and adequacy concentrations in the plant part be as large as possible to help minimize sampling and analytical errors (11).

The relationships between nutrient concentrations in some potato plant parts and crop growth or yields are well-known (2, 5, 6, 10, 12, 14). Several

plant parts are acceptable for differentiating between nutrient deficiency and adequacy (5, 6). The fourth petiole of the most recently matured leaf from the growing tip generally satisfies the criteria for use as a diagnostic plant part, particularly for the macro-nutrients. The leaflets are usually stripped off the petiole and discarded during field sampling. They may be left on the petiole but different diagnostic norms must be used. The leaflets plus the petiole are sometimes used for evaluating micro-nutrient status.

It is difficult to only sample the fourth petiole from the growing tip. Often younger or older petioles are selected for analyses. This is not a serious problem if one consistently samples a younger or older petiole, and if a properly calibrated nutrient relationship is available for the particular petiole sample mix. However, misleading conclusions and recommendations will occur if the diagnostic norms for the fourth petiole are used to interpret the analyses for petioles from different positions or from a mixed sample, and if concentrations depend upon petiole position. Nutrient concentrations in the plant generally change with plant age. This and the complex supply, translocation and utilization relationships in the plant may cause petioles from different positions to have different nutrient concentrations. Preliminary data indicated that some nutrient concentrations in a portion of the upper-stem were similar to those in the fourth petiole. The objective of this study was to evaluate the nutrient relationships between the upper-stem and fourth petiole of Russet Burbank potato plants.

Methods and Materials

Several irrigated Russet Burbank potato experiments were conducted in southern Idaho and northern Utah during 1987 and 1988. Treatments depended upon location and encompassed N, K, P, Zn or Mn fertilizer applications. All nutrient applications generally increased tuber yields, except for Mn. Each experiment contained three or four replications. Standard cultural practices were followed when possible in all experiments. Soils at the locations were classified as Aridisols or Mollisols, with textures from silt loam to sandy loam.

Deficient and adequate fertilizer treatments were sampled to obtain a range of nutrient concentrations in the petiole. Thirty to forty plants per plot were sampled two to three times during tuber bulking. The growing tip was excised between the sixth and seventh leaf. The fourth leaf was removed from the stem, the leaflets stripped off and the petiole saved. All remaining leaves and the terminal meristem were detached from the stem (Fig. 1). The remaining (upper-stem) portion was saved for chemical analyses. The petiole position effect was evaluated by saving all the excised petioles from selected adequately fertilized treatments in N or P experiments

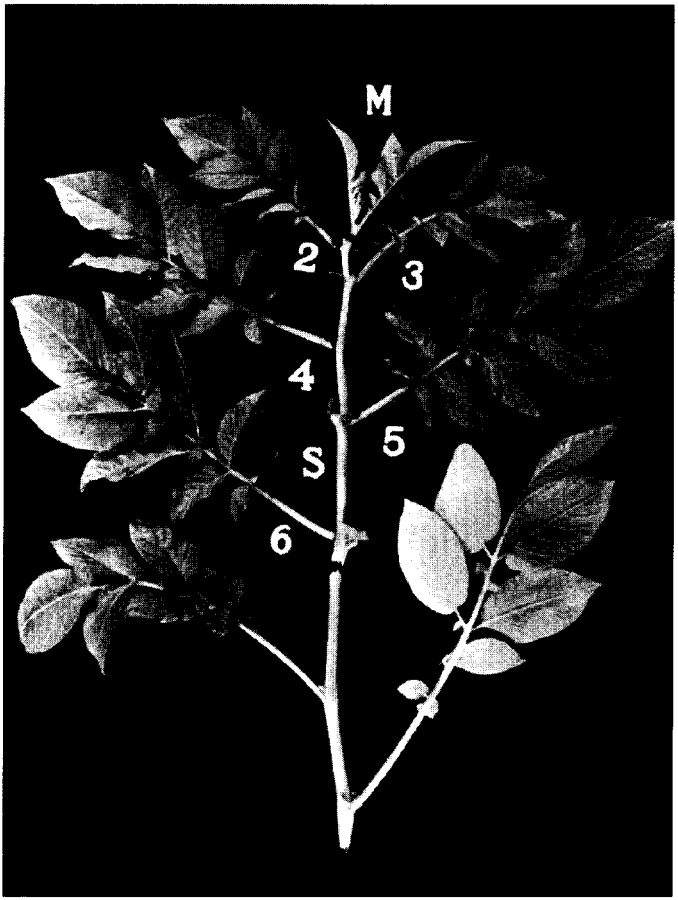

FIG. 1. Identification of plant part for each petiole position and upper-stem sample. (M = terminal meristem; S = upper-stem; 2 - 6 petiole position).

