MINERAL ELEMENT CONTENT OF POTATO PLANTS AND TUBERS VS. YIELDS[1]

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ABSTRACT

Linear equations for estimating the amounts of N, P, K, Ca, Mg and S removed from the soil as a function of yield are given for Russet Burbank potatoes. The equations were obtained from chemical analyses of potatoes grown using various ratios and rates of fertilizer, planting dates and harvest dates during 1966 to 1969 in the Columbia Basin of the state of Washington. The percentage mineral element composition of the tubers remained relatively uniform for the different ratios and rates of fertilizer but varied some due to the length of season. The correlation coefficients of chemical composition of the vines with chemical composition of tubers were low as were those relating amount in vines to yield. The correlation coefficients relating amounts of elements in the tubers to yield were 0.9 or greater.

INTRODUCTION

The highest yields of potatoes per acre in the nation are produced under the conditions of Washington's Columbia Basin where days are long and hot, and water can be provided as needed for plant growth. The potatoes are harvested from 100 to 175 days after planting. Commercial yields vary from 300 to 700 cwt per acre. Experimental yields of 1385 cwt per acre were achieved on a plot basis.

The potato literature is replete with reports on potato fertilization and the effect on yield, tuber quality and plant and tuber composition. There are, nevertheless, inconsistent and incomplete data, especially for high potato yields. Fertilization effects reported in the literature are often confounded by other environmental influences, especially in low rainfall areas wherein insufficient water could limit or even reduce tuber yield if soil fertility levels are too high.

Thirty-five references which bear directly or indirectly on the subject of mineral element composition of potatoes were found. Smith (6) included most of the earlier work in his review. A few citations are, nevertheless, in order. MacGregor and Rost (5), Carpenter (2) and Loginow (4) found no tendency of the elements they studied to accumulate in the tubers. Brautlecht and Getchell (1) gave approximate percentages for 14 different elements in potato tubers. The values generally are consistent with those of Kunkel (3) but the yields of tubers were much lower.

It is the purpose of this report to present the equations for predicting removal of mineral nutrients from the soil and their usefulness.

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[1]Received for publication March 19, 1973. Scientific paper 3850, Washington Agricultural Experiment Station, Pullman, Washington. Cooperative study between Washington State University and the Washington State Potato Commission. Work was conducted under Project 1385.

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Materials and Methods

General considerations:

Potato tubers were analyzed for major and minor elements yearly from 1966 through 1969. The total plant (except roots) was analyzed in 1967 and 1968. All experiments were conducted on Shano silt loam soils which had never been planted to potatoes. Therefore, potato root diseases were not a factor. All fertilizers were applied at planting time in equal bands about 2 inches to the side and slightly below the bottom of the seed piece. The plants were furrow irrigated. Insects and diseases were controlled as in commercial potato production.

Tuber tissue:

A longitudinal center slice about ⅛ inch thick was cut with a stainless steel knife from about ten thoroughly cleaned tubers to provide 100 g of fresh tissue which was homogenized in a blender in 100 ml of 95% ethyl alcohol for 2 min. The resultant slurry was quantitatively transferred to pint Mason jars and dried for 36 hr at 80 C (176 F). The dry weight of the tissue was determined and a portion of the cake was crushed with a mortar and pestle until it passed through a 40 mesh sieve.

Vine tissue:

The green vines were sewn into cheese cloth bags and weighed within minutes after pulling. Tubers from these same plants were harvested for chemical analyses. The vines were suspended from the ceiling of a shed until air dry after which time they were crushed, re-weighed and passed twice through a hammer mill. Each time the dust-like fractions were discarded because the lower leaves had been in contact with the soil and contained many fine soil particles. The discarded portion comprised a very small percentage of the total sample. The tissue volume was reduced to approximately 50 g which was ground to pass through a 40 mesh screen in a Wiley mill.

It is recognized that the results for minor elements in the vines are approximate because it was not possible to wash and dry the vines from such large experiments.

Chemical analyses:

The chemical analyses were performed with standard laboratory equipment and procedures as presented by Woodbridge and Lasheen (7). As a check on the procedures for micro elements each of ten samples were homogenized and divided into six subsamples. One sample of each was given to a commercial testing laboratory using spectrographic methods, another was given to a university laboratory using atomic absorption procedures, and a third was given to the university spectroscopic analyst in the chemistry department. At a later date the remaining three samples were renumbered and respective samples sent to the analysts.