during mid-tuber bulking. All samples were dried at 60 C, ground to pass a 40-mesh screen, and stored until analysis. A subsample from each sample was extracted and analyzed for NO_3-N by a specific-ion electrode (8). Another subsample was wet-ashed with a $HCLO_4$-HNO_3 mixture. The digested solution was analyzed for P colorimetrically (4); K, Ca, Mg, Zn, Cu and Mn by atomic absorption spectrophotometry; and S turbidimetrically (13). All analyses are reported on a dry matter basis.

Six individual grower fields of Russet Burbank potatoes near Kimberly, Idaho were sampled in 1987 to compare petiole with upper-stem nutrient analyses for monitoring the plant's nutritional status under field conditions. Two people independently selected a petiole and an upper-stem sample from about a two-acre portion of each field five times during tuber bulking. All cultural practices were controlled by the respective grower.

TABLE 1.—*Effect of petiole position below the meristem on selected nutrient concentrations where N and P were adequate.*[a]

Petiole position	Nutrient				
	NO_3-N	P	K	Zn	Mn
	(mg kg^{-1})	(%)	(%)	(mg kg^{-1})	(mg kg^{-1})
2	13000c	0.29a	8.0c	37.0a	29.2c
3	15100bc	0.24b	9.1b	31.8b	29.8c
4	15700b	0.22c	9.7ab	24.5c	30.0c
5	18200a	0.20d	9.7ab	22.5c	32.8bc
6	19200a	0.19e	9.9ab	19.3d	36.5b
7	19400a	0.17f	10.0a	18.8d	41.0a
C.V., %	14.3	7.8	2.4	5.6	8.3

[a]Each mean is an average of 20 observations and is different at the 0.05 probability level with Duncan's multiple range test if followed with different letters.

Petiole and upper-stem nutrient analyses were related using linear regression procedures on both the research (controlled experiments) and grower data sets. Regression relationships were evaluated for equality of slope and intercepts for each nutrient (9). In addition, petiole and upper-stem data from the growers' fields were evaluated with the studentized t-test. Duncan's multiple range test was used to separate petiole position means.

Results and Discussion

Petiole Position Effect—Average petiole NO_3-N, K and Mn concentrations were higher in the lower petioles (5 through 7), while P and Zn concentrations were lower (Table 1). Because highly mobile nutrients (such as P) are translocated to the growing meristem, they may accumulate in the youngest plant parts. The NO_3-N concentrations in upper petioles may be lower than those in the lower petioles because nitrate reductase activity is higher in the younger leaves. The average concentration difference between adjacent petiole positions was generally not large (Table 1), however as much as 5000 mg kg^{-1} NO_3-N difference existed in some comparisons of petiole positions three, four and five. There was very little effect of petiole position on NO_3-N or P concentrations when nutrient availabilities were less than optimal (Data not shown). Overall, these differences could cause interpretation problems of petiole analyses, particularly if the calibrations for the fourth petiole were used for samples containing a significant portion of petioles from other positions.

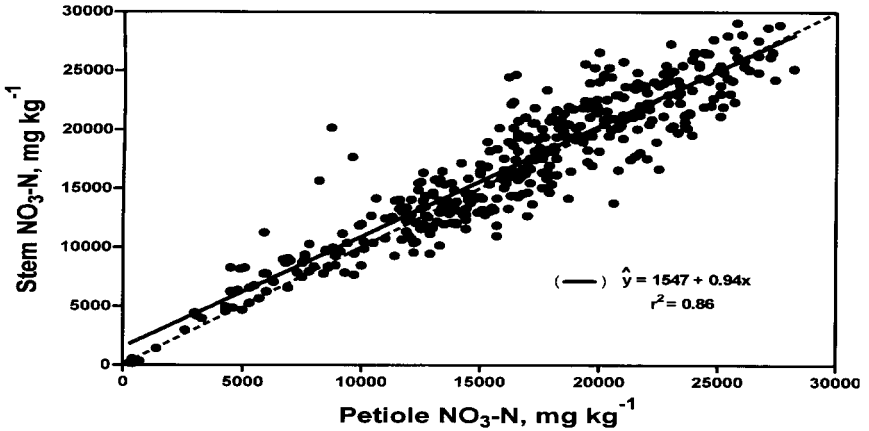

FIG. 2. Comparison of fourth petiole and upper-stem NO_3-N concentrations. (Dashed line is for a 1:1 relationship; 392 paired samples.)

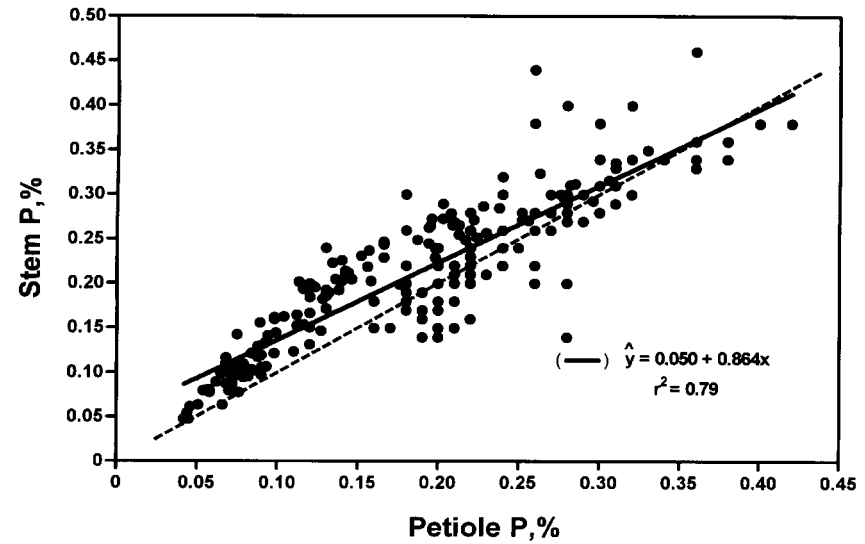

FIG. 3. Comparison of fourth petiole and upper-stem P concentrations. (Dashed line is for a 1:1 relationship; 232 paired samples.)

Petiole vs. Upper-Stem, Research Data Set—There were significant linear relationships between the fourth petiole and upper-stem for all nutrients using the research data set (Table 2). Coefficients of simple determination (r^2) varied from 0.86 for NO_3-N to 0.19 for S. Nutrients that were not fertil-

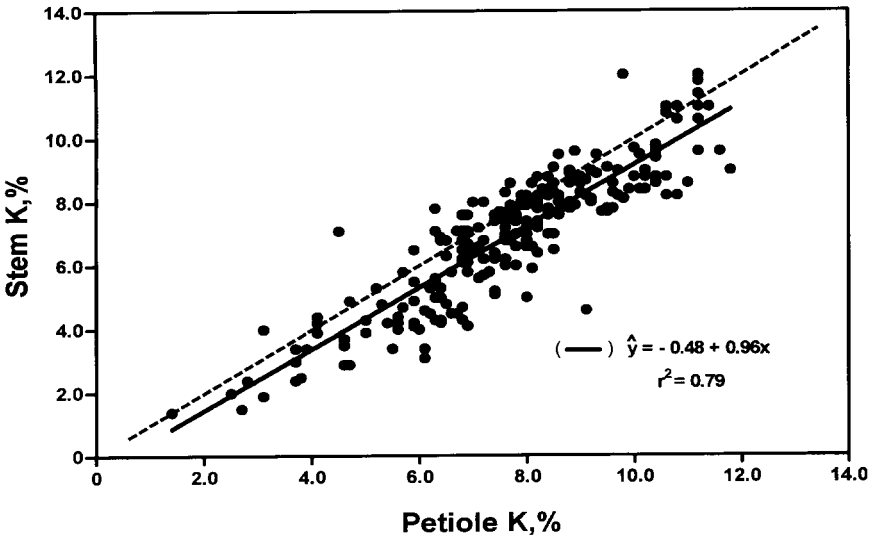

FIG. 4. Comparison of fourth petiole and upper-stem K concentrations. (Dashed line is for a 1:1 relationship; 232 paired samples.)