Though the vines were not washed the samples were, nevertheless, as good as the laboratory analyses. For the most consistent spectrographic analyst the percentage error for duplicate sets of samples ranged from 4 to 37% for Zn; 0 to 14% for B; 4 to 17% for Mn; 0 to 29% for Fe; and 0 to 50% for Cu. When the results of the two spectroscopists were compared the averages for the ten samples differed from 1 to 21% depending upon the element. When the results of the spectrographic method were compared with those of atomic absorption the percentage error for the means of ten samples ranged from 6 to 22% depending upon the element. The per cent of all elements in the vines might tend to be high because of contamination but the relative differences should be valid. The minor element data presented were obtained by atomic absorption.

1966 Study:

Russet Burbank seed pieces were planted on April 13 and 14, 9.3 inches apart in rows 34 inches apart. The experiment consisted of four rates each of N, P and K factorially arranged with six replications. The rates per acre were as follows: 0, 130, 260, 390 lb N; 0, 58, 116, 175 lb P (0, 133, 267, 400 lb P_2O_5) and 0, 110, 221, 332 lb K (0, 133, 267, 400 lb K_2O). Each fertilizer treatment was applied to the same plot in both 1965 and 1966. Plots were 11.33 feet wide (4 rows) and 29 feet long. During harvest on October 12-14, approximately ten tuber samples from each plot were saved and prepared for chemical analysis.

1967-1968 Study:

The plot area selected for this study had been cropped to dry land wheat prior to 1965 and was leveled for irrigation. In 1966, the area was planted to wheat, fertilized with a broadcast application of 160 lb N and 35 lb of P (80 lb P_2O_5) per acre and irrigated. The experiment consisted of four harvest dates approximately 1 month apart as main plots, four dates of planting 2 weeks apart as subplots, five rates of pelleted 16-16-16 (N, P_2O_5, K_2O) fertilizer and eight replications. Treatments were applied to the same plots (10.67 by 29 feet) in both 1967 and 1968. Tuber and plant samples from plots receiving 1250 and 3125 lb fertilizer per acre from each planting and harvest date from each replication were saved for analysis.

To test the effect of the concentration of one ion on the concentration of another in the tops and tubers, numerous linear correlation coefficients were calculated.

1969 Study A:

Seven high yielding unnamed potato clones were grown using 440 lb of N, 236 lb of P (540 lb P_2O_5) and 448 lb of K (538 lb K_2O) per acre. Each clone was replicated five times. They were planted April 22 in rows 32 inches apart with 9.3 inches between seed pieces. The tubers were harvested October 30, stored at 39 F (4 C) until February and then tissue was prepared for analysis.

1969 Study B:

Russet Burbank, Kennebec, White Rose, Norgold Russet and Cascade seed was planted April 12 in rows 32 inches apart with 9.3 inches between seed pieces. Each variety was grown on four fertilizer levels using 625, 1250, 1878 and 2500 lb per acre of a pelleted 16-16-16 fertilizer. Six randomized blocks were used. The tubers were harvested October 15. The tissue was prepared for analysis shortly thereafter by the methods previously described.

Results

The results of the chemical analyses for the Russet Burbank (RB) variety are emphasized throughout this report, because it is the principal potato variety grown in the Pacific Northwest. There is, however, a marked similarity between the amount of nutrients removed from the soil by this and other potato varieties when grown in the Columbia Basin.

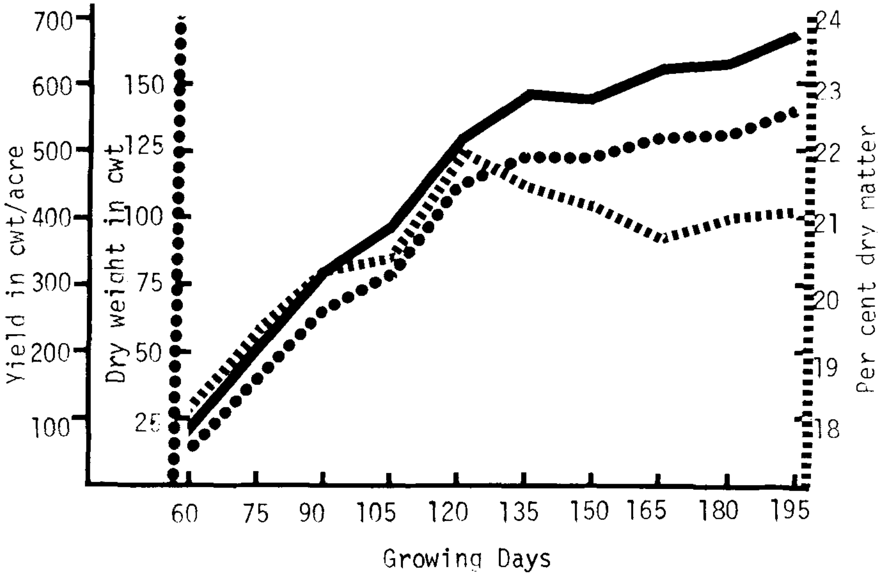

FIG. 1.—Relationships of growth period, total yield, total dry matter content and percent dry matter for Russet Burbank potato tubers in 1967-1968.

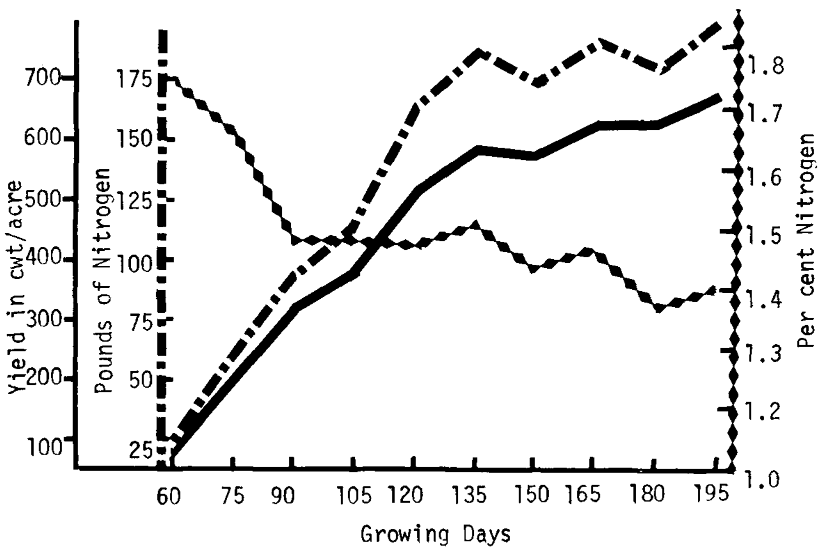

FIG. 2.—Relationships of growth period, total yield, total nitrogen and percent nitrogen for Russet Burbank potato tubers in 1967-1968.

The 1967-1968 data were averaged to show the relationships among yield, total dry matter produced and percentage dry matter of the tubers (Fig. 1). Yield and total dry weight increased as the length of the growing season increased. The percentage dry matter of tubers increased to a

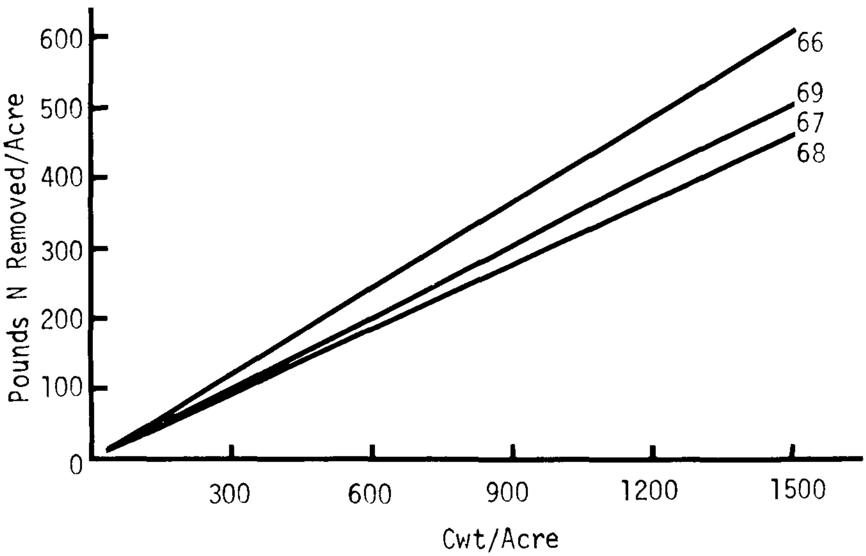

FIG. 3.—Regression lines for four years for Russet Burbank potatoes showing the relationship of total yield to the amount of nitrogen in the tubers.

maximum at 120 days after planting then decreased with increased growing time. The magnitude of the differences in percentage dry matter among fertilizer levels differed but the trends were the same. As yield of tubers increased the amount of nutrients removed from the soil increased even though the percentage decreased as illustrated by nitrogen in Fig. 2.