izer variables had lower coefficients, *i.e.*, Cu and S. Higher coefficients for Ca and Mg probably reflect their inverse relationship (multicollinearity among variables) with K (3).

Concentrations of NO_3-N, P and K in the petiole and upper-stem were similar across all concentrations (Figs. 2, 3 & 4). Regression slopes were near unity for NO_3-N and K (Table 2). The stem contained slightly more P when the petiole had less than about 0.40% P (Fig. 3), however the 90% confidence interval completely enclosed the 1:1 line for P (not shown). The relationships for both NO_3-N and P appear to pass through the origin rather than having a positive intercept (Figs. 2 & 3). A multiplicative model ($y = ax^b$) forced the line through the origin for P and had an r^2 of 0.81. Potassium had a negative intercept (Fig. 4), implying that stem K concentration was about 0.5% lower than the petiole's.

Zinc deficiency occurs in potatoes when petiole Zn concentrations are 10-15 mg kg^{-1} (2, 12, 14). The stem-petiole Zn relationship included Zn concentrations from deficient to more than adequate (Fig. 5). Upper-stem Zn concentrations were consistently 40% higher than those in the petiole and encompassed a wider range than the petiole. A petiole Zn concentration of 15 mg kg^{-1} would be equivalent to about 21 in the upper-stem. These observations are similar to those of Bowan and Leggett (1).

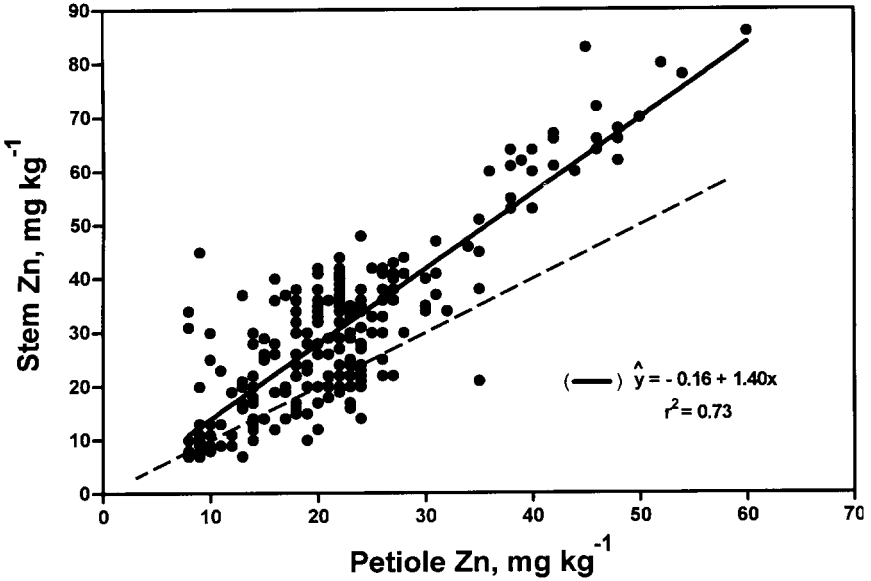

FIG. 5. Comparison of fourth petiole and upper-stem Zn concentrations. (Dashed line is for a 1:1 relationship; 232 paired samples.)