The amount of N removed per acre in the tubers is shown in Fig. 3 for the years 1966 through 1969. The graphs for P and K removed per acre are similar with less difference among years than the graph for N. Considering the differences in growing conditions among seasons the data are in good agreement. This is especially true in the range of yields from 300 to 600 cwt per acre, which includes most current commercial yields in the Columbia Basin.

The 1967-1968 RB data were used to compute the regression equations for nutrient uptake and yield of tubers. The results of the regression analyses for the major nutrient elements are given in Table 1.

The regression line for N calculated for RB potatoes from the 1967-1968 data is shown in relation to the points for N for five commercial varieties, Fig. 4. The values for N for the commercial varieties are above the regression line for RB; however, the regression line for the varieties other than the RB variety is not significantly different ($P > 0.05$). It is noted that the highest yield of RB in our plots was 1100 cwt/acre and thus the line in Fig. 4 is extended in order to correspond to the largest yield of 1385 cwt/acre of another variety. The nitrogen content of the five commercial varieties was somewhat higher than the average for RB. The P content was somewhat lower but the K content was about the same. The linear correlation coefficients relating percentage composition to yield were negligibly low whereas those relating pounds of N, P, K in the tubers to yield were consistently high, Table 2. A more useful

TABLE 1.—*Regression equations and linear correlation coefficients for nutrient uptake and yield for Russet Burbank tubers for the 1967 and 1968 experiments (sample size = 512, s_b = standard deviation of regression coefficient, $s_{y \cdot x}$ = standard deviation of regression line).*

Equation	r	Lbs/cwt (s_b)	Lbs/acre ($s_{y \cdot x}$)
$N = -7.777 + 0.311Y$	0.94	0.0051	22.71
$P = -1.088 + 0.076Y$	0.91	0.0015	6.68
$K = -0.939 + 0.446Y$	0.95	0.0062	27.82
$Ca = -0.504 + 0.008Y$	0.76	0.0003	1.38
$Mg = -0.779 + 0.026Y$	0.94	0.0004	1.91

TABLE 2.—*Linear correlation coefficients relating yield to chemical composition of Russet Burbank potatoes (sample size = 256), 1968 data.*

		Percent			Lbs/Acre		
		N	P	K	N	P	K
Yield	Cwt	—0.16	—0.12	—0.23	0.93	0.90	0.93
Pounds	N		0.39	0.49		0.89	0.91
Pounds	P			0.56			0.94

TABLE 3.—*Pounds of mineral nutrients removed from the soil per hundred weight of potato tubers.*

Element	Lbs/100 cwt
Nitrogen	30.0
Phosphorus	7.0
Potassium	44.0
Calcium	0.8
Magnesium	2.5
Sulfur	2.4
Zinc	0.02
Copper	0.016
Manganese	0.015
Iron	0.047
Boron	0.007

summary of the results of the regression analyses for the 1967-1968 RB data is given in Table 3. From these relationships, it is possible to estimate the quantities of mineral nutrients removed from the land for a given sized potato crop. These data can be used in a type of "nutrient removal" approach to fertilizer recommendations to indicate the difference between the nutrients applied in the fertilizer and those removed from the land by the crop.

The effect of one mineral element on the concentration of another within the vines and tubers was studied by linear correlation analysis. The most noteworthy correlations were between N in the vines as affected by P (.80), K (.66) and Ca (—.47) in the vines; N in the tubers and K (.53) in the tubers; P in the vines and K (.61) in the vines; K in the vines and K (.52) in the tubers.