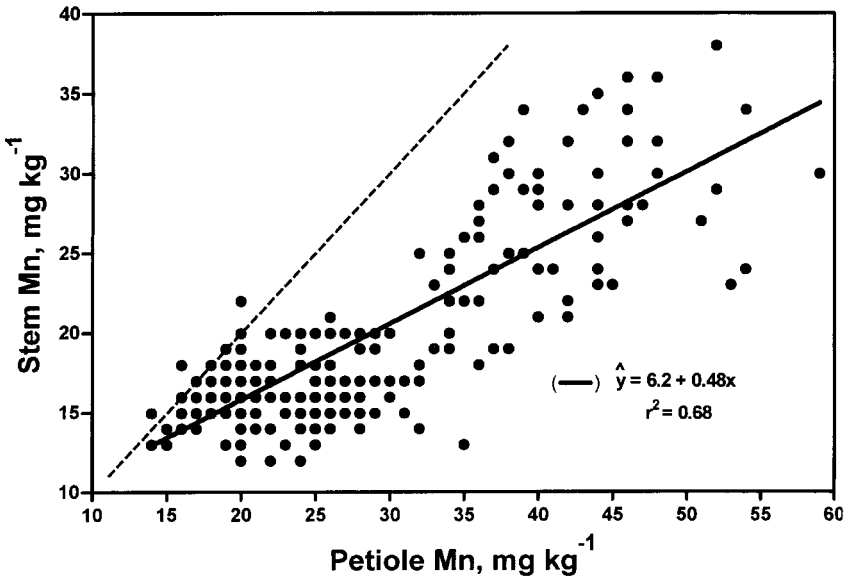

FIG. 6. Comparison of fourth petiole and upper-stem Mn concentrations. (Dashed line is for a 1:1 relationship; 232 paired samples.)

Manganese concentrations in the upper-stem were about 48% of those in the petiole (Fig. 6). The petiole vs. upper-stem Mn relationship had a y-intercept of 6.2 mg kg^{-1} Mn. The upper-stem appears a less desirable plant part than the petiole for Mn nutritional monitoring because of its smaller concentration range. Less than 20-30 mg Mn kg^{-1} in the petiole are considered from Mn deficient plants (2, 12, 14).

A good relationship between petiole and upper-stem was obtained for both Ca and Mg (Table 2). Petiole concentrations varied from 0.65 to 2.2% Ca and from 0.45 to 2.0% Mg. All concentrations found in this study would normally be considered adequate for plant nutrition (12, 14). Both slopes were less than one suggesting that the concentration range in the petiole was greater than that in the upper-stem for both Ca and Mg. The higher concentration of Ca and Mg in the petiole may partially be because of the relative immobility of these ions in the plant, particularly Ca.

Both Cu and S relationships had lower coefficients (r^2) than the other nutrients (Table 2). All petiole Cu and S concentrations (not shown) were sufficient (12, 14). Part of the variability may be because of surface contamination from sprays containing Cu and S applied for early blight, white mold (*Sclerotinia sclerotiorum*) or powdery mildew (*Erysiphe cichoracearum*) control.

Petiole vs. Upper-Stem, Grower Data Set—Linear regression equations relating petiole and upper-stem nutrient concentrations on the grower data set generally had higher coefficients of simple determination (r^2) than those for the research data set (Table 2). The slope for Zn and the intercepts for P, K, Ca and Zn were significantly ($Pr<0.05$) different between the two equations (Table 2). The slope difference for Zn was probably not large enough to be of practical consideration, *i.e.*, 1.40 vs. 1.13 (Table 2). Intercept differences may be from analytical errors during sample analysis or surface contamination of the samples with nutrients from foliar sprays, soil particles, or disease control sprays. Surface contamination would be more of a problem with the petioles than with upper-stems for the same mass.

Petiole and upper-stem means across all samplings from the grower fields were statistically different for K, Zn, Mn, Ca and Cu (Table 3). Different Zn, Mn and Cu concentrations would be expected based on the equations (Table 2). The K concentration difference is of little practical significance since it is relatively small (Table 3). Coefficients of variation (C.V.) were larger for Mn and Cu in the upper-stems and for NO_3-N in the petioles. The larger C.V. for petiole NO_3-N may be because some petioles from other positions were included in the sample, although the samples were carefully taken.

Additional Considerations—Normally, 30 to 50 individual petioles are needed for sufficient dry matter for all chemical analyses. Since a single upper-stem contains considerably more dry matter than a single petiole,

TABLE 2.—*Linear regression equations for research and grower data sets between fourth petiole (x) and upper-stem (y) for the indicated nutrients, and the probability of different intercept or slope parameters between the respective equations.*[a]

	Research Field Data Set		Grower Field Data Set		Parameter[b]	
Nutrient	Equation	r^2	Equation	r^2	Intercept	Slope
					—Pr > F—	
NO_3-N	y = 1547 + 0.94x	0.86[a]	y = 827 + 0.95x	0.92	0.330	0.786
P	y = 0.05 + 0.86x	0.79	y = 0.023 + 0.92x	0.93	0.022	0.334
K	y =-0.48 + 0.96x	0.79	y =-1.27 + 1.10x	0.86	0.038	0.064
Ca	y = 0.31 + 0.59x	0.64	y = 0.39 + 0.58x	0.75	0.040	0.965
Mg	y = 0.21 + 0.73x	0.77	y = 0.16 + 0.81x	0.90	0.119	0.111
Zn	y =-0.2 + 1.40x	0.73	y = 7.3 + 1.13x	0.72	0.038	0.025
Mn	y = 6.2 + 0.48x	0.68	y = 8.4 + 0.44x	0.76	0.227	0.243
Cu	y = 3.4 + 0.80x	0.32	y = 2.0 + 0.95x	0.21	0.687	0.512
S	y = 0.17 + 0.52x	0.19	—	—	—	—

[a]All r^2 significant at the 0.05 probability level.
[b]Probability of equation parameters for research and grower data sets being different.

TABLE 3.—*Comparison of mean and C.V. (coefficient of variation) for petiole and upper-stem samples from growers' fields (n = 60).*

	Petiole		Upper-stem		Petiole vs.
Nutrient	Concentration	C.V.(%)	Concentration	C.V.(%)	Upper-stem[a]
NO_3-N, mg kg^{-1}	16920	9.8	16970	0.9	NS
P, %	0.28	9.8	0.28	7.5	NS
K, %	7.8	5.9	7.3	9.1	***
Zn, mg kg^{-1}	22.8	11.3	33.2	12.2	***
Mn, mg kg^{-1}	39.7	10.8	25.7	17.2	***
Cu, mg kg^{-1}	6.9	19.2	8.6	35.5	***
Ca, %	1.5	7.0	1.3	8.5	***
Mg, %	1.0	8.5	1.0	7.5	NS

[a]NS = nonsignificant; *** = means significantly different at 0.001 probability level.

there will be a tendency to take fewer upper-stems for a sample. However, the same number of upper-stems and petioles should be taken to adequately represent a production area. The larger mass of upper-stem sample will require more drying space and may be more difficult to dry.

The relationships found in this study are for the Russet Burbank variety. It will be necessary to verify or identify the upper-stem and petiole nu-

trient relationships before adopting the upper-stem for other varieties since nutrient concentration differences among varieties are known (12, 14). Additional studies may be needed to establish the nutrient relationships if the stem is excised at different leaf positions. Diurnal and moisture stress effects on nutrient concentrations in the upper-stem are also unknown. Before the upper-stem is used to monitor the plant's nutrition status, it will be necessary to know the relationships between the upper-stem nutrient concentrations and tuber yields. The petiole vs. upper-stem nutrient relationships shown in this study suggest that the yield vs. upper-stem nutrient relationships will probably be acceptable.

This study showed that the petioles below the fourth petiole contained higher concentrations of NO_3-N, K and Zn, but lower concentrations of P and Mn. The fourth petiole NO_3-N, P and K diagnostic concentrations now used for interpreting plant nutrient status can also be used for upper-stem samples. An upper-stem critical Zn or Mn concentration would be about 28 and 16 mg kg^{-1}, respectively, if the fourth petiole critical Zn or Mn concentration was 20 mg kg^{-1}. Critical Ca, Mg, Cu or S upper-stem concentrations could not be estimated because all this study's concentrations were above established critical concentrations. The upper-stem plant part was successfully used to monitor six commercial potato fields for plant NO_3-N, P and K status. A significant advantage of the upper-stem is the elimination of petiole selection problems when sampling.

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