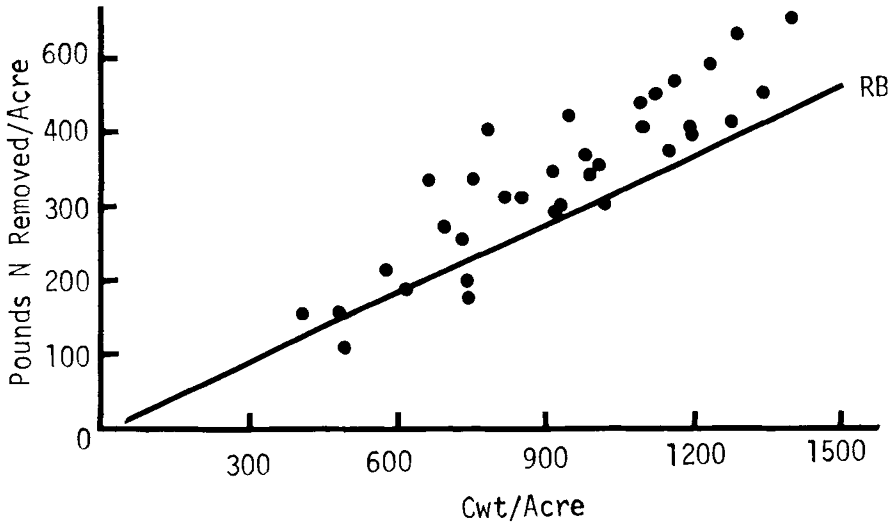

FIG. 4.—Relationship of nitrogen removal and total yield of seven high yielding varieties with reference to the 1967-1968 regression line for Russet Burbank potato tubers.

Another way of evaluating the data is by analysis of variance and the percentage composition data for 1967-1968 were used. There were highly significant differences in percentage composition of the tubers for those main effects which influence yield, namely — harvest and planting dates, fertilizer rates, and years. First order interactions for fertilizer rates and harvest dates were significant for N, P, K, S, B, Zn and Fe. The first order interaction for years by harvest dates was significant for N, P, K, Ca, Mg, S, Zn, Cu and Mn. In many cases the differences were small, and perhaps inconsequential, but on a percentage basis the differences become large. For example, the difference in percentage nitrogen in the tubers between the low and high fertilizer rates was only 0.3% which is a difference of 23% when based on the amount in the tubers at the lower fertilizer rate.

There were highly significant differences in percentage composition among the main effects for vines. As with tubers the differences were associated with those main effects which influenced yield. A number of the first order, second order and the third order interactions for N and P were significant, not only for the elements added in the fertilizer but for some of the other mineral nutrients taken up by the plant.

When the statistical analyses for vines and tubers were compared it was evident that the mineral element composition of vines was more sensitive to growing conditions and the degree of vine dying than was the composition of the tubers.

DISCUSSION

Statistical differences:

A number of first order interactions were significant at the 5% level or greater. Most of these were associated with fertilizers x harvest dates and years x harvest dates. That interactions involving years would be significant is not surprising, firstly because the same treatments were put on their respective plots for two consecutive years, secondly because of differences in growing seasons and thirdly because with eight replications the degrees of freedom for the error terms were large so that relatively small differences became statistically significant. For example, for the main effects there were 256 values in each mean for years and fertilizer rates and 128 values for planting and harvest dates. Thus the mean percentages were established with considerable precision and were used to compute the amount of nutrients present in a given size potato crop.

Implications:

Knowing that potato tubers of the common varieties are relatively constant in percentage composition regardless of yield, fertilizer applied or cultural practices used makes the results of these studies useful in estimating the quantities of fertilizer needed to grow large yields of potatoes and to determine the quantities of mineral nutrients removed from the land. The quantity of nutrients removed from the land is determined by the yield of potatoes. Factors which modify the size of the yield also modify the amount of nutrients removed from the soil without greatly modifying the mineral element composition. Excess nutrients, especially nitrogen, may increase the above ground vegetative growth without increasing the yield of the tubers and hence mineral element composition of the total plant is poorly correlated with yield. Whatever the concept of luxury fertilizer consumption may entail it applies mostly to the foliage which is returned to the soil and not to the tubers.

Acknowledgments

The authors are grateful for the assistance of Mrs. Jeanette Jenne and Mrs. Helene Butala in reviewing literature and preparation of the manuscript, to Dr. Cyril Woodbridge under whose supervision the chemical analyses were performed and for the financial support granted by the Washington State Potato Commission; Chevron Chemical Company, Ortho Division; the American Potash Institute; and the Pacific Northwest Plant Food Association.

